Realizing the New Paradigm for Engineering Education

Proceedings

June 3-6, 1998
Omni Inner Harbor Hotel
Baltimore, Maryland

Conference Co-Chairs:
Edward W. Ernst
University of South Carolina

Irene C. Peden
University of Washington

Engineering Foundation Conferences
Three Park Avenue
New York, NY 10016-5902
T: 1-212-591-7836; F: 1-212-591-7441
e-mail: engfnd@aol.com; www: http://www.engfnd.org

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Preface

Although change in engineering education has been a continual topic of discussion among engineering educators for the past century, during specific periods the intensity of the discussion increases significantly. The past decade has been one of those periods. The NSF and others have encouraged and supported innovation; we have had several conferences, workshops, and studies. These efforts have produced a consensus about what engineering education should be - what the stakeholders expect in the content of the curriculum, innovative approaches to teaching, and involvement of students. Achieving the change needed in engineering education programs across the country has become the current barrier that must be surmounted for engineering education to realize the new paradigm for engineering education and to serve its stakeholders even better.

These Proceedings present the written record of a June 3-6, 1998 conference that provided a forum for a variety of academic experiences with substantive modernization of engineering education to be shared and compared. A broad segment of the engineering education community received the meeting notice, and workshop participants then selected themselves for attendance. They were academics working within their own institutions to achieve the new paradigm and others that were interested in undertaking such an effort. The conference, sponsored by the Engineering Foundation and the National Science Foundation, was directed toward increasing the participation of colleges of engineering in Systemic Engineering Education Reform (SEER). It was timed to complement a then-recent solicitation of proposals in support of the NSF Action Agenda for Systemic Reform in Engineering Education, and to follow up a 1995 NSF-sponsored workshop devoted to the need and urgency for the academic community to rethink the substance and presentation of undergraduate engineering education.

The conference explored what an individual institution does to change from its present approach to the new engineering education, one that seeks to develop students as emerging professionals with the motivation, capability, and knowledge base for life-long learning; one that helps students see the whole world and sense the coupling among seemingly disparate fields; one that incorporates a diversity of backgrounds and approaches; and one that enhances student capability to build connections between the world of learning and the world beyond.

These pages contain background and scene-setting material (Ernst and Prados papers) as well as the perspectives of industry (Glenn), the National Academy of Engineering (Wulf) and the National Science Foundation (Bordogna). The NSF-sponsored Engineering Education Coalitions are represented (Bilgutay and Mutharasan, Eifert, Friedman, Watson) as well as institutions whose programs were sponsored either internally or by NSF outside the Coalition format (Carlson and Sullivan, Olds, Parrish, Penfield, Phillips). The views of all participants in the conference are consolidated in the reports of the workshop sessions that comprise the last section of these proceedings.

Speakers were selected for their unique abilities to offer insights into the Drivers for Change (Accountability, Engineering Workplace, Technologies) and the nature of their successes and roadblocks as Paradigm Shifters within their institutions, be the latter public or private, large or small, technically oriented or multiversity.

Five groups of workshop participants addressed three key questions, namely:
1. How can we use the challenges of the engineering workplace, ABET Engineering Criteria 2000 and experiences of others to create change at my institution?
2. How can we use information technology and the experiences of others to create change at my institution?
3. What can we do to implement engineering education reform and what is my part in doing this?
Their deliberations and conclusions were recorded and briefed as the last agenda item of the conference.

The conference organizers are indebted to all who participated, with special thanks to Drs. John Prados, Ernie Smerdon and Marshall Lih, representing the Engineering Education and Centers Division of NSF’s Engineering Directorate; Dr. Henry Shaw, representing the Engineering Foundation; and most especially to Dr. Joseph Bordogna, Acting Deputy Director of the National Science Foundation and recent NSF Assistant Director for Engineering for his unwavering support and dedication to timely and effective undergraduate education in engineering.

Edward W. Ernst
Irene C. Peden
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Action Agenda for Systemic Engineering Education Reform: Next Steps

John W. Prados
University of Tennessee

Introduction

My task is to discuss briefly the background for the current engineering education reform movement, to outline a major National Science Foundation initiative to support that movement, and to suggest the principal issues on which you should focus (and NOT focus) during the next 2.5 days of this conference.

Most of you are aware of the major forces that make engineering education reform imperative if we are to give our graduates the knowledge, intellectual skills, and functional capabilities they will need to provide technical innovation and leadership in the 21st century. These may be summarized as follows.

• The major driver for engineering employment has shifted from defense to commercial competition, leading manufacturers and service providers to focus increasingly on time-to-market, cost, quality, and customer orientation.
• Rapidly emerging information technologies offer opportunities to be more creative, to "work smarter"; these have the potential to revolutionize learning, both in school and on the job.
• A constantly changing work environment calls for astute interpersonal skills; engineering employment opportunities are shifting to smaller firms and non-traditional areas.
• Massively integrated populations place environmental protection, health, and safety at the front end of design; mandates for zero discharge, the need to consider total life-cycle costs for new products, and the impact of social and political concerns on engineering decisions have dramatically changed the economic basis of project evaluation.

As outlined in the preceding paper by Ed Ernst, a large number of reports and papers concerning engineering education have appeared over the past twenty-five years, including those by prestigious organizations such as the National Research Council, the National Academy of Engineering, the American Society for Engineering Education, and the National Science Foundation.

Those issued over the past ten years have shown remarkable agreement on the attributes needed in 21st century engineering graduates and in the need for a new educational paradigm to develop these attributes. There is also broad agreement that systemic reform of engineering education will require a concurrent change in engineering school academic culture from its current basis in:

• compartmentalization of knowledge
• individual specialization
• a predominantly research-based faculty reward structure to one that values:
• integration as well as specialization
• teamwork as well as individual achievement
• educational research and innovation as well as research in the engineering sciences.

Our Task at This Conference

Our principal task at this conference is to identify effective strategies to bring about such systemic engineering education reform at the diverse engineering schools of this country, especially our own. To succeed in this endeavor, we must not become distracted by redefining the broadly accepted vision for effective engineering education - The What - and the acknowledged obstacles to achieving this vision - The Excuses. The focus of our deliberations must be action - The How and The Who!

Let us take as givens the needed characteristics of the New Engineering Education Paradigm:

• an engineering faculty dedicated to developing emerging professionals—not merely filling empty heads with knowledge
• a curriculum that maintains a solid mathematical and scientific knowledge base
• an educational structure that integrates subject matter, and shows relationships among subject areas from the beginning of each student's program
• educational methods that stress active learning, emphasize industry-based projects, and depend much less on lectures
• strong emphasis on communication, teamwork, and group problem-solving skills
• a diverse student population
• regular, well-planned interaction with industry.

Let us also avoid dwelling on the obstacles to implementing this paradigm:

• the slowness of academic institutions, by curies-old tradition, to change
• the typical faculty governance process that can easily talk proposed changes to death
• an educational tradition in the United States that is teacher-centered, not learner centered
• a strong academic culture focused on individual, specialized achievement that inhibits faculty collaboration, especially across disciplinary boundaries

Realizing the New Paradigm for Engineering Education
• the usual faculty reward system and funding patterns at research universities that discourage the investment of significant faculty time in educational innovation
• the culture at some institutions that frowns on industry collaboration and the remote locations of others that make such collaboration difficult.

To accomplish the goals of this conference we must focus our thoughts on
• The How -formulating effective steps for achieving the desired vision
• The Who - identifying the key change agents and ways to commit them to action.

Drivers for Change

• An effective strategy for systemic engineering education reform will take advantage of the current drivers for change that already exist and attempt to leverage these for maximum effect. These drivers include:
  • the industrial advisory boards of engineering colleges and departments, which are becoming increasingly proactive in advocating the educational changes necessary to meet employers’ needs for entry-level engineers
  • engineering professional societies, especially the American Society for Engineering Education (ASEE) and the Education Society of the Institute of Electrical and Electronics Engineers (IEEE), which have issued major reports and statements advocating systemic engineering education reform and which publish the results of engineering educational research in peer-reviewed journals
  • private foundations, for example, the F. W. Olin Foundation, which recently announced a major grant to endow a new engineering college that will implement the desired educational paradigm without the handicap of an existing academic culture, and the Lemelson Foundation, which supports the National Collegiate Inventors and Innovators Alliance (NCIIA) that provides grants to multidisciplinary student-faculty teams to develop patentable inventions
  • the Accreditation Board for Engineering and Technology (ABET), whose efforts to promote engineering education reform through outcomes-based accreditation criteria will be described in a subsequent paper
  • the National Science Foundation (NSF), whose latest initiative to encourage and support systemic engineering education reform is outlined in the following section
  • developments in information technology and cognitive science that both enable and promote engineering education reform.

NSF Investments in Engineering Education Reform

For more than twenty-five years, the National Science Foundation has provided grants to support engineering education reform. Some of the milestones in these NSF investments are:
• pre-1980: engineering education projects funded as part of general mathematics, science, and engineering education improvement programs (for example, NSF supported development of a project based curriculum, “the WPI Plan” at Worcester Polytechnic Institute, as well as individual investigator grants)
• 1986: a report of the National Science Board (NSB), “Undergraduate Science, Mathematics, and Engineering Education” (the “Neal Report”) calls for special emphasis on mathematics and engineering (this led, for example, to the support of integrated mathematics-science-engineering lower division curricula at Drexel University and Rose Hulman Institute of Technology)
• 1989: the NSF-sponsored “Belmont Conference” of academic, government, and industry leaders calls for major systemic engineering education reform through establishment of consortia of diverse engineering schools; led to establishment of the Engineering Education Coalitions
• 1990-1994: Six engineering education coalitions established with NSF support and two with support from the Technology Reinvestment Project Manufacturing Education and Training (TRP/MET) Program.
• 1995: NSF-sponsored “Action Agenda” workshop, co chaired by Irene Peden and Ed Ernst, calls for strong focus on implementation, dissemination, and evaluation of engineering education reform efforts, along with the supporting academic culture change
• 1997: NSF announces the “Action Agenda for Systemic Engineering Education Reform,” an outcomes based program focused on action goals.

NSF investment in engineering education reform has been significant. Over the six-year period, FY 1991-1996, the approximate funding for major engineering education programs, not including laboratory equipment grants, has been as follows:

<table>
<thead>
<tr>
<th>Program</th>
<th>FY1991-96 Funding million ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course and Curriculum Development</td>
<td>8.5</td>
</tr>
<tr>
<td>Undergraduate Faculty Enhancement</td>
<td>5.9</td>
</tr>
<tr>
<td>Computer Science &amp; Engineering Educational Innovations</td>
<td>4.0</td>
</tr>
<tr>
<td>Engineering Education Coalitions</td>
<td>74.6</td>
</tr>
<tr>
<td>Combined Research/Curriculum Development</td>
<td>23.7</td>
</tr>
<tr>
<td>NSF Six-Year Total</td>
<td>36.7</td>
</tr>
<tr>
<td>TRP/MET Projects, Including Two Coalitions</td>
<td>40.0</td>
</tr>
<tr>
<td>Total NSF plus TRP/MET1</td>
<td>76.7</td>
</tr>
</tbody>
</table>

The Course and Curriculum Development and Undergraduate Faculty Enhancement Programs are funded through the Division of Undergraduate Education of the
Education and Human Resources Directorate (DUE/EHR); the Computer Science and Engineering Educational Innovations are funded through the Computer and Information Science and Engineering Directorate (CISE); and the Engineering Education Coalitions and Combined Research/Curriculum Development Programs are funded through the Engineering Education and Centers Division of the Engineering Directorate (EEC/ENG). Most of these programs require that the NSF awards be matched with institutional and/or industrial funds, producing a significantly larger total investment than indicated in the table above.

Over the past two years a new strategy for Engineering Directorate educational investments has been formulated, based on the recommendations of the 1995 Action Agenda Workshop and planning by NSF staff. The major points of this strategy are:

• to start no new Engineering Education Coalitions
• to focus the efforts of existing Coalitions on evaluation, dissemination, and institutionalization of promising educational innovations, rather than on developing new innovations
• to begin new programs emphasizing evaluation, dissemination, and institutionalization as the current Coalitions complete their maximum funding periods (10 years) and/or phase down
• to seek closer integration of Engineering Directorate engineering education programs with those of the Education and Human Resources, Computer and Information Science and Engineering, and other directorates.
• to seek new ways to encourage an academic culture that supports engineering education innovation, along with the integration of education and research.

To help define this strategy more clearly, an Action Agenda Task Group was established in September 1996 and functioned over the next year. This Task Group:

• was composed of seven members representing six of the NSF directorates
• was charged to recommend an investment portfolio for systemic engineering education reform and a plan of evolution from the current investment in Coalitions to a new set of systemic reform investments
• conferred with a number of engineering education reform leaders, as well as other NSF staff members
• developed guidelines for the Action Agenda for Systemic Engineering Education Reform, an outcomes-based program that seeks proposals to achieve identified Action Agenda Goals, with major emphasis on evaluation, institutionalization, and dissemination.

The program guidelines (available at http://www.nsf.gov/pubs/1998/nsf9827/nsf9827.htm) do not prescribe the sorts of activities that will be supported but instead specify specific goals that the program seeks to achieve and invite proposals that will support these goals. The Action Agenda Goals, taken directly from the program guidelines, are as follows:

"Goals for Teaching and Learning Methods
Create a learning environment in which it can be clearly demonstrated that the faculty who participate in the engineering program view themselves as mentors dedicated to nurturing and developing students; develop and use advanced educational materials founded in learning theory and cognitive sciences research that promote student-based learning; provide learning experiences that meet the needs of students with different learning styles; integrate their education and research roles; stress active, collaborative learning with less dependence on lectures; integrate subject matter by showing relationships from the beginning of the student's program; utilize emerging information technologies and network communications; and develop students' capability and motivation to engage in lifelong learning."

"Goals for Curricular Content
Create engineering curricula, through a combination of learning experiences not limited to traditional course structures, that maintain a solid mathematical and scientific knowledge base and also: integrate subject matter by introducing fundamental principles in the context of applications; integrate development of teamwork, communication, and group project definition and problem-solving skills in learning experiences throughout the curriculum; address issues of cost and timeliness, quality, social and environmental concerns, health and safety, etc., in the context of engineering practice; recognize diverse learning styles and career goals; increase opportunities for international experience, possibly taking advantage of distance learning technologies; and integrate research and education."

"Goals for Constituencies and Networks
Create an environment for the overall engineering education program that increases the successful participation of underrepresented groups in engineering through effective strategies for recruitment and for enhancing retention and progression to graduation; develops effective linkages with elementary and secondary education, two-year colleges, dual-degree programs, and other transfer institutions; maintains regular, well-planned interaction
with industry; supports creation of a network of engineering education leaders; creates, maintains, and disseminates a body of evaluation findings; increases the incentives to department chairs, deans, and institutional administration to reward faculty who develop or implement successful innovations in teaching and learning; and reduces the time and cost required to earn an engineering degree."

"Special emphasis will be placed on multiple goal achievement, firm institutional commitments to integrate the project results into ongoing educational programs, and the extent to which proposed projects go well beyond course development and modest curricular changes."

Proposals will be judged with reference to the current NSF Merit Review Criteria, with specific application to the Action Agenda Program. These are stated in the program guidelines as:

"Under Criterion 1: What is the intellectual merit and quality of the proposed activity?
1. To what degree does the proposed project address the Action Agenda Goals set forth in the program announcement?
2. How well conceived and organized is the proposed project?
3. What are the demonstrated capabilities of the project team, their understanding of the issues involved in systemic engineering education reform, their access to needed resources, and their commitment to the accomplishment of the effort?
4. Is there a robust evaluation system that demonstrates achievement of the Action Agenda Goals?

Under Criterion 2: What are the broader impacts of the proposed activity?
1. What is the likelihood of sustained impact on educational processes, diversity of graduates, and institutional culture after NSF funding ends?
2. What is the probable impact of the project results and the proposed dissemination process on the broader engineering education community?"

In summary the key concepts embodied in the Action Agenda Program are:

- The Action Agenda is the “post-coalition” phase of NSF efforts to encourage systemic engineering education reform.
- The Action Agenda is outcomes oriented; proposals will be judged on their potential to achieve identified goals in ways that will benefit significant numbers of engineering students; goal achievement must be demonstrated through a strong evaluation system.

The program emphasizes evaluation, institutionalization, and dissemination of existing educational innovations, rather than creation of new innovations (although these are not ruled out); of particular interest is demonstration of the effectiveness of innovations for institutions and student populations different from those at the originating institution.

The Action Agenda proposal guidelines were posted at the NSF website on December 8, 1997. The first proposal deadline was March 31, 1998, with proposal review and initial awards scheduled for late spring. A second competition is scheduled with a proposal deadline of December 1, 1998. It is anticipated that annual competitions will be held thereafter, with December 1 proposal deadlines.

The award period will normally be one, two, or three years. Award size is expected to range from $100,000 to $600,000 per year for up to three years. Approximately $5 million is expected to be available to fund awards for each of the first two competitions. Available funding is expected to increase over time as the Coalitions phase down and/or complete their funding periods.

Over the next 2.5 days the conference participants will experience:
- Motivation through a keynote address by the Acting NSF Deputy Director, Dr. Joseph Bordogna
- Understanding of the Drivers for Change through presentations reflecting the impact of:
  - engineering employers
  - NSF
  - ABET
- information technologies
- Models of Success through presentations by Paradigm Shifters, describing successful change that has been implemented at a variety of institutions
- Planning Our Own Steps through a series of facilitated, small-group workshops

This is an exciting time for engineering education, and we hope that this conference will allow you to experience and contribute to this excitement. We CAN make a difference. Let’s use the opportunity of this conference to devise effective strategies for making that difference at our own institutions!
Imperative for Reform: Challenges to 21st Century Engineers

- Major driver for engineering employment has shifted from defense to commercial competition; focus on time-to-market, cost, quality, customer orientation.
- Intelligent technologies offer opportunities to be more creative, "work smarter;" can revolutionize learning.
- Constantly-changing work environment calls for astute interpersonal skills; employment opportunities shifting to smaller firms, non-traditional areas.
- Massively integrated populations, place environment, health, and safety at the front end of design; zero discharge, life-cycle costs, social and political concerns change the classical economic balance.
### Broad Agreement on the Need for Change

- Multiple reports over the past ten years show remarkable consistency in the attributes needed in 21st Century engineering graduates and in the need for a new educational paradigm to develop these attributes.
- There is also broad agreement that systemic reform of engineering education will require a concurrent change from the predominant engineering school culture based on compartmentalization of knowledge, individual specialization, and a wholly research-based reward structure to one that values integration as well as specialization, teamwork as well as individual achievement, and educational research and innovation as well as research in the engineering sciences.

### So Let's Not Rehash the Obvious!

(after the next two slides)

Take as givens:
- *The What* -- a vision for 21st century engineering education
- *The Excuses* -- obstacles to achieving this vision

Focus on:
- *The How* -- effective steps for achieving the vision
- *The Who* -- key change agents and ways to commit them to action
### The New Engineering Education Paradigm

- Faculty dedicated to developing emerging professionals
- Maintain solid mathematical and scientific knowledge base.
- Integrate subject matter; show relationships from the beginning of the student's program.
- Stress active learning; emphasize industry-based projects; depend less on lectures
- Address issues of cost and timeliness, quality, social and environmental concerns, health and safety, etc.
- Stress communication, teamwork, group problem solving skills. Encourage diverse student academic backgrounds
- Maintain regular, well-planned interaction with industry

### So Why Doesn't It Happen?

- Academic institutions, by centuries-old tradition, are slow to change.
- Faculty governance process often talks proposed changes to death.
- Educational tradition in the U.S. is teacher-centered, not learner centered.
- Strong culture focused on individual, specialized achievement inhibits faculty collaboration, especially across disciplinary boundaries.
- Faculty reward system and funding patterns in research universities discourage the investment of significant faculty time in educational innovation.
- At some institutions, industry collaboration is frowned upon; at others, remote location makes such collaboration difficult.
### Drivers for Change

- Engineering college and departmental advisory boards
- Engineering professional societies, for example: Institute of Electrical and Electronics Engineers Educational Activities Board (IEEE/EAB)
- American Society for Engineering Education Engineering Deans' Council (ASEE/EDC) Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREE) (primarily aerospace)
- Private foundations, for example, the F. W. Olin Foundation (Olin College); the Lemelson Foundation (National Collegiate Inventors and Innovators Alliance)
- The National Science Foundation
- The Accreditation Board for Engineering and Technology (ABET)
- Information technology and cognitive science (enablers)

### NSF Engineering Education Investments: Some Milestones

- **Pre-1980:** Engineering education projects funded as part of general undergraduate science, math, and engineering programs. (*e.g., WPI Plan*)
- **1986:** NSB report, "Undergraduate Science, Mathematics, and Engineering Education" (the "Neal" report) calls for special emphasis on math & engineering. (*e.g., Drexel "E4 Program and Rose-Hulman integrated first-year math, science, & engineering*)
- **1989:** "Belmont Conference" of academic and industry leaders calls for major systemic engineering education reform through consortia of diverse engineering schools.
- **1990-1994:** Six engineering education coalitions established with NSF support and two through TRP/MET.
- **1995:** "Action Agenda" workshop calls for strong focus on implementation, evaluation, dissemination, and academic culture change.
- **1997:** "Action Agenda for Systemic Engineering Education Reform" announced; outcomes-based program focused on action goals.
NSF Engineering Education Funding
FY 1991-1996

<table>
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<tr>
<th>Program</th>
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<tr>
<td>Course and Curriculum Development (DUE)</td>
<td>$8.5 million</td>
</tr>
<tr>
<td>Undergraduate Faculty Enhancement (DUE)</td>
<td>5.9</td>
</tr>
<tr>
<td>Educational Innovations (CISE)</td>
<td>24.0</td>
</tr>
<tr>
<td>Engineering Education Coalitions (ENG)</td>
<td>74.6</td>
</tr>
<tr>
<td>Combined Research/Curriculum Development (ENG)</td>
<td>23.7</td>
</tr>
<tr>
<td><strong>NSF Six-Year Total</strong></td>
<td><strong>136.7</strong></td>
</tr>
</tbody>
</table>

Technology Reinvestment Project/Manufacturing

<table>
<thead>
<tr>
<th>Program</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education and Training (TRP/MET)</td>
<td>40.0</td>
</tr>
<tr>
<td><strong>Total NSF plus TRP/MET</strong></td>
<td><strong>176.7 million</strong></td>
</tr>
</tbody>
</table>

*Major programs, not including laboratory equipment grants*

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Strategy for the Future

*Based on recommendations of 1995 Action Agenda Workshop and discussions with NSF staff*

- Start no new coalitions.
- Focus the efforts of existing coalitions on evaluation, dissemination, and institutionalization of promising educational innovations, *not more innovations*.
- Begin new programs with this focus as coalitions end (max 10 yr) and/or phase down.
- Seek closer integration of ENG education programs with those of EHR, CISE, etc.
- Seek new ways to encourage supportive academic culture and to integrate education and research
Action Agenda Task Group  
September 1996 - September 1997

• Established by NSF Engineering Directorate with 7 members from 6 NSF directorates
• Charged to recommend an investment portfolio for systemic engineering education reform and a plan of evolution from current investment in Coalitions to a new set of systemic reform investments
• Conferred with engineering education reform leaders and other NSF staff
• Developed guidelines for the *Action Agenda for Systemic Engineering Education Reform*; outcomes-based strategy seeks proposals to achieve identified Action Agenda Goals, with major emphasis on institutionalization, evaluation, and dissemination.

Goals  
Teaching and Learning Methods

- Faculty act as mentors, dedicated to nurturing and developing students as emerging professionals
- Develop and use educational materials founded in learning theory and cognitive science research
- Provide learning experiences that meet the needs of students with different learning styles
- Integrate education and research roles; stress active, collaborative learning; fewer lectures
- Integrate subject matter by showing relationships from the beginning of the student's program
- Utilize emerging information technologies
- Develop capability, motivation for lifelong learning
Goals: Curricular Content

- Maintain solid math and science knowledge base
- Integrate subject matter from math, basic science, humanities and social science, and engineering by introducing fundamentals in the context of application
- Integrate teamwork, communications, group problem definition and solving throughout the curriculum
- Address issues of cost and timeliness, quality, social and environmental concerns, health and safety, etc., in the context of engineering practice
- recognize diverse learning styles and career goals
- Increase opportunities for international experience, possibly using distance learning technologies

Goals: Constituencies and Networks

- Increase success of underrepresented groups with effective strategies for recruitment, retention, and progression to graduation in engineering
- Develop effective linkages with K-12, 2-year colleges, dual degree programs, other transfer institutions
- Maintain regular, well-planned interaction w/industry Create network of engineering education leaders
- Create, maintain, arid disseminate evaluation findings that identify successful practices for replication
- Create incentives for chairs, deans, etc., to reward faculty who develop/implement learning innovations
- Reduce time & cost required for engineering degree
Merit Review Criteria

**Intellectual merit and quality of the proposed activity**
- Degree to which Action Agenda Goals are addressed?
- How well conceived and organized is the proposed project?
- What are the demonstrated capabilities of the project team?
- Is the proposed evaluation system likely to demonstrate Action Agenda Goal achievement?

**Broader impacts of the proposed activity**
- Will there be sustained impact on institutional culture, processes, and graduate diversity after NSF funding end?
- What is the probable impact of project results and dissemination process on the broader engineering education community?

Key Concepts

- The Action Agenda is the "post-coalition" phase of NSF efforts to encourage systemic engineering education reform.
- The Action Agenda is *outcomes-oriented*; proposals will be judged on their potential to achieve identified goals in ways that will benefit significant numbers of engineering students -- must demonstrate goal achievement through a strong evaluation system.
- Emphasis is on *evaluation, institutionalization, and dissemination* of existing educational innovations -not creating new innovations. Demonstrate effectiveness for institutions/student populations different from those at the originating institution.
Path Forward

- Action Agenda Proposal Guidelines posted on web (only)
  December 8, 1997; first proposal deadline March 31, 1998
  Panel review & initial awards in spring 1998
- Second and subsequent deadlines December 1 (annual); awards following spring
- Award size $100K-600K, up to 3 years, -$5 million available first year; may increase as coalitions phase down and complete funding periods

The Next 2.5 Days

- **Motivation** -- Keynote Address, J. Bordogna
- **Understanding** -- Drivers for Change
  » Engineering Employers
  » NSF
  » ABET
  » Information Technologies
  » Other?
- **Models of Success** -- Paradigm Shifters
- **Planning Our Own Next Steps** -- Workshops
Realizing the New Paradigm for Engineering Education

The Professional Engineer in 2010

Joseph Bordogna
National Science Foundation
http://www.nsf.gov/bordogna

Engineering Foundation Conference
Baltimore, Maryland
4 June 1998

A 21st Century World

- Information Explosion
- Global Economy
- Cognitive Revolution
- International Partnerships
- Diverse Workforce
- Finite Resources
- Creative Transformation
- Environmental Sustainability
- Continuous Innovation
- Demographic Shifts
- Infrastructure Renewal
- Career-Long Learning
Innovating vis-a-vis Productivity

The source of wealth is something specifically human: KNOWLEDGE

Knowledge applied to tasks we already know how to do is PRODUCTIVITY

Knowledge applied to tasks that are new and different is INNOVATION

*Managing for the Future: The 1990s and Beyond*
*Peter F. Drucker, 1992*
Realizing the New Paradigm for Engineering Education

Innovation Dynamo

<table>
<thead>
<tr>
<th>Core</th>
<th>Vectors</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savvy S&amp;E Intellectual Capital</td>
<td>Enabled Discovery</td>
<td>Wealth Creation</td>
</tr>
<tr>
<td>Positive Economic Environment (Capital, Regulatory...)</td>
<td>Workforce</td>
<td>Economic Opportunity</td>
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<tr>
<td>Robust SET Infrastructure</td>
<td>Connections (ind./Univ./ Govt.)</td>
<td>Enterprise Transformation</td>
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<tr>
<td></td>
<td>Ubiquitous Tools</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complexity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diversity</td>
<td></td>
</tr>
</tbody>
</table>

Complex Technologies & Global Markets
Comparison of Top 30 Exports, 1970 & 1994

<table>
<thead>
<tr>
<th></th>
<th>1970</th>
<th>1994</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Process</td>
<td>58%</td>
<td>8%</td>
</tr>
<tr>
<td>Simple Product</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex Process</td>
<td>31%</td>
<td>59%</td>
</tr>
<tr>
<td>Complex Product</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

"Economic well being in the future will likely go to those who are successful in innovating complex technologies."

Source: Kash & Rycroft, "Technology Policy in the 21st Century".
Realizing the New Paradigm for Engineering Education

Organization Norm Specification
(Tacit rule of behavior - usually unwritten notions of how to act/how not to act)

<table>
<thead>
<tr>
<th>Autonomy Driven</th>
<th>Control Driven</th>
<th>Cooperation Driven</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taboos</td>
<td>Not taking initiative</td>
<td>Doing one's own thing</td>
</tr>
<tr>
<td>Traditions</td>
<td>Celebrating freedom</td>
<td>Celebrating continuity</td>
</tr>
<tr>
<td>Trappings</td>
<td>Horizontal differentiation</td>
<td>Vertical differentiation</td>
</tr>
<tr>
<td>Turf</td>
<td>Property of each individual</td>
<td>Property of the organization</td>
</tr>
<tr>
<td>Tempo</td>
<td>Civilized</td>
<td>Regimented</td>
</tr>
<tr>
<td>Technology</td>
<td>To enhance individual performance</td>
<td>To constrain/replace people</td>
</tr>
<tr>
<td>Thrust</td>
<td>In each individual's capacity</td>
<td>In the wisdom of management</td>
</tr>
<tr>
<td>Teamwork</td>
<td>Situational</td>
<td>Scripted</td>
</tr>
</tbody>
</table>

R.W. Keidel, 1988
Corporate Players: Designs for Working and Winning Together

How Old Corporate Structures Use Technology

- Autonomy-Driven Corporation
  » Cultivates and Rewards the Individual
  » Technology Seen as Tool to Enable More Productivity

- Control-Driven Corporation
  » Puts the Organization First
  » Technology Used to Constrain or Replace the Individual
### The Knowledge Age Workplace: Technology Used to Cooperate

Technology is used to
- Enhance Group Performance
- Celebrate Flexibility
- Stimulate Creativity
- Enable Market-Changing Ideas

### Seeing What’s Visible: 21st Century Academe

<table>
<thead>
<tr>
<th>Traditional</th>
<th>Emerging</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Department-based</td>
<td>• Topic-based</td>
</tr>
<tr>
<td>• Campus-centric</td>
<td>• Global Reach</td>
</tr>
<tr>
<td>• Few Links to Industry</td>
<td>• Robust Industry Partnership</td>
</tr>
<tr>
<td>• Building-Block Courses</td>
<td>• Holistic Curriculum</td>
</tr>
<tr>
<td>• Research vs. Education</td>
<td>• Integration of Research &amp; Education</td>
</tr>
</tbody>
</table>
NSF Outcome Goals

- Discoveries and across the frontier of science and engineering
- Connections between discoveries and their use in service to society
- A diverse, globally-oriented workforce of scientists and engineers
- Improved achievement in mathematics and science skills needed by all Americans
- Meaningful information on the national and international science and engineering enterprise

NSF Core Strategies

- Develop Intellectual Capital
- Strengthen the Physical Infrastructure
- Integrate Research and Education
- Promote Partnerships
Integrating Research and Education

Definition

The weaving of knowledge creation, knowledge integration, and knowledge transfer into a robust whole that both defines and enables the process of continuous learning and the quest for new knowledge.

At all levels the learning process is enabled and enriched by:

- discovery, curiosity and inquiry
- the dynamics of the shared student-teacher experience
- a holistic faculty and student body and effective partnerships
- availability of information/cognitive resources

Role of Academe: Building Capacity for Learning and Innovation
NSF Themes

- Knowledge & Distributed Intelligence
- Life and Earth's Environment
- Educating for the Future

Knowledge & Distributed Intelligence in the Age of Information

- Next Generation Internet
- Multidisciplinary Approaches
  - Knowledge Networking
  - Learning and Intelligent Systems
  - New Computational Challenges
# Learning and Intelligent Systems

- Learning Technologies
- Insights Into Learning and Cognitive Functioning
- Computational Tools in Learning
- Collaborative Learning Across Physical and Virtual Communities
- Collaborative Human-Machine Learning
- Using Digital Libraries in Learning
- Knowledge-on-Demand Pedagogies

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<table>
<thead>
<tr>
<th>Career Fundamentals</th>
<th>The Year 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplicity</td>
<td>What was, and is harder to get</td>
</tr>
<tr>
<td>Complexity</td>
<td>What is, and will be</td>
</tr>
<tr>
<td>System</td>
<td>Features not gleaned from the parts</td>
</tr>
<tr>
<td>Productivity</td>
<td>A 20th century focus</td>
</tr>
<tr>
<td>Innovation</td>
<td>A 21st century focus</td>
</tr>
<tr>
<td>Commodity</td>
<td>What all that is new, becomes</td>
</tr>
<tr>
<td>Design</td>
<td>Manifestation of intent</td>
</tr>
<tr>
<td>Team</td>
<td>Intellectual diversity</td>
</tr>
<tr>
<td>Cognition</td>
<td>Major computer-communications tool</td>
</tr>
<tr>
<td>Making &amp; Moving</td>
<td>Adam Smith's stuff</td>
</tr>
</tbody>
</table>
The Credentials/Skill Set
The Year 2010

- Handle projects from initial conception of an idea through to product realization
- Understand, nurture, and capitalize sustainably on nature
- Be alpha-numeric literate
- Articulate team goals, influence others to invest in them, evince trust at all levels
- Envision rational solution scenarios to open-ended challenges
- Act as catalyst and master integrator in multifaceted, multidisciplinary projects
- Understand and practice quality issues

The Credentials/Skill Set
The Year 2010

- Manifest a strategic intent in design
- Enable comfort in interpersonal relations
- Pursue standards-based practice
- Practice creative transformation
- Focus on innovation
- Sense the coupling among seemingly disparate issues
- Make sense of complexity
- Contribute to, extract from, participate in the world's collective intelligence base
- Be an astute observer of strategic inflection points and anticipate their consequences at the moment of inflection
Societal Image of the Engineer
The Year 2010

- Astute maker
- Trusted innovator
- Ensurer of safety/quality of life
- Change agent
- Master integrator
- Enterprise enabler
- Technology steward
- Knowledge handler

Hardening of the Categories

There is no graver threat to the process of discovery than that dread disease, ‘hardening of the categories’.

-- Bob Miller
Science Artist
San Francisco
Analysis Presupposes Synthesis

For where the understanding has not previously combined, it cannot dissolve, since only as having been combined - by the understanding - can anything that allows of analysis to be given to the faculty of representation.

Kant
Critique of Pure Reason

Enabling the Nation’s Capacity to Perform
Engineering at the Interface of Human and Physical Systems
Challenges for 21st Century Academe

Educate students to:

- See the world whole; sense the coupling among seemingly disparate fields of endeavor
- Perform synthesis in balance with analysis
- Build connections between the world of learning and the world beyond
- **Innovate**

Putting Our Ideals to Work
The Year 2010

"An ideal is but a flaming vision of reality."

Joseph Conrad
(1857-1924)
## Components of a Holistic Baccalaureate Education

<table>
<thead>
<tr>
<th>Vertical (In-depth) Thinking</th>
<th>Lateral (Functional) Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract Learning</td>
<td>Experiential Learning</td>
</tr>
<tr>
<td>Reductionism - Fractionalization</td>
<td>Integration - Connecting the Parts</td>
</tr>
<tr>
<td>Develop Order</td>
<td>Correlate Chaos</td>
</tr>
<tr>
<td>Understand Certainty</td>
<td>Handle Ambiguity</td>
</tr>
<tr>
<td>Analysis</td>
<td>Synthesis</td>
</tr>
<tr>
<td>Research</td>
<td>Design / Process / Manufacture</td>
</tr>
<tr>
<td>Solve Problems</td>
<td>Formulate Problems</td>
</tr>
<tr>
<td>Develop Ideas</td>
<td>Implement Ideas</td>
</tr>
<tr>
<td>Independence</td>
<td>Teamwork</td>
</tr>
<tr>
<td>Technological - Scientific Base</td>
<td>Societal Context</td>
</tr>
<tr>
<td>Engineering Science</td>
<td>Functional Core of Engineering</td>
</tr>
</tbody>
</table>

## Digital Technology is Enabling Collective Intelligence

For the first time we have the ability to extract, preserve and organize the collective intelligence of entire populations.

Douglas Englebart
I hope to communicate the urgency I feel for the need for these changes, as well as something of their nature. Most, but not all, of what I will say is contained in one or more recent reports (American Society for Engineering Education, 1994; National Research Council, 1995; National Science Foundation, 1995). So, much of my message is not “new news,” but little of what these reports recommend has been implemented, and indeed there seems to be little sense of urgency. Quite the contrary, there is widespread complacency, in my view. And, in some areas, I feel even the reports don’t go far enough.

I want to talk about what should be—but aren’t yet—watershed changes in engineering education. I hope to make three introductory remarks before getting to the substance. First, a caveat: I am going to paint with a broad brush. I know there are exciting, innovative programs in a number of engineering schools. Perhaps most schools are trying one or two novel things. My remarks are an effort to generalize the status of the entire engineering education enterprise; this kind of approach will explicitly miss these “points of light.”

Second, a word about my view of what an engineer does, since this colors my ideas of how an engineer needs to be educated. Science is analytic—it strives to understand nature, what is. Engineering is synthetic—it strives to create what can be. My favorite operational definition of engineering is “design under constraint.” Engineering is creating, designing what can be, but it is constrained by nature, by cost, by concerns of safety, reliability, environmental impact, manufacturability, maintainability, and many other such “ilities.” Engineering is not “applied science.” To be sure, our understanding of nature is one of the constraints we work under, but it is far from the only one, it is seldom the hardest one, and almost never the limiting one.

Third, the practice of engineering is changing. Indeed, those changes are what underlie the urgency I feel for a new approach to engineering education. Growing global competition and the subsequent restructuring of industry, the shift from defense to civilian work, the use of new materials and biological processes, and the explosion of information technology—both as part of the process of engineering and as part of its product—have dramatically and irreversibly changed how engineers work. If anything, the pace of this change is accelerating.

**Chance: Broad, Deep and Accelerating**

Although there are exceptions, in general, engineering education has not kept up with this changing environment. I think it is only a slight exaggeration to say that our students are being prepared to practice engineering in a world that existed when we were trained a generation or two ago. They are not being prepared for the 21st century.

So, what needs to change? A lot, I think! Most obviously, we need to focus on curriculum, pedagogy, and diversity. I will say a bit about each of these, but the need for change goes deeper. We need to question whether the BS should be the first professional degree. We need to scrutinize the current system of faculty rewards. We need to seriously consider the need for formalized lifelong learning, the adequacy of student preparation in grades K-12, and the importance of technological literacy in the general population.

The list is long and the time short, so I will say only a few words about only some of these to give you a sense of both the vector of change that is needed and why I feel urgency about it. I am also going to jump around in this list because these issues are not independent of each other.

Most professions (e.g., business, law, medicine) do not consider the bachelor’s degree a professional degree. Engineering does. Doing so is a misrepresentation, both to the student and employer. Let’s consider just a few of the problems this causes:

- The engineering BS program has bloated to over 130 credit hours and still doesn’t cover requisite material.
- Companies generally invest 1 to 2 years in training new BS hires, completing the job left unfinished by our undergraduate programs.
- Liberal education in the humanities is being squeezed out of the engineer’s undergraduate experience, as are courses in social and management sciences.
- These problems are exacerbated as a number of states begin to mandate a maximum of 120 hours in the BS degree track.

The squeeze caused by treating the BS as a professional degree provokes recitation of the mantra, “the undergraduate curriculum should teach (only) the fundamentals.” Everyone agrees with that, pretty much. The difficulty comes when we try to decide which fundamentals are truly fundamental. The last major curriculum change in engineering, the move to what is referred to as “engineering science,” occurred following WW II. Since then, the fundamentals have been seen largely as continu-
ous mathematics and physics. But, as I said earlier, engineering is changing!

The new fundamentals include information technology (IT), which will be embedded in virtually every product and process in the future. That is, the "design space" for all engineers will include IT. Discrete mathematics, not continuous mathematics, is the underpinning of IT. Biological materials and processes are a bit behind IT in their impact on engineering, but they are closing fast. Thus, the chemical and biological sciences are also becoming fundamental to engineering. In addition, the modern engineer must design under constraints that include global cultural and business contexts, so he or she must understand those constraints at a deep level. We can't just add these new elements to a curriculum that's already too full, especially if we still claim that the baccalaureate is a professional degree. We have to look critically at the current cherished fundamentals and either displace them or find ways to cover them much more rapidly.

I don't want to engage in the teaching-versus-research debate. I believe, as I suspect most of you do, that teaching and research complement each other and that, by and large, there is a high correlation between good teaching and good research. In my admittedly idiosyncratic career, the number of cases of genuinely good teachers who were not good researchers is very small.

But in engineering education I think we have an additional problem, and it's one I want to emphasize. Recall that my definition of engineering is design under constraint. I believe the process of design is a synthetic, highly creative activity. Can you think of any other creative field on campus where the faculty are not expected to practice or perform? Art, music, drama? Even if you don't buy that engineering is creative in the same way as art or music, performance-oriented professions such as medicine and law expect their faculty to practice that profession. Can you imagine a medical school where the faculty was prohibited from practicing medicine? Yet, this is just the situation we have in engineering.

Engineering faculty are, for the most part, judged by criteria similar to the science faculty, and the practice of engineering is not one of those criteria. The faculty reward system recognizes teaching, research, and service to the profession, but it does not give the same status to delivering a marketable product or process, or designing an enduring piece of the nation's infrastructure.

Of course, what you measure is what you get. For the most part, our faculty are superb "engineering scientists," but they are not necessarily folks who know a lot about the practice of engineering. At most schools, for example, it's hard to bring someone onto the faculty who has spent their career in industry, even though such people would be extremely valuable to the students; their resumes simply don't fit what the reward system values. Sometimes, it's even hard to get recognition for a sabbatical in industry.

Please understand that I am not criticizing the current faculty. I am one of them, and I respect my colleagues greatly. Rather, I am criticizing a system that prevents us from enriching faculty with a complementary set of experiences and talents. But, to close the loop, the current faculty are the folks with the largest say in the engineering curriculum. Given this, it should not be a big surprise that industry leaders have been increasingly vocal about their discontent with engineering graduates.

Work-Force Diversity

Now, let's explore the issue of diversity. We've leveled off at less than 20 percent of entering freshman being women, and the number of underrepresented minorities is stuck in single digits. That's unacceptable! By the way, this is not an equity issue, it's a work-force issue. As a creative field, without diversity, engineering cannot take advantage of life experiences that bear directly on good engineering design. A clever TV ad that depicts the trials of a woman in high heels trying to get out of her sport-utility vehicle illustrates the point: Until recently, the U.S. auto had been designed for the 50th-percentile male.

The situation is simply unacceptable and will become increasingly unacceptable to industries that need diversity among their engineers in order to compete in a global market. I have no silver-bullet solution, but it is obvious to me that there is a crying need to coordinate the many good programs at various universities, professional societies, and the like. We're not getting the "bang for the buck" that we should.

I'd like to briefly consider the long-term educational needs of engineers. The half-life of engineering knowledge—the time in which half of what an engineer knows becomes obsolete—varies by field, but is estimated to be in the range of 2.5 to 7.5 years. To be sure, job-specific knowledge is gained in the process of doing that job. But we must question the value of narrow specialization at a time when engineered systems are becoming larger, more complex, and involve components and processes from many more fields of engineering.

The notion of lifelong learning has not been part of the engineering culture, either among individual engineers or at engineering schools. This must change. Individual engineers have to take responsibility for their own careers, and part of that responsibility is to keep abreast of the new fundamentals. Merely taking training on the latest technology isn't good enough. The fundamentals you learned in college probably are still fundamental, but they now aren't the only ones in this rapidly changing profession.

I am especially concerned that continuing education, with some exceptions, is mostly relegated to non-top-tier schools and, increasingly, to for-profit organizations. Unlike business schools, where the best of the best have embraced executive training and where the best faculty vie to teach these courses, the best faculty at our best engineering schools studiously avoid involvement in continuing education.
The Role of IT in Pedagogy

Let me turn now to pedagogy. While it is tempting to devote this entire article to this subject, I want to focus on just one issue: the opportunity for information technology to fundamentally change and dramatically improve the effectiveness of learning. So far, this hasn't happened.

As someone who has watched the development of computers for nearly 40 years, I know that the first use of IT developments is always to automate, in basically the same way, what we are already doing. The important, even profound, uses are when we do something different and better. Educational technology seems mired in that first use-predominantly automated drill. A system, called Plato, developed at the University of Illinois when I was a graduate student there in the early 1960s, contained most of the ideas in today's computer-assisted instructional systems. I don't find it surprising that many professors still depend on overheads, whiteboards, and lecture for much of the teaching they do.

Yet, at the same time, we know from research in learning that the lecture format is far from optimal. An approach called "asynchronous learning networks" has shown that comparable or better results can be obtained among students and faculty who communicate only over computer networks. I interpret these results mostly as a condemnation of the lecture format, which is somehow failing to exploit the benefits of personal interaction.

The profound uses of IT, I suspect, lie in its ability to provide access to vast information sources, to support discovery-based educational experiences safely, and to more aggressively support peer-to-peer education. In particular, the team-oriented design projects used by many schools, and which I applaud, could be dramatically expanded through the use of simulation and virtual reality. While, in the end, it's important to get one's hands dirty, the material, cost, and other constraints of doing actual physical fabrication limit the number of such experiences a student can get. Virtual fabrication in a high-fidelity simulated environment can greatly enrich the undergraduate experience.

For many years, I have been a professor at the University of Virginia, which was founded by Thomas Jefferson on the conviction that we could not have a democracy without an educated citizenry. I think Jefferson would consider the current state of his democracy alarming. Technology is one of the strongest forces shaping our nation, and our representatives in Congress are called upon regularly to vote on issues that will profoundly affect the nation and whose roots are technological. Yet, both those representatives and the people who elect them are, for the most part, technologically illiterate. Every person with a "liberal education" needs to be technologically literate!

I am consciously saying "technologically literate" and not just scientifically literate because it's not enough to understand something of nature, what is. An understanding of the larger "innovation engine," the process by which an understanding of nature is converted into what can be into a better, richer life-is critical. Engineering schools have not traditionally provided courses for liberal arts ma-

References


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Engineering Workplace Perspective

Arthur L. Glenn  
Associate, Burdeshaw Associates, Ltd. Retired Vice President, General Electric Company

Abstract

This paper reviews the many changes which are taking place in the industrial workplace, and presents the challenges our engineering education must meet to assure that our graduating engineers are properly prepared to be successful in this transformed industrial environment.

General Electric has always been a leader in improving how corporate America does business, and has been a shining light in the past two decades in transforming itself to meet the increased worldwide competition. This paper tracks the transformation of GE since 1980, focusing on the many changes that were made and how they were accomplished to become the most highly valued company in the world, as measured by market capitalization. A new engineering education paradigm is inferred from these workplace changes. The paper concludes with recommendations for changes to engineering education to better prepare graduates for the transformed workplace.

I. Introduction

Thank you for this opportunity to share some of my beliefs regarding the need for a new paradigm for engineering education. Many of us have heard definitions of salespersons and engineers as follows: sales persons know less and less about more and more until they know nothing about everything, while engineers know more and more about less and less until they know everything about nothing. Well, if will be the basis for my remarks. However, my other experience as a rocket research engineer, as a commissioned officer in the Army, organization theory, psychology, and philosophy were not interest to me. Other disciplines such as finance, marketing, English literature were included in my studies, but were of little interest to me. Other disciplines such as finance, marketing, organization theory, psychology, and philosophy were not included as electives, but all of these became quite important to me in my career.

As I recall, I found relevance in physics, chemistry, and math, but many of my fellow students did not, and I hear students today saying that they have trouble understanding the importance these subjects.

II. A Well Rounded Education is Important for all Engineering Undergraduates

Many argue that not all engineering graduates aspire to become the head of a major project, or a senior leader in the workplace, and perhaps my experience was sufficiently unique that those who have similar aspirations will be motivated to learn it on their own just as I did. However, I believe that that approach places many graduates at risk in our workplace today.

What I hope to do is to persuade you that the broader context of engineering education is necessary for our engineering graduates today and tomorrow, and if we don't broaden the education, we will be shortchanging them to be prepared for the workplace they will find. I also hope to convince you that it can be done in the current nominal four-year undergraduate period. I will do this by describing the GE workplace, and how it evolved over time, and is still evolving to a more challenging situation than ever. Then, I will discuss why I believe we need a new paradigm to properly prepare our graduates. Since most of my working experience was at GE, that workplace, it no longer is. Today, to keep up with the as president of a large environmental products and services everyday normal activity, everyone must know a great deal company and in my current part time consulting work, adds about more and more. I spent many years at General Electric, primarily in the Aerospace business of high technology electronic systems, but also a very exciting ten years in the high technology medical electronics business as head of Computed Tomography, better known as CAT scanners, and head of Magnetic Resonance, better known as MRI. Both of these are commonplace today, but when I was involved in the late 1970s and during the 1980s they were just emerging as the diagnostic imaging modality of choice for many procedures.

The reason that I have been involved in engineering education reform is that late in my career, I realized how much on-the-job training was necessary for me to do my job. Most of this learning was outside the normal bounds of engineering. From my perspective, it no longer is. Today, to keep up with the pace of modern businesses, we must know everything, while engineers know more and more about less and less until they know everything about nothing. Well, if will be the basis for my remarks. However, my other experience as a rocket research engineer, as a commissioned officer in the Army, organization theory, psychology, and philosophy were not interest to me. Other disciplines such as finance, marketing, English literature were included in my studies, but were of little interest to me. Other disciplines such as finance, marketing, organization theory, psychology, and philosophy were not included as electives, but all of these became quite important to me in my career.

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III. Why GE?

GE is a very large multi-national corporation that employs many engineering graduates. It is recognized as a leader in more than sixteen independent businesses. Anyone who has watched the transformation of GE under Jack Welch, a Ph.D. chemical engineer, would agree that GE has been one of the most astounding business success stories in the past two decades. Before Jack became CEO in 1980, GE was considered a highly successful corporation, but he saw a real danger in staying as it had been because the world was going to change drastically, and American enterprise would need to change to keep up. Many of my fellow employees
had difficulty with this new paradigm, since GE was successful by most measures. However, looking back we can see how correct he was. As an employee, especially in a salaried job, it was necessary to understand what he was saying and its relevance in order for each of us to make good decisions, both professional and personal. History shows that those who understood it contributed mightily: those who did not, fell behind. Much of what he said was not in engineeringese but in ordinary business terms as you will see as I review the steps in the transformation. Please make your own estimate of how much of what he said would be understood by our engineering graduates from what they are learning today.

IV Transformation of GE

His first moves, which he later described as changing the hardware, began in 1981. He started with a new description of the company, dividing it into three business circles: Technology, Services, and Core Manufacturing, and he included in those circles only those businesses which were number one or number two in their market as measured by share. Those outside the circles were to be fixed (achieve #1 or #2), sold or closed, pretty unsettling for those employed in those marked businesses. To understand what he was saying, one would have to know about market trends, market share, competitors, and the attractiveness of products relative to competition, not something our typical engineering graduate of today learns about. He also delayered the organization, by removing sectors, groups and strategic business units from the corporate structure. In his words, "We cleared out stifling bureaucracy, along with the strategic planning apparatus, corporate staff empires, rituals, endless studies and briefings, and all the classic machinery that makes big company operations smooth and predictable - but often glacially slow. As the underbrush of bureaucracy was cleared away, we began to see and talk to each other more clearly and more directly." For this "seeing and talking to each other" to succeed requires each person in every discipline to understand the importance of the contributions of all of those disciplines. In 1988, he began to change the software. The slogan "Speed, Simplicity, and Self-confidence" urged everyone to act more independently, to simplify activities, and to accomplish those simplified activities faster. For this to be accomplished, everyone had to be involved. His desire was, and I quote, "to give every one of the 220,000 employees what the best small companies give people: voice". This evolved into a company-wide program called "Work-Out", the idea of which was to remove useless work from the workplace. In this, and again I quote, "People of disparate ranks and functions search for a better way, every day, gathering in a room for an hour, or eight, or three days, grappling with a problem or an opportunity, and dealing with it, usually on the spot - producing real change instead of memos and promises of further study." You can see the need to work effectively in teams, and communicate well in this environment. In 1992, this concept was implemented company-wide.

at the Management Institute at Crotonville, NY where multidiscipline groups from different business units came to share their successes and disappointments with each other. Again I quote Mr. Welch, "Crotonville has become a vehicle for learning and sharing the best practices that can be found anywhere around the globe .... [It] combines the thirst for learning of academia with an action environment usually seen only in small, hungry companies." And I'll add, "where people work across broad assignments to get the job done". He described the emerging culture as "Boundary less Behavior" The sweetest fruit of this new culture was, "the demise of Not-Invented-Here and its utter disappearance from our Company. We quickly began to learn from each other: productivity solutions from Lighting; quick response asset management from Appliances; transaction effectiveness from GE Capital; the application of bullet train cost-reduction techniques from Aircraft Engines; and global account management from Plastics- .... [also] ideas from great companies of the world. Wal-Mart taught [us] the direct customer feedback technique. New product introduction came from Toshiba, Chrysler, and Hewlett-Packard. Advanced manufacturing from American Standard, Toyota and Yokogawa. Allied Signal, Ford and Xerox shared their insights into a quality initiative. Motorola which created a dramatically successful, quality-focused culture has been more than generous in sharing its six sigma experience " His vision was described in 1996 as "Growing Rapidly into the Next Century," and it focused on Globalization, New Products, Information Technology, Service, and Quality.

V GE's Expectations

In the 1997 annual report, published in March 1998 he focused on Globalization, Services, and Six Sigma quality, defined as, "a disciplined methodology that focuses on moving every process that touches our customers—every product and service—toward near-perfect quality". In that same report, under a subheading, "This is now the business of the company; 'A' products and 'A' services delivered by 'A' players around the globe." He characterizes "A" players in functions most likely to employ engineers as follows: "In engineering, 'A' [players] are those who embrace the methodology of Design for Six Sigma. 'A' engineers can't stand the thought of riding it out in the lab, but rather relish the rapid pace of technological change and continually reeducate themselves to stay on top of it. 'In manufacturing, 'A' players will be people who are immersed in Six Sigma technology, who consider inventory an embarrassment, people who understand how to drive asset turns and reduce inventory while at the same time increasing readiness to serve the customer. 'In sales, 'A' players will use the enormous customer value that Six Sigma generates to differentiate from the competition, to find new accounts, and to refresh and expand the old ones-as contrasted with 'C' players whose days are spent visiting 'friends' on the milk-run circuit of customer calls."
VI. Measures of Success

Has it been successful? A commonly used business measure is the total return to the shareholders. Since he initiated this program in 1980, the total return to shareholders has been $235 billion, and GE now has the highest market capitalization of any company in the world. If a shareholder had $100 invested in 1980, and reinvested all the dividends in stock, today it would be worth nearly $3500, compared to $1555 returned from the 30 Dow Jones industrial stocks, or $1300 returned from the broader S&P 500 stocks. Pretty successful by those measures people-wise, other companies seek out GE employees, especially managers and engineers, to fill their ranks as much if not more than from any other company in the world.

VII. The Need for Change

With all of these changes occurring in the workplace, is it any surprise that industry is advocating changes to the education of their new hires? And the workplace will continue to change at an equal or even a more rapid pace. Many of us believe that if a company is not on the leading edge in its industry, in this rapid-paced shrinking world, its chances for long-term independent survival are dim. So to keep pace we must not only keep up with technology changes, we must change other practices as well. Modern core engineering content is assumed by hiring employers, but it must be accompanied by a much broader education than ever before, if graduating engineers are to be successful in today's companies.

VIII. Recommended New Paradigm

Teaching our engineering students modern core engineering will require a good grounding in math, chemistry, and physics. However, we must demonstrate the relevance of these basic sciences to their ultimate education and practice, so that students excel at them because of their importance in grappling engineering fundamentals. But that alone won't be enough to get students off to a good start in their careers. They will need to learn the context in which they must communicate their ideas and other information effectively. Work in corporations, with rare exception, is done in teams, usually made up of people from many different business functions with widely varying educational backgrounds. The teams in GE's Work-Out activities, as well as the Crotonville idea exchange, are multidisciplinary, so not only learning to work in teams, but working in teams with members from diverse business functions is a way of life. This requires each member to have an understanding of all functions of the business; engineering, manufacturing, sales, service, marketing, finance, legal, and human relations, to be an effective contributor to each business team. An understanding of economics, statistics, psychology of human relations, environmental and safety considerations, and organization dynamics is vitally important in today's corpo-rate workplace. The better the employees understand these, the more valuable they will be. Today's workplace is less structured than ever before. We have not yet reached the fully virtual corporation, but we're moving in that direction. In the ever-increasing unstructured environment, leadership becomes a necessary ingredient to make progress at any organizational level where permanent managers are scarce. Maybe everyone can't be the leader, but understanding the importance of leadership sure helps everyone to get the job done.

IX. How Can it be Done?

Now that I've covered what I believe is important for engineering graduates to learn as undergraduates, how are we going to do this? We must realize a new paradigm which must come as much from other colleges on campus as from engineering. We discussed relevance, and that is what we must inject into the education process. So often, we hear students commenting that early course work isn't interesting and they don't understand what it has to do with engineering. Certainly in this audience, we now know why it is relevant, but did we when we were students? And how would we make it relevant? That is why context is important. You have read much about how GE uses multifunctional teams to solve problems. I believe that multidisciplinary team teaching is a useful step to bring about relevance in our education process without extending the time to graduate. If we could do more to integrate oral and written communications as part of all design courses, or physics and chemistry taught as part of the engineering discipline in which they are used, I believe that would go a big way to get the students to understand their importance. There are many successful examples of this at many university locations now, and it works, but we must extend it to all students. Finance, accounting, marketing, economics, statistics, safety, and environmental issues can be part of any design project. Literature, psychology, organization dynamics, and philosophy can provide important background in any teamwork-based studies, but those courses must be taught in such a way that their relevance to engineering is understood. All of these are important for the student to grasp the context of his/her work in relation to the whole. And this makes for better communications with others involved.

X. Conserving Students' Time

If we use an integrated teaching approach, I believe that we may be able to make these changes, and meet the requirements for graduation in the same class time as we do today. In the industrial workplace, that is called productivity-doing more with the same resources. But the resources I wish to conserve are the students'; the often overlooked primary customer. In business, productivity adds value for the customer without raising price; in education, our productivity gains should give the students a more valuable education without increasing the time and cost to graduate.
Xi. Summary

Yes, we do need a new paradigm, but I believe we need the new paradigm as much to reinvent the teaching workplace to make it more integrated, as focusing on what should be taught. Undoubtedly this will be tough to implement, but so is change in any large organization. Can American higher education take a page from corporate America's book to boost productivity by getting more value from every credit hour, and graduate better prepared engineers ready to take their place in our fast-moving workplace? I believe we can, but the paradigm must reach outside engineering and involve a "boundaryless" approach to get the most from all faculty across the entire university. If we can do this, we can better educate our engineers to continue to play their prominent roles in the ever-changing workplace in the next millennium just as they do today. Your industrial partners are ready to help in any way we can, but we are outsiders. You must huddle with your faculty and work toward a new paradigm which is embraced by all, if you are to be successful with the new paradigm.

References

EC 2000: A Driver for Change

Edward A. Parrish, President
Worcester Polytechnic Institute

Introduction

The Nation has witnessed some 20 years of growing concerns over its relative competitive position in a global economy and the perceived decline of our educational standards. As the future state of the former is determined by the latter's, educational reform has received considerable attention. While much of the focus has been on the K-12 system, higher education has not escaped criticism. The increasing pressure for improvements led to the assessment movement that defined the 1980s.

Among the more public reactions to these issues was the 1986 action of the National Governors Association that called for "every college and university ... to implement systematic reforms that use multiple measures to assess undergraduate student learning." The general response was a change from input measures (SAT scores, number of computers and books available to students, selectivity, percent of faculty with terminal degrees) to output measures (knowledge and skills obtained by students, graduation rates, placement data, success of graduates). Mechanisms used to perform assessment included student grades in various courses and laboratories, quality of student projects, local and state tests, and nationally normed tests. For the most part, institutions used their own criteria and developed their own processes, which made comparisons within states difficult and those between states impossible.

Despite these efforts, the results were significantly below expectations. This led policy makers to question the wisdom of continuing public funding at traditional levels. In addition, parents and students began more and more to question the value of their personal investments in education. The congruence of these forces turned the 1990s into the decade of accountability, with which educators still are struggling.

The intent of accountability is to focus on external constituencies (customers or stakeholders, depending upon point of view) and to employ common and comparable performance indicators. Literally hundreds of different indicators are in use, with the more typical being admissions standards along with enrollment, retention, and graduation data, etc. By 1996, more than half the states were involved in performance assessment.

At the K-12 level, the Third International Mathematics and Science Study produced more bad news. Conducted in 1995, it was the largest and most comprehensive study ever undertaken and had an international average of 500 for both math and science scores. US students scored below average in both subjects, realizing a score of 461 on mathematics and 480 on science.

In higher education, the recent report from the Boyer Commission on Educating Undergraduates [1] criticizes the value received at major research universities. While accounting for only 3% of the more than 3500 institutions of higher education, together they produce 56% of the science and engineering BS degrees and thus have significant impact on the Nation's future technical workforce. The report states that, "Too often graduates leave without knowing how to think logically, write clearly, or speak coherently." It goes on to suggest that graduate receive too little of real value beyond a credential to land a first job.

Drivers for Change

The reports referred to above represent stinging criticisms of the results from a host of efforts to improve the educational systems in this country. It seems apparent that accountability will become a growing force for change in the future, and begs the question, accountable to whom? There are several answers, including the state and Federal governments, employers (via market forces), and professional peer groups.

In the early part of this decade, government was a significant driver [2]. For example, there were federally mandated standards that replaced the institutionally defined measures. In 1992, the amendments to the Higher Education Act created State Postsecondary Review Entities (SPREs) which prescribed extensive quality standards and review processes to be used by accreditors. They also provided detailed control over administrative and financial matters that required frequent reporting. Compliance was obtained through leveraging of federal financial aid to institutions.

Institutions mobilized considerable opposition to the SPREs, objecting to the one-size-fits-all approach and the associated threats to institutional autonomy. In the move to deregulation following the 1994 elections, the SPREs were eliminated. While this was celebrated in many institutions, it did open the door for accreditation agencies to link their internal standards to actual performance.

Concurrent with these governmental actions, industry began to mount its own concerted efforts to improve engineering education. From its perspective, engineering programs in the vast majority of schools were too science oriented and lacking in design content and opportunities to translate theory into practice. Industrial representatives became broadly involved in studies by ASEE, the NSF coalitions, and ABET directed at encouraging change and accountabil-
An early indicator of the kinds of outcomes desired from engineering education was Boeing's "Attributes of an Engineer" shown in Table 1. Shortly thereafter, ASEE published the so-called Green Report [3], that included needs to be addressed in curricula, as shown in Table 2. Similar kinds of recommendations came from the Engineering Education Board of the National Research Council. In addition, the massive effort associated with the NSF Engineering Education Coalitions gained considerable attention. All of these activities added to the mounting pressure on ABET to address the need to stimulate change. The Board-appointed Accreditation Process Review Committee identified a number of issues that required attention, the first of which was: "The current accreditation criteria are too long and by their very nature encourage a rigid, bean-counting approach that stifles innovation." This in turn led to action by the Engineering Accreditation Commission (EAC) resulting in the NSF Criteria Workshop held in New York City in May of 1994. This brought together about sixty participants from industry, government, and academia to discuss the criteria. The recommendations calling for revolutionary changes were published in a report and given to the EAC's General and Program Criteria Committee for action. Following a year of effort, the committee's recommendations were unanimously adopted by the EAC and by the ABET Board in 1995 and now form what is known as Engineering Criteria 2000.

Pilot visits under the new criteria were carried out at the University of Arkansas and WPI during 1996-97 and at Georgia Tech, Harvey Mudd, and Union College during 1997-98. The next three years will provide opportunities for interested institutions to volunteer for evaluation under EC 2000, with mandatory use beginning in 2001-02.

The new standards are set forth in eight criteria, and also address coop and advanced level programs. As these are well documented (e.g., www.abet.org), they will not be discussed in detail here. However, it is desirable to look at Criterion 3 dealing with program outcomes and assessment and its congruence with the earlier studies cited.

Five of the eleven attributes address technical competencies required of graduates. Arranged at the top of the list in Table 3, they encompass the hard skills associated with professional engineering practice as referred to in Tables 1 and 2. The remaining six outcomes reach beyond technical competence into areas normally associated with a liberal arts education. These are often referred to as soft skills within technological communities. The overlap with the recommendations emanating from ASEE and others is substantial; in particular, the influence of industrial perspectives is evident. Consequently, programs achieving accreditation under EC 2000 should produce graduates to industry's liking.

Criterion 3 also requires performance in that an assessment process must be in place with documented results. It is also necessary that outcomes are related to institutional mission and program objectives and that they are measured. Finally, it must be demonstrated that results are used for program improvement.

**EC 2000 as a Driver**

The new criteria also have strategic value to institutions. They are flexible and will accommodate a wide variety of institutional missions and program goals. In this regard, they destroy the "cookie-cutter approach" to meeting ABET standards which has long plagued innovative programs. The performance aspects also will help institutions address accountability issues because emphasis is placed on learning, not accumulating credits. In many ways, the questions raised are more important than the criteria themselves.

As an example of the impact of the changes implied by EC 2000, consider the situation at WPI which has been at odds with ABET for many years. In 1970, WPI implemented a flexible curriculum with no prescribed prerequisites and individual programs of study. Students engaged in team-based experiential learning through major project requirements that involved interdisciplinary topics; the entire curriculum was outcomes oriented and required passing of a competency examination for graduation. To reduce competition among individual students, a unique grading system was employed and no grade point averages were calculated.

As can be imagined, evaluators had real problems trying to use checklists for compliance. With no prescribed curriculum, it was not possible for evaluators to compare sample transcripts to various specimens. Over the years, these conflicts led to a reluctance by the faculty to innovate further, feeling that "ABET won't let us do Eventually, the competency exam was replaced with distribution requirements and few significant improvements occurred. With the advent of EC 2000 and the pilot evaluation in 1996, suddenly ABET and WPI were on the same page. As a result, considerable attention is being given to strategic issues within the curricula and improved assessment processes are being implemented.

**Conclusions**

There are many potential advantages associated with implementing engineering programs under EC 2000. These new criteria are extremely responsive to issues raised by industry for many years, and remove the prescriptive, bean-counting methods historically associated with ABET evaluations. While past and existing criteria contain a section dealing with innovative programs (11.A.7.), it was rarely if ever exercised. Thus, new and innovative programs were essentially stifled from development and many engineering programs suffered from a lack of differentiation.

Under EC 2000, there is real hope for broad educational programs within engineering schools. While not sacrificing technical competencies, graduates should emerge with experiences in working on multicultural, interdisciplinary teams, with strong communication skills, an appreciation for the impact of technology on society and the role of ethics in the development and implementation of that technology, and an appropriate global perspective. In addition, graduates of these programs will be flexible and adaptive to...
changing needs, with an ingrained appreciation for the value of continual professional renewal.

Close inspection will also reveal that EC 2000 facilitate defragmentation and lead to a clarification of institutional and program goals. In this context, they offer transcendent purposes including a more holistic approach to the total educational experience of engineering students, reaching well beyond distinct courses and individuals. The resulting whole should truly be greater than the sum of the parts. In this sense, the new criteria can be a significant catalyst for change.

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2. Peter T. Ewell, Jane V Wellmar, and Karen Paulson, "Refashioning Accountability:
The MIT EECS Master of Engineering

Paul Penfield, Jr.
Massachusetts Institute of Technology

Jesus A. del Alamo
Massachusetts Institute of Technology

Abstract

In 1994 thirty-five students were in the first group to receive the Master of Engineering degree from the MIT Department of Electrical Engineering and Computer Science. Now, four years later, about 200 such degrees are awarded each year. About two-thirds of EECS undergraduates participate.

This new degree program was intended to prepare a person for a successful career as a practicing engineer, or at least a career that starts out that way. Its design was based on a simple theory of the various types of careers our graduates might aspire to. It was intended to be the department's flagship program.

The result is an integrated five-year program leading to the simultaneous award of a bachelor's and a master's degree. The structured style typical of undergraduate programs is seamlessly combined with the advanced specialization found in graduate programs, so that students can plan a five-year experience in a unified way. Students may specialize anywhere within the broad discipline comprising the union of electrical engineering and computer science.

Because the program combines undergraduate and graduate elements in novel ways, securing university approvals was not straightforward. A business plan was necessary to justify the additional resources needed to staff the program. Care had to be taken to ensure that our bachelor's and doctor's programs were not adversely affected. Concerns were raised about possible narrowing of student experience, premature specialization, and general increase in student pace and pressure. Some wanted the new program to have an increased liberal or general education component.

While designing this new program, we took the opportunity to rethink our other programs. We made the electrical science and engineering program and the computer science and engineering program identical in structure, and started a third program with a broader foundation in both EE and CS. All three programs are accredited by ABET and two of them also by CSAB.

The program is considered to be a success, yet its essential features have not yet been adopted by other departments at MIT, nor, to our knowledge, at other universities.

I. What Is the New MIT EECS Master of Engineering Program?

Since 1993 the Department of Electrical Engineering and Computer Science at MIT has offered a program leading to the Master of Engineering (M.Eng.) degree. The Department is the largest at MIT, typically awarding over a third of MIT's 1000 bachelor's degrees per year. The M.Eng. Program prepares over 200 students per year for careers that start out with the practice of engineering.

This five-year program combines the classroom structure typical of undergraduate study with the advanced material and specialization needed by today's engineering graduates. Students receive simultaneous S.B. and M.Eng. degrees. It is currently described as the Department's flagship degree program, aspired to by the vast majority of undergraduates.

II. Why Was This Program Needed?

The educational programs of the Department are based on a simple model. Bachelor's degrees are intended for general education of students, for preparation for life, and for foundation for a variety of careers, including especially electrical engineering and computer science. The Department's S.B. programs are designed for people seeking a general education with strength in science and engineering. These programs may be considered the modern form of a liberal education - modern in the sense that they are centered on science and technology, and liberal in the sense that they provide broad intellectual development and can lead to many different types of careers.

The new M.Eng. Program includes the liberal education of the bachelor's programs but then goes further. It leads students toward a particular career that, at least initially, includes the practice of engineering. This program requires a combination of technical breadth and specialization, along with a thesis. These prepare students for the design, analysis, and synthesis tasks of engineering. Experience has shown that for the greatest success in engineering, education at the master's level is needed. MIT EELS graduates have demonstrated this last point by seeking, in very large numbers, professional education beyond the bachelor's level.

Doctoral study, with its deep research experience, is for those who seek careers involving the discovery, codification, and transmission of the knowledge on which EECS is based. These careers can include not only traditional teaching and research, but also any activities that benefit from knowing what it is like on the frontiers of knowledge.

In some fields prospective researchers often continue their education past the doctorate in a post-doc position. While these programs are useful in further developing research skills, they too often have the reputation of serving as an employment buffer when supply of research personnel is scarce.
At many universities EE and CS (and computer engineering) are considered separate fields of study, but at MIT the prevailing attitude is that they constitute an inseparable single discipline. Graduates will find themselves in situations where the rapidly changing boundaries between hardware and software, between algorithms and chips and between communications and computation defy engineering solutions that are narrowly based. Therefore at the undergraduate level the curriculum includes material from all these areas, and students are required to have broad exposure.

Before 1990, the EECS programs at MIT did not adhere to these principles. There were separate EE and CS bachelor's programs. It was difficult to fit in the breadth needed by modern engineers. At the same time, the master's program served mainly as a proving ground for would-be Ph.D. students, and over the years the S.M. theses had become extremely long and deep. Admission to the S.M. program was based on potential to perform doctoral research, rather than on ability to be an engineer. Finally, the prevailing pattern of four years for the bachelor's program followed by one or two years for the master's introduced an inherent inefficiency, although it did facilitate shuffling of students among different universities at the end of four years.

III. How Was This Program Developed?

The need for reform was recognized at MIT, principally by Prof. William M. Siebert, during the 1980s. He discussed the notion of a new approach to "the First Professional Degree" in several venues, and gradually persuaded the faculty in the Department of its merit. In 1989, this project was made a priority within the Department. A small committee was set up to oversee its design, and the department faculty were given the opportunity, in several forms, to let their views be known, and to participate in the details. The key people were Prof. Siebert, Campbell L. Searle, John V Guttag, and the department head, Paul Penfield, Jr.

In 1992 the plans were formulated more completely. Informal presentations were made to many MIT committees. One of the problems encountered was that the traditional governance of the university was (and still is) split along the lines of undergraduate/graduate programs. The proposed new program was not based on this paradigm and therefore committees were unsure how to treat it. To this day the administration of the program is more difficult by the fact that it does not respect this split.

It was decided that for the program to succeed there had to be a consensus among department faculty. Several informational meetings were held, and in the end every faculty member, without exception, was expected to write a letter to the department head stating whether he or she was in favor, and if so, why, and if not, why not. This was not a secret ballot -everybody had to stand up and be counted. The result was that there was overwhelming support along with recognition of some concerns outlined below.

A business plan, made to justify the additional resources needed to operate the program, was approved by the MIT Provost in 1992. A description of the planned program and its need was provided to the MIT faculty. The necessary faculty votes were made at the MIT Faculty Meeting on November 18, 1992. The first graduates of the program received their degrees in 1994. In 1998 an internal review, mandated by the 1992 faculty vote, considered numerous concerns that were raised when the program was being designed.

Implementation was done under policy guidelines developed by the Department's Professional Education Policy Committee, chaired by Prof Jesus A. del Alamo. While the program was being developed, the engineering education community was kept informed by a series of conference presentations. Now that the program has been in operation long enough for an assessment, it is appropriate to present an evaluation of its success.

IV Concerns

There were many concerns expressed by various people about the new program. Would the highly successful VI-A Internship Program be affected? (This program already offered a more or less seamless five-year program leading to simultaneous S.M. and S.B. degrees with industrial experience.) Would the department's doctoral program be adversely affected? Would the program prove to be so attractive that an unhealthy fraction of MIT undergraduates selected EECS as a major? Would there be enough shortterm thesis topics available? How would the M.Eng. thesis be kept from becoming as long as most S.M. theses of that day? How would the new S.M. thesis be kept similarly short? Would students be able to afford the cost of the fifth year of education? Would the notoriously intense pace and pressure of the undergraduate experience be increased, thereby undermining the liberal goal of the program? Would students be driven to try to finish the program in four years rather than five, perhaps to save money? Would there be negative effects on those not admitted? There was concern about the program's effect on gender and racial diversity of the MIT EECS student body - would minority groups be selectively favored or disfavored?

Some people would have liked the additional year to be spent in part on topics to broaden the students' perspective on society and the context in which engineering is done. As it was, one additional free elective was added but all the rest of the fifth year was to be devoted to technical material. Some considered this to be an opportunity lost.

V The Program as It Turned Out

While the M.Eng. Program was being designed; the opportunity was taken to reform the S.B. programs also. The structure of the OVI-10 Electrical Science and Engineering program and the OVI-3O Computer Science and Engineering program were aligned. A common core of material at the
Realizing the New Paradigm for Engineering Education

sophomore level was retained. The junior-level advanced undergraduate courses were examined and a new one dealing with control, communications, and signal processing was introduced. To serve the needs of students, who wished to retain breadth past the sophomore year and not necessarily specialize in either EE or CS, a new 6VI-26 program was designed, named Electrical Engineering and Computer Science. This had the same structure as the other two programs, but (after 1996) students were required to have junior-level exposure in both EE and CS. This new program is the most constrained and difficult of the three, and it is also the most popular. The M.Eng. Program, by encouraging breadth within EECS, is seamless with respect to the distinction between EE and CS.

The M.Eng. Program involves admission with a minimum of fuss and bother after the third year. Those admitted can be assured of their ability to stay for the fifth year and seek the M.Eng. and S.B. degrees simultaneously, and can therefore plan their final two years with that objective in mind. They can delay until the fifth year some S.B. requirements in order to fit into their senior year a graduate course that may be offered alternate years. Or they can take, as seniors, graduate courses that lead to a M.Eng. thesis. In general they can plan a single program of study rather than two separate 4-year and 1-year programs. Also, the classroom orientation of the undergraduate years is carried through to the fifth year. These are the two ways in which this program is seamless across the undergraduate-graduate boundary.

Despite its seamless character, the program still retains some important distinctions between the undergraduate and graduate years. Financial aid is not as readily available for the fifth year, and goes from being need-based to being merit-based, although funds were raised to pay the interest on loans taken out by M.Eng. students. The thesis, normally done during the fifth year, requires a graduate level of motivation and independence on the part of the student. In general, fifth-year students are expected to display the level of maturity and responsibility normally associated with graduate study. They are also expected to maintain B or better grades.

At the same time this program was put into place, the S.M. program (which continues to be available to graduate students from outside but not to MIT EECS students) was changed so that the thesis expectations match those of the M.Eng. That is, the S.M. thesis no longer can be a multiyear mini-doctoral thesis. To enforce the shorter theses, the department adopted a policy that financial aid administered by the department would stop after four semesters for S.M. students or three semesters (beyond the eight for the undergraduate program) for M.Eng. students.

The need for M.Eng. students to be exposed to contextual and professional material have been partly addressed. Some small-scale experiments have involved new courses with names like "Ethics and the Law on the Electronic Frontier," "The Structure of Engineering Revolutions," and "Structure, Practice and Innovation in EECS." An annual department-wide event named Master Works features talks by master's candidates about their theses; so many students participate that six parallel sessions are needed.

VI. Results

The M.Eng. Program has proven to be very popular. Typically there are between 300 and 350 students per year majoring in EECS (out of about 1000 undergraduates at MIT per year), and two-thirds of those stay for the M.Eng. degree. It was a surprise that only 65% of the M.Eng. degrees are actually given simultaneously with the S.B. degree; the other 35% of students manage to earn their S.B. in four years and decide to march at commencement with their classmates.

Accreditation was not sought for the M.Eng. program, but rather for the three S.B. programs. The VI-1 and VI-3 programs, being continuations of prior accredited programs, were accredited in 1995-96, the only difference from prior years being that VI-3, because of its name "Computer Science and Engineering" required accreditation by both ABET and CSAB. The VI-2 program, because it was innovative in not requiring specialization in either EE or CS, was more of a challenge to the accreditation process. The accreditation team visited in October, 1995. At that time the program was in the process of being strengthened to require breadth at the junior level. This change convinced the visitors that all graduates had sufficient advanced technical material in both EE and CS. The VI-2 program was accredited by both ABET and CSAB. The program was also back accredited for two years so as to cover all its graduates.

There continues to be great interest among MIT undergraduates in EECS. Student enrollment has increased since 1994, and in particular the increase in computer science has been extraordinary. Prior to 1990 the number of students in EE was generally twice the number in CS. During the 1990s there has been a shift of interest away from EE into CS, and in 1998 there are more than twice as many VI3 as VI-1 students (this trend is being felt at almost all universities). However, the most interesting development is that over half of the EECS students now select VI-2, the most demanding of the three programs, and the one that does not force specialization in either EE or CS. The students apparently believe that their options will remain the greatest if they are familiar with both EE and CS technical material.

Enrollment in the VI-A Internship program is about 30% lower now than it was before the M.Eng. Program. Perhaps this is a result of changes in industry (more emphasis on short-term results). Or perhaps it is because some earlier VI-A students, not really interested in the industrial experience, joined VI-A only because it was a fast route to a master's degree. Without such students, whose needs are now served by the new M.Eng. Program, the VI-A program is stronger, even if smaller.

After a two-year transition period when students and supervisors alike were testing the system, the shorter
master's thesis is working very well. There are a sufficient number of interesting, appropriate topics, and each year there are only one or two students who lose financial aid because their theses are not finished in time. About 70% of the M.Eng. students receive some sort of financial support, typically as a Research Assistant or a Teaching Assistant. The rest pay their way through a combination of outside fellowships, loans, and personal funds.

The M.Eng. students are selected on the basis of their ability to perform academically at the first-year graduate level, whereas S.M. students are selected (from outside applicants) on the basis of their potential for doctoral work. Thus one might expect the S.M. students to do significantly better academically. This is not the case. The GPA of M.Eng. students after their first four years is 0.08 point below that of S.M. students. The acceptance rate of M.Eng. students into the doctoral program is high for those who apply. The five-year schedule is a realistic one - the average time from entry to MIT to the M.Eng. degree is 5.1 years. M.Eng. students participate in undergraduate research at a high level, and the number of double degree programs and external minors is higher for M.Eng. students than the general population. Thus the M.Eng. Program does not seem to narrow the outlook and perspective of the students.

It is interesting to ask whether M.Eng. students recover the cost of the program. Of course students should seek higher education because of the increased opportunities it gives them throughout their life, and the greater control over their own destiny. However, a case can be made that the M.Eng. is a sound financial investment. Starting salaries for MIT EECS M.Eng. and S.M. graduates are each about $8400 per year more than the average MIT EECS S.B. graduate. The financial investment of the M.Eng. degree, without any financial aid such as fellowships or RA or TA positions, is the tuition (about $24,000) plus the lost earnings for one year (about $32,000), or a total of $76,000. The payback period is thus less than ten years, even assuming that the gap between the master's and bachelor's pay does not increase with time.

In general students are pleased with the program. In the 1997 exit survey, 97% of the students said it was worth the extra effort to complete it. Aspects that were particularly appreciated included the convenience and efficiency of the seamless program, and the thesis experience. About half the respondents said they were headed directly for a technical job, the other half planned such things as working toward a Ph.D., a job on Wall Street, or medical school.

The recent search for an EECS Department Head gave an opportunity for assessing faculty opinions about the M.Eng. Program. The search committee let the faculty who met with them raise issues on their own, and the M.Eng. Program was a frequent topic. Many faculty feel that the idea is sound but the implementation needs significant adjustment. A suggestion often made was that admission be more selective. Some faculty blame the M.Eng. Program for the lack of resources, including both faculty time and TAs, to devote to advanced graduate courses. Some faculty believe that M.Eng. theses do not advance their own research operations as much as the normal Ph.D. theses or the traditional S.M. theses and therefore do not wish to participate as fully as others. Faculty who teach first-year graduate courses report that the M.Eng. students are not as well prepared as the S.M. students (this is not surprising since they are selected using different criteria) and it is necessary to reduce the amount of material taught as a result. They also report that the style of these courses changes to serve the larger audience, often in a negative way.

Another issue of great importance is the increased enrollment in EECS. MIT allows undergraduates a free choice of major starting at the end of the freshman year, and the fraction that select EECS has now risen to over 35%. Most observers believe that the popularity of the M.Eng. Program is a significant cause, but other factors include the increased pervasiveness of electronics, communication, and computation in society, the attractive career opportunities in these fields, and in general their "high tech" image. The department's ability to respond to the perceived weaknesses in the M.Eng. Program will depend on getting the resources needed to cope with the large student demand.

In the administration of the program, there are many ways in which the seamless character of the program is at odds with the typical university pattern. For example, the MIT Registrar feels a mandate to compute separate GPA and grade reports for the undergraduate and graduate portions of a M.Eng. student's overall program. Hence there is a flurry of activity every year to move courses around between the graduate and undergraduate buckets merely to satisfy the Registrar.

The M.Eng. Program requirements are complicated, perhaps more complicated than necessary, so student advising is a challenge.

VII. Next Steps

Like all programs, the M.Eng. Program must evolve. Continued attention must be paid to implementation details, under the principle that if you don't take care of the details, then the details will take care of you.

The M.Eng. Program is being reviewed in 1998, in accordance with the original 1992 faculty vote. The present paper is based in part on that review, which identified some weaknesses that threaten the program, and offered several steps that should be taken to strengthen it.

Among the important issues discussed in that review was the impact of the less well prepared M.Eng. students on first-year graduate courses. Recently the department's doctoral program was reviewed from a "clean slate" point of view, and one of the results from that study will be the development or refinement of first-year graduate courses that will serve both the potential doctoral students and the terminal M.Eng. students.

V111. Other Similar Programs
This M.Eng. Program seems to be based on a sound model of education at the various levels (bachelor's, master's, and doctoral). Overall, it is operating very successfully.

Despite the success of this program, other MIT M.Eng. Programs have not been based on the same seamless five-year model. Instead, they have been one-year professional programs, rather like a typical MBA, sometimes with a requirement of industrial experience.

As far as is known, other universities have not adopted this approach either.

References

Introduction

This report on the "Harvey Mudd Experience" sets forth the "Harvey Mudd Mission" and a consistent set of "Goals for Engineering Graduates." To meet these goals, a non-specialized curriculum has been devised that provides the broadest possible exposure to the sciences and humanities within the time constraints of the four-year engineering curriculum. The Engineering program is divided into three stems: engineering science, systems, and design. Design is embodied primarily in the well-known Harvey Mudd Engineering Clinic.

The Clinic is a university-based program which utilizes sponsored industrial research and development projects for its design courses. Projects are carried out by student teams counseled by an engineering professor and a counterpart industrial liaison. Currently some twenty-five projects are conducted each year. The program is now 35 years old and, to date, there have been a total of 673 projects for 212 individual sponsors.

The Institutional Setting

Harvey Mudd College (HMC) is a coeducational, undergraduate college of engineering and science with about 640 students and 71 full-time equivalent faculty. It is located an hour east of Los Angeles, California in a cluster of five undergraduate colleges organized roughly along the lines of Oxford and Cambridge. The College is young, having graduated its first engineering class in 1961. It is highly selective and privately supported. Degrees may be achieved in engineering, computer science, mathematics, biology, chemistry, and physics. The entering first-year class contains 175 students of whom 25% are women; all are qualified intellectually to become practicing engineers. Of the 175 entrants, about 40% become engineering majors, and nearly all will graduate in four years and proceed to engineering practice, graduate school, or a myriad of other endeavors.

The Institutional Mission

Harvey Mudd College was formed in the mid1950's to provide the broadest exposure for engineering students to the sciences and humanities within the time constraints of the four-year engineering curriculum. Furthermore, the College seeks to prepare graduates for leadership roles in an increasingly complex world and to ensure that they have an understanding of the impact of their work on society. From the start, the intent of the engineering educators was to provide both a sound theoretical base as well as the realism of engineering practice. to this end, the follow

The Engineering Curriculum

The curriculum which was devised to meet these goals includes the first three semesters as a common core with only the first-year engineering projects course and an introduction to Engineering Systems course being administered by the engineering faculty. Formal entry into the engineering program begins in the middle of the second year. Engineering at Harvey Mudd is not specialized; instead an undesignated B.S. is awarded. Furthermore, engineering is divided into these stems: engineering science, systems, and design. In addition, by College policy, our curriculum requires about 30% humanities and social sciences.

Realizing the New Paradigm for Engineering Education
Development of the Clinic

The Educational Task

When Harvey Mudd College was founded in the mid-1950's, the curriculum designers were seriously concerned with the weakness of professional elements of the program. The engineering science courses were perceived to teach analysis effectively, but professional training requires more than lectures and problem solving of textbook examples.

Thus, it was felt that the Harvey Mudd program lacked several important elements. The following deficiencies were perceived:

- Inexperience with open-ended problems;
- No development of project skills;
- Little exposure to realism;
- No exposure to professional practice;
- Faculty practice off-campus.

The Proposed Solution

It was concluded that elements of cooperative education, the engineering practice school, and the medical school's clinical practice could be adapted and incorporated into an open-ended, problem-solving experience which we would title the "Engineering Clinic." The Harvey Mudd Engineering Clinic would draw problems from the surrounding community and would bring to the campus a close approximation to professional engineering practice.

TABLE 3
CURRICULUM DEFICIENCIES

- Inexperience with open-ended problems;
- No development of project skills;
- Little exposure to realism;
- No exposure to professional practice;
- Faculty practice off-campus.

TABLE 4
ENGINEERING CLINIC CHARACTERISTICS

- A teaching clinic, providing professional services.
- Services meet professional standards.
- Student participates under faculty direction.
- Student's participation is organized for learning as well as providing services.
- Seminars or discussions are used to identify principles and procedures.
- Student is given increasing responsibility.

Operation of the Clinic

Primary responsibility for planning, organizing, and executing rests with the student team. The team submits to the client an initial proposal, plus periodic reports and a final report accompanied by any required hardware or software.

Communications and Reporting

At appropriate times during the year, the student team, faculty adviser, and company liaison meet for a design review. At least once a semester teach team gives a 20-minute oral presentation to faculty, students and invited guests at a seminar which is held weekly throughout the year. We encourage team presentations at the location of the sponsor.

The most important form of oral reporting takes place at the end of the year on "Projects Day". At this event all student projects are presented to an audience of project sponsors, prospective sponsors, faculty, students, and visitors. Projects Day is run in the format of a technical meeting. Some two hundred guests attend this day, and the event has great motivational impact on the entire program.

There are generally two major written reports associated with a Clinic project; most important is the final report written at the end. This becomes the permanent record of the project work. Also, in most cases, a mid-year progress report is written.

Project Characteristics

A good project is one which emphasizes the application of theory, involves engineering design work, and necessitates a team approach. In general, the projects are open-ended, rigorous and comparable to graduate-level sophistication. Projects are normally completed in one academic year.

Program Funding

Funding for the Clinic program is provided by the sponsor companies. The fee for private-sector clients was originally determined as the average cost of instruction per project year, as if we taught nothing but projects. The result is a cost-shared, fixed fee that covers not only all the direct expenses, but the additional cost of essentially tutorial instruction. Figure 1 shows how this fee has changed over the past years. Total program funding is now significant, being over $800,000 per year.

Results To Date

As one measure of success, the Clinic progressed, over a period of about 20 years, from one project financially supported, to a group of 25 per year so supported. Figure 2 shows how the total number of projects has grown over the past years and also provides some indication of the proportion of projects that have been funded. To date the Clinic has completed 673 projects for 212 individual sponsors.

Assessment of the Clinic

Evaluation of the Clinic program is continuous. It occurs in the form of student reaction, the reaction of employers (who now consider the Clinic experience to be the most significant characteristic of our graduates), Clinic project sponsors, participating faculty, and our graduates.

Furthermore, assessment can be viewed in at least two ways. First, and most important, would be the impact of the program on the preparation of graduates for engineering practice. A second view might be assessment by sponsors as

Realizing the New Paradigm for Engineering Education
to the effectiveness of the program with respect to industry-university interaction.

Examples of information pertaining to impact on preparedness are shown in the next two sections. Sponsor evaluation of the program is illustrated in the third.

**Recruiter Survey**

In the fall of 1997, we surveyed recruiters of Harvey Mudd College students. The purpose was to evaluate the preparedness of our graduates for industry. Eight areas were specified that directly related to the "Mission of the College" and to our "Goals for Graduates" for Engineering. Six of the areas related directly to the purpose and practice of the Engineering Clinic.

Recruiters were asked to rate the following on a scale of one to ten (with ten being the highest rating). Forty-two recruiters responded, and the average response to areas rated are shown below.

**TABLE 5**

<table>
<thead>
<tr>
<th>HMC Graduates</th>
<th>Avg</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiar with engineering practice</td>
<td>7.8</td>
<td>30</td>
</tr>
<tr>
<td>Assume leadership roles</td>
<td>8.0</td>
<td>33</td>
</tr>
<tr>
<td>Express creativity in project work</td>
<td>8.5</td>
<td>33</td>
</tr>
<tr>
<td>Demonstrate evidence of management skills</td>
<td>7.4</td>
<td>33</td>
</tr>
<tr>
<td>Appreciation for non-technical aspects of design</td>
<td>7.6</td>
<td>23</td>
</tr>
<tr>
<td>Responsibly attack open-ended problems</td>
<td>8.5</td>
<td>32</td>
</tr>
</tbody>
</table>

Of course we have no way of comparing these responses to a sample control group that has not experienced the Clinic program, or to graduates of another institution. Nevertheless, the generally high ratings and, in particular, the very high ratings associated with creativity and willingness to attack open-ended problems, indicate the clinic experience is achieving the hoped-for results.

**Alumni Survey**

Nine years ago, we surveyed Clinic graduates on their impressions of their Clinic experience. Results are presented in Table 6. Responses are quite encouraging. As might be expected, those more than ten years out of HMC rate their experience even more highly than more recent graduates.

A perhaps stronger indication of alumni support is that about one-fourth of our current projects are directly the result of efforts by these graduates. This has a significant positive effect on current students and prospective project sponsors.

**Sponsor Survey**

A significant measure of client satisfaction is that about two-thirds of our current sponsors continue the next year. This is the backbone of the Clinic’s continued success.

In addition, a survey of previous year’s sponsors is conducted each summer by the Harvey Mudd College Clinic’s Advisory Committee, now a standing committee of the College’s board of trustees. Committee members include many middle management engineers from industry and government laboratories. Results of selected questions from our most recent survey are presented in Table 7. As can be seen, the results are quite favorable.

**TABLE 6**

<table>
<thead>
<tr>
<th>ALUMNI SURVEY — FALL 1989</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale 1 to 7 ( 7 = Most Favorable)</td>
</tr>
<tr>
<td>Graduated</td>
</tr>
<tr>
<td>Before 1980</td>
</tr>
<tr>
<td>After 1980</td>
</tr>
</tbody>
</table>

**TABLE 7**

<table>
<thead>
<tr>
<th>SPONSOR SURVEY 1996-97</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Quality of Company Presentation</td>
</tr>
<tr>
<td>Excellent</td>
</tr>
<tr>
<td>Above Average</td>
</tr>
<tr>
<td>Average</td>
</tr>
<tr>
<td>Poor</td>
</tr>
<tr>
<td>2. Quality of Final Report</td>
</tr>
<tr>
<td>Highly Polished</td>
</tr>
<tr>
<td>Above Average</td>
</tr>
<tr>
<td>3. Usability of Report</td>
</tr>
<tr>
<td>More than Expected</td>
</tr>
<tr>
<td>Essential Information</td>
</tr>
<tr>
<td>Lacked Essential Information</td>
</tr>
</tbody>
</table>

In addition, sponsors were asked to estimate the cost benefit of the program to their companies. Ten sponsors tried to put a dollar value on their projects, and the average figure was $91,600. When asked whether future sponsorship would depend on business needs or corporate citizenship, seventeen replied and split equally: business needs 50% and corporate citizenship 50%.

**The Future**

The Engineering Clinic program at Harvey Mudd College is now a mature and successful part of the engineering curriculum. What might we then predict for the future of the program based on the last thirty years of experience?
First, the program will continue to change. Clinic is a dynamic process by its very nature. Each new academic year 25 completely new projects are started and taken to completion by 25 new teams of students. Faculty, students and company liaisons learn to adapt to this change every year. There is no reason to doubt that the nature of the projects brought to the program each year will be as ambitious and challenging as they have always been and will reflect the needs of the companies who sponsor the projects. The changing business climate in Southern California has been perfectly reflected by the changing mix of projects that have come to the college each year.

Another clear trend is that more colleges and universities are seeing the benefit of a clinic-based project approach to education, not just in engineering, but across all disciplines. In recent years, both the Computer Science and Physics Departments at Harvey Mudd have established their own "clinic" programs. One might expect that it can only be a matter of time before colleges like Harvey Mudd will require all of their students to have a clinic project experience. This will lead to increased interaction among all college academic departments and greater institutional involvement in the management of the program.

Finally, it is clear that as more of our graduates take their place in industry and the business world, with a positive experience of the benefits of Clinic in their education at Harvey Mudd, they will become the source of new projects for the next generation of students in the program. What we can be sure of is that the future of the Engineering Clinic program will be as full of exciting and challenging problems as the past thirty years.

References


Acknowledgments

The author wishes to acknowledge the major contributions to the Clinic of Professors Jack Alford and Mack Gilkeson who originated the concept in 1963, and professor T. T. Woodson who materially accelerated the Clinic's growth during his time as Director. In addition, Professor Tony Bright has just completed five very productive years as Director.
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Realizing the New Paradigm for Engineering Education
THE CLAREMONT COLLEGES

• The Claremont Graduate School

• Claremont McKenna College

• Harvey Mudd College

• Pitzer College

• Pomona College

• Scripps College

HARVEY MUDD COLLEGE

MISSION

* BREADTH OF TECHNICAL EDUCATION
* DEVELOP LEADERSHIP
* DEVELOP UNDERSTANDING OF
* IMPACT OF WORK ON SOCIETY
### GOALS FOR GRADUATES

1. Acquaint students with engineering practice
2. Develop skills, by use, in computation
3. Foster creative ability through projects
4. Gain insight into management through group projects.
5. Develop appreciation for non-technical aspects of design
6. Foster willingness to responsibly attack open-ended problems.

### ENGINEERING MAJOR

- Non-specialized BSc degree
- 12 courses in Humanities/Social Sciences (13)
- 11 courses in common science/mathematics core (10)
- 13 required courses in engineering; 3 elective courses in engineering
CURRICULUM PROBLEMS

Inexperience with open-ended problems
No development of project skills
Little exposure to realism
No exposure to professional practice
Faculty practice off campus

ENGINEERING CURRICULUM

ENGINEERING SCIENCE:
- CHEMICAL/Thermo
- Electrical
- Materials
- Computer
- Mechanical

SYSTEMS:
- Introductory
- Advanced (2)

DESIGN:
- Engineering Project
- Experiential Engineering
- Engineering Clinic (3)

EMPHASIS:
- Three technical electives
- Choice of clinic projects
THE CLINIC PROJECT

- 9 Month Duration
- Design - Fabricate - Test
- Plan - Monitor - Review
- Teamwork - Communication

ENGINEERING CLINIC
CHARACTERISTICS

1. A teaching clinic, providing professional services.

2. Services meet professional standards.

3. Student participates under faculty direction.

4. Student’s participation is organized for learning as well as providing services.

5. Seminars or discussions are used to identify principles and procedures.

6. Student is given increasing responsibility.
THE CLINIC TEAM

- 4 - 5 Engineering Majors
  (3 Seniors, 1-2 juniors)
- Faculty Advisor
- Company Liaison

ENGINEERING CLINIC CALENDAR

- Organization of Teams
- Orientation Day
- Proposals to Clients
- Project Seminars
- Mid-Year Reports
- Projects Day
- Final Reports
Realizing the New Paradigm for Engineering Education
OUTCOMES
INSTRUMENTS

- "CLASS OF 1997 ANNUAL REPORT"
- EMPLOYER SURVEY 1997
- CLINIC ADVISORY COMMITTEE "CLINIC CLIENT SURVEY"
- CLINIC PROGRAM "LIAISON SATISFACTION SURVEY"
- PROJECTS DAY "EVALUATION FORM"
- CLINIC PRESENTATION FEEDBACK
- TEAM LEADER SURVEY 1993 & 1995
- FACULTY ADVISOR SURVEY 1994
- ALUMNI SURVEY 1989

RECRUITER SURVEY 1997

Scale 1 to 10 (10 = Best)

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<td>8.5</td>
<td>32</td>
</tr>
</tbody>
</table>
TEAM LEADER SURVEY 1994

1. Clinic Course Rating
   Highest 75%
   Average 20%
   Lowest 5%

2. Most Significant Learning
   Project Management 50%
   Personnel Management 30%
   Technical Skills 10%
   Communication Skills 10%
SPONSOR SURVEY
1996-97

1. Quality of Company Presentation

   Excellent  3
   Above Average  8
   Average  1
   Poor  0

2. Quality of Final Report

   Highly Polished  7
   Above Average  11

3. Usability of Report

   More than Expected  6
   Essential Information  7
   Lacked Essential Information  2

RESULTS TO DATE 1998

35th YEAR OF ENGINEERING CLINIC

673 PROJECTS, 212 SPONSORS

ALL BRANCHES OF ENGINEERING

ALUMNI REPORT MOST USEFUL

SUPPORTED BY TRUSTEES, FACULTY, SPONSORS, ADMINISTRATION, STUDENTS
Realizing the New Paradigm for Engineering Education

Engineering Clinic Project Sectors

- Government/Utilities
- Electronic/Computer/Communication
- Aerospace
- Mechanical/Civil/Chemical

Number of projects

The Colorado School of Mines: A "Laboratory" for Innovation in Engineering Education

Barbara M. Olds  
Colorado School of Mines

Abstract

The Colorado School of Mines (CSM) has a long history of encouraging and supporting innovation in engineering education. Our small size (2400 undergraduates), focused mission (all students are engineering and applied science or economics majors), close ties to industry and alumni, lack of administrative layers, and traditional focus on teaching make us in many ways an ideal "laboratory" setting for innovative programs. In the late 1970's a number of programs were developed in response to our "Profile of the Future Graduate," a document developed with input from industry, alumni, faculty, and students which maps remarkably well on the ABET Criteria 2000. Among the attributes emphasized in the "Profile" (in addition to technical excellence) were the ability to communicate effectively, the ability to work in teams, an appreciation of the liberal arts, and enthusiasm for life-long learning.

To address these attributes the EPICS (Engineering Practices Introductory Course Sequence) and McBride Honors Program in Public Affairs for Engineers were developed. With frequent revision in response to stakeholder needs, these programs are both thriving after nearly 20 years. This paper will briefly describe the EPICS and McBride Programs, focusing on the lessons we have learned about curriculum innovation at Colorado School of Mines over the past two decades.

I. The Colorado School of Mines and the Future Graduate Profile

The Colorado School of Mines (CSM) is a 124-year-old institution of engineering and applied science with a special focus on earth resources, the environment, and related fields. The School offers undergraduate through doctoral degrees in chemistry, chemical engineering and petroleum refining, economics, engineering (with concentrations in civil, electrical, and mechanical), geological engineering, geophysical engineering, mathematical and computer sciences, metallurgical and materials engineering, mining engineering, petroleum engineering, economics, and engineering physics. The undergraduate student body numbers about 2400, while the graduate school enrolls 800 students. Entrance requirements are among the highest in the U. S. for public institutions of higher learning.

In 1979, after two years of discussion with the board of trustees, administrators, industry employers of CSM graduates, faculty, and students, the "Profile of the Future Graduate" was approved by the faculty. Although a subsequent "Graduate Profile" was approved in 1994 and is currently being implemented, the 1979 "Profile" provided the impetus for the innovations described in this paper. Among the attributes which the authors of the 1979 "Profile" argued that the school "must strive to foster... in all graduates" were:

- Technical competence
- Communication skills (written, oral, graphical)
- Ability to work in diverse teams
- Life-long learning
- Awareness of the impacts of non-technical influences
- Integrity and self-discipline

EPICS and the McBride Honors Program are two successful responses to the needs articulated in the "Profile."

II. EPICS

EPICS (Engineering Practices Introductory Course Sequence) was started in 1982 with help from a grant from the Exxon Education Foundation. Although it has undergone a variety of revisions in the last 15 years, EPICS remains a two-year sequence required of all first and second year students. The program focuses on introducing students to design and engineering practice by having them solve open ended problems and develop communication skills. Students work in teams to solve authentic, open-ended problems for outside clients, usually small businesses and non-profit entities. These projects involve non-quantifiable elements such as social, ethical, or political factors and incomplete data on such things as economic or environmental costs [1, 2].

Although freshman design courses are a staple of many engineering programs today, when EPICS began there were few models. The EPICS developers, including professors Dick Culver, Mike Pavelich, Joann Hackos, Bill Mattingly, and John Hogan, drew on such innovations as the Harvey Mudd College Design Clinic and WPI's Interactive Qualifying Project (IQP) and Major Qualifying Project (MQP) in designing the program.

A. Projects

Over the years we have learned that successful projects share certain characteristics:

- They are open-ended
- They provide the opportunity for self-education
- They provide the opportunity for teamwork
- They require the integration of subject matter
- They are credible to students
Freshman projects are undertaken by large numbers of students who work in teams for an outside customer. Recent projects have included designing playground equipment for disabled children for a local school, a project that was featured on NBC Nightly News this spring, and designing solar ovens for use in Mali, Africa. EPICS classes sometimes participate in ASEE student design competitions, where they have won several awards in recent years. In the first year class many student teams work on the same project; they compete with each other for the right to present their results to the client or to travel to the annual ASEE conference.

Sophomore projects are more sophisticated technically. Generally a group of 4 or 5 students works for an entire semester on a problem for an outside client. Only one team works on each project and there is a great deal of student/client interaction. Typically, these projects are sponsored by government entities, e.g. small Colorado mountain towns that cannot afford to hire consultants, or are "back burner" or scoping projects for local businesses. For example, many projects in recent years have focused on helping small municipalities develop plans to address Americans with Disabilities requirements. No fees are charged for these projects, but clients are expected to help defray project costs.

B. Lessons Learned

After nearly two decades of EPICS, we have come to realize a number of important factors in implementing an innovative course in which faculty are expected to serve as coaches/mentors and students are responsible for much of their own learning:

• It is important to understand students' intellectual development. We have employed Perry's model of intellectual development [3] as well as King and Kitchener's Reflective Judgment model [4] to help us understand and encourage our students' ability to make informed judgments based on appropriate use of evidence.

• It is important to provide opportunities for faculty development. Many faculty are not used to teaching primarily method rather than content and to coaching/mentoring rather than lecturing. They deal with problems such as knowing when to interact as students are working; the urge to overteach; and the frustration that arises when tangible results from project classes cannot be accurately predicted. From the beginning, new EPICS faculty are paired with experienced faculty members in teaching teams. In addition, annual workshops are held to introduce new faculty to the teaching approaches required in EPICS and to provide materials and other support.

• It is important to have campus buy-in for a non-traditional class such as EPICS. Such support can be built more easily if carefully documented results from the program and a good assessment and evaluation plan are available. EPICS began as a small pilot project which was voted a school-wide requirement by the entire faculty in 1985. The developers of EPICS carefully docu

A. Mission and Goals

The McBride Honors Program mission and goals statement focuses on developing participants' skills, knowledge, and values as they prepare to become leaders. Among the skills emphasized are communication skills, civil discourse, and critical thinking. Knowledge includes both theoretical and practical knowledge of the relationships among economic, political, social and cultural systems. Values include development of a reflective mind, willingness to accept personal responsibility for their actions, sensitivity to diversity, and love of learning.

The program goals map well onto the ABET Criteria 2000 attributes, especially “an understanding of professional and ethical responsibility” (3f), “an ability to communicate effectively” (3g), “the broad education necessary to understand the impact of engineering solutions in a global/societal context” (3b), “a recognition of the need for and an ability to engage in life-long learning” (3i), and “a knowledge of contemporary issues” (3j).

After a rigorous application process, approximately 10 percent (50 to 55 students) of the first-year class at CSM is admitted to the McBride Honors Program each year. Special features of the program include: small seminars (faculty-student ratio of 1-10 or less), an interdisciplinary approach (faculty from engineering and science and faculty from the humanities and social sciences serve as co-moderators for each seminar), the opportunity for one-to-one tutorials with faculty, the opportunity to practice oral and written communication skills, a Washington, D.C., public
policy seminar, the requirement of a practicum experience (either an internship, a thesis, or foreign study), and the development of a community within a community. Successful completion of the program satisfies all of CSM's humanities and social sciences requirements.

B. The Seminars

Each seminar is led by a principal moderator (a content specialist) and one or more associate moderators (usually engineering and science faculty). Seminars traditionally meet on Wednesday nights for three hours. They are student-centered, with students responsible for much of the classroom activity. Typical McBride seminar activities include Socratic questioning, formal debates, small-group discussion, team projects, individual or team research, tutorials, and symposia. Seminar titles include: Paradoxes of the Human Condition; Cultural Anthropology; Comparative Political and Economic Systems; Technology and Socio-economic Change; International Political Economy; U.S. Public Policy; Foreign Area Study; Leadership and Power; and Science, Technology, and Ethics.

C. The Practicum

Each student in the McBride Program must complete a practicum—a thesis; an internship with a corporation, government entity, or non-profit; or study abroad. The practicum is designed to give students "hands-on" experience with the concepts they have been studying in the classroom. Students completing an internship take a public policy seminar which includes a weeklong visit to Washington, D.C. to meet with policy makers and explore policy issues. Students keep a journal during their internship and write a substantive report after it is completed; the report must address how the internship met the following program goals:

- To become familiar with the organizational structure, culture, and complexities of a private company or public agency.
- To become aware of how the organization interacts with other elements of society including businesses, communities, governments, and other countries.
- To work on substantive projects.
- To make presentations and write reports on projects.
- To reflect critically on the internship experience and its relationship to the McBride Honors Program goals.

Students who choose to travel abroad spend a semester learning about the history, culture, economy, technology, and public policy of the country they will be visiting. Students travel to the country for approximately one month during the summer with two CSM faculty sponsors. The trip gives McBride students the first-hand experience that is an invaluable part of their international education. The program currently sponsors trips to the following countries/regions on a rotating basis: Chile, South Africa, China, Turkey, Brazil, and Southeast Asia. Students must keep a journal during the trip and write an extensive paper on their return. In the paper they are asked to discuss in depth some aspect of the cultural, economic, technical, or political scene in the country they visited. The report must synthesize the "book learning" they gained in the preparatory seminar with the hands-on experience they gained through travel.

D. Assessment

We have put in place a longitudinal portfolio assessment plan to provide feedback both to individual students and to the McBride Honors Program as a whole. We are in the process of developing a web site for the program which will allow students to store their portfolios electronically. Although it is still relatively new, this assessment program is already paying dividends in terms of explicit formative feedback for the students and excellent input to the faculty for improving the program.

E. Lessons Learned

- We believe that the McBride Honors Program has thrived because of the strong support it receives from the engineering and science faculty on our campus. Approximately 30 percent of the total CSM faculty have served at least one term on the Tutorial Committee, a four-year commitment to teaching and program governance.
- The school recognizes that it has a strong recruiting and retention tool in the McBride Program. Many students are either attracted to CSM or remain here because of the Program.
- The program was endowed when CSM president emeritus Guy T. McBride, Jr. retired approximately 15 years ago. The endowment funds provide the program with a certain amount of independence and immunity from the fickle winds of state and institutional funding. They also allow us to support student enhancement activities such as an annual retreat for all freshmen in the program, the Washington, D.C. public policy seminar, and overseas travel.

IV Conclusion: Advantages of CSM as a "Laboratory" School

Like several other engineering institutions where curricular innovation has taken place (WPI, Harvey Mudd, Rose-Hulman), CSM is a small institution with a focused mission and a traditional emphasis on good teaching. We also have very few administrative layers, basically department heads and a vice president for academic affairs. These factors make it relatively easy for a faculty member to propose and pilot a new idea in a short amount of time. In addition, interdisciplinary educational research has been a tradition since programs such as EPICS and McBride Honors were instituted; success breeds success, and contact with faculty from other disciplines breeds good ideas. As a result, we have developed a "culture of innovation" on campus, where the first response to a new idea is more likely to be, "Let's try it and see what happens," rather than "It can't be done." Under the leadership of our VPAA, John Trefny, and his associate, Nigel Middleton, CSM is in the midst of a sweeping reform of the undergraduate curriculum which is
being phased in starting in the fall of 1998. We hope that reform keeps us at the cutting edge of innovation in engineering education.

References


Redesigning Engineering Education

William W. Durgin, Associate Provost Worcester Polytechnic Institute
Edward A. Parrish, President Worcester Polytechnic Institute

Abstract

In developing the PLAN, WPI sought to address concerns inherent to its then traditional curriculum that was rigid, unresponsive to differences among students, and was compartmentalized by independent departments so that intellectual growth was fragmented.

The PLAN was an entirely new and different educational program responsive to the needs of students and society while nurturing sensitivity to the ideas and values of our society. It included fundamental departures from the traditional elements of technical education including:

A. The achievement of competence rather than the accumulation of credits.
B. Individual freedom and responsibility in planning the program of study.
C. A large component of project and independent study learning.
D. Emphasis on education as a cooperative venture between faculty and students.

Frequently, changes to engineering curricula involve the addition of new material to a well-established body of knowledge. Deciding which components to eliminate becomes the central issue in curricula reform. To adopt and implement the PLAN, the WPI community necessarily employed a more fundamental approach by focusing on learning rather than information transfer.

Introduction

The impetus for curricular reform was faculty recognition that "the school didn't have goals for the future." Debate in a faculty meeting led to the appointment of a planning committee that studied the matter and made reports over an eighteen-month period. This process involved students, faculty, administrators, trustees, and alumni and resulted in a plan, the WPI PLAN as it came to be known, which was voted by the faculty and adopted by the administration and trustees. The faculty vote was not unanimous; one-third of the faculty did not vote in the affirmative.

These same thoughts were echoed in "The Engineering Education Coalitions" which traces the origin of the coalitions to the late 1980's when senior NSF managers sought to change the prevailing paradigm of engineering education to a comprehensive approach that focused on connecting and integrating curricular elements. The program aimed to establish curricula that would engage students in exciting and fulfilling studies and provide them with a strong foundation and the capacity for lifelong learning.

What WPI has learned as a community about implementing a "change in the prevailing paradigm" may be helpful at other institutions as the coalitions proceed in their efforts to challenge conventional thinking about engineering education throughout the US. What WPI has learned has also aided greatly in repositioning WPI as a broader comprehensive university seeking to define the kind of liberal education needed for the next century.'

Original WPI PLAN

The PLAN consisted of several principal elements along with assessment mechanisms. It was begun in 1971 when WPI was predominately an engineering school. The principal components were:

D Projects and Independent Study - approximately 25 percent of students' time would be spent applying theoretical knowledge to practical problems. It was envisioned, for example, that undergraduate students would work side-by-side with faculty members and graduate students at the frontiers of discovery.

D Internship Centers - students would conduct meaningful work in line with their studies in an industrial setting under the guidance of a faculty member.

Multidisciplinary Approach - combining the study of science and engineering with courses in the humanities and social sciences.

D Intersession - a concentrated time between terms during which visiting scholars would conduct seminars and short courses.

D Calendar - four terms each seven weeks in length plus a summer term.

The degree requirements specified that students must demonstrate competence by applying knowledge to unfamiliar problems. To this end, it was envisioned that each
student would pass a comprehensive examination and satisfactorily complete two advanced level projects (each the equivalent of a term's academic work or one-quarter academic year) and complete satisfactory studies in a minor field. By the time the first class graduated, the comprehensive examination had been implemented as a competency examination. Evaluation consisted of written evaluations of project and independent study work on an "acceptable" or "acceptable with distinction" basis. Competency examinations were administered by the appropriate disciplinary department and were strictly on a pass/fail basis. Problems were original and unfamiliar to students. Typically, students were given a few days to research and work the problem and prepare a written response, which was submitted to an examining committee, much like a thesis committee. Students were then given an oral examination and informed immediately whether or not they had demonstrated competence. Students were eligible to take the competency examination after successful completion of a minimum quantity of academic work. It could be retaken any number of times, but most students successfully demonstrated competence within four years. A few were successful after three or three and one-half years while some took longer than four years.

The structure of the PLAN included a number of significant departures from traditional engineering and science pedagogy. Students were given the freedom and the responsibility for their own courses of study in a non-prescriptive environment with a focus on outcomes. The curriculum was largely project-based with the projects drawn from the "real world." Students necessarily learned to deal with open-ended problems, to learn on an as-needed basis, and to take responsibility for their own progress. The PLAN dramatically increased the advising responsibility of the faculty and was believed to be more cost-efficient. The PLAN recognized that knowledge of human relationships and human need was as important to engineers and scientists as to liberal arts majors. Students were required to conduct substantive study in the humanities and (soon) would be required to conduct one of the project activities at the interface of technology and society. Finally, the PLAN was envisioned to substantively involve graduate students in the undergraduate program and to have undergraduate project activity intimately connected to graduate research. It was planned that the undergraduate student would not only experience multidisciplinary projects, but also would be partners in the excitement of a broad spectrum of collegiate life.

The WPI PLAN at Present

Three projects, distribution requirements and some ancillary elements constitute the present degree requirements. The projects and their principal outcomes are:

The Humanities "Sufficiency" Project, which measures whether the student has achieved a sufficient background in a self-selected area of the Humanities or Arts (for engineering and science students) to be likely to continue lifelong learning in that area;

The "Interactive Qualifying Project" (or IQP) which assesses the capacity of students to reflect on the impacts of science and/or technology on societal values and structures; and The "Major Qualifying Project" (or MQP) which measures the ability of students to begin working on open-ended professional problems at the level assumed of someone beginning professional practice or graduate school.

Collectively, WPI believes these three projects provide students with a learning environment where they have rich opportunities to achieve the goals the faculty articulated in 1987:

> To lead students to develop an excellent grasp of fundamentals in their principal areas of study.
> To lay a foundation for life-long renewal of knowledge.
> To gain a mature understanding of themselves.
> To form a deep appreciation of the interrelationships among basic knowledge, technical advance, and human need.

Required projects form the core of the PLAN. The curriculum is designed so that faculty spend substantial time working with individual or small teams of project students in a cooperative environment.

First, the Humanities "Sufficiency project. The WPI faculty believe strongly that every student should attain substantive understanding of the humanities through study in a sequence of thematically related courses and project work. The experience was designed to allow students to acquire an understanding of how knowledge is obtained and expressed in a non-technical area. Students, with the support of advisors, select five courses where they must define a thematic or intellectual relationship for example, five courses dealing with aspects of history of science, or theater production, or creative writing. They conclude their sequence of study by writing, with a single faculty advisor, a final project wherein they conduct independent study and a critical or research essay (or original work or performance).

The Interactive Qualifying Project resulted from faculty concern that students needed to develop appreciation of the inter-relationships of science, technology, and society. The objective of the IQP is to enable graduates to understand, as citizens and professionals, how their careers will affect the larger society of which they are part. This project is the equivalent of three courses and is typically conducted in a small team setting under the guidance of one or more faculty advisors. Any faculty member can advise...
any undergraduate(s) in this project activity. As such, the faculty, as a whole, clearly has ownership of the IQP and has developed an expectation that everyone ought to participate.

Interactive Qualifying Projects by definition are set in a societal context and are frequently pre-arranged with other organizations such as government agencies, museums, societies, and foundations. Students are expected to prepare a proposal, conduct background research, conduct the study, and prepare a written report. Students make frequent oral reports during the project and many make formal presentations at the project conclusion. The faculty advisor works with the project team throughout the project, finally reading and evaluating the report. Thus, the report itself is the outcome reflecting achievement of understanding of the interrelationship of technology and society in an instance, that usually has broad implications.

The three courses equivalence for the IQP is, in fact, one of the principal reasons WPI adopted a seven-week term basis for the academic schedule. Normally, students take three courses per term, but clearly can pursue the entire IQP in one seven-week term which provides opportunity for of campus project centers. Approximately one-third of WPI undergraduates take advantage of this opportunity to conduct their IQPs at established residential project centers in Washington, DC, San Francisco, Bangkok, London, Venice, Puerto Rico, Costa Rica, and elsewhere.

The final project-based degree requirement is the Major Qualifying Project (MQP). Our faculty wanted to be sure that the students demonstrate, in their major field of study, the application of the skills, methods, and knowledge of the discipline to the solution of a problem that would be representative of the type to be encountered at the beginning of one's career. Typically, small teams are formed to focus the project work on a topic offered by industry, the faculty, or the students themselves. Again, the course equivalence is three courses, but usually spread throughout the year. Both the advisor and students must be in the same discipline, although multi-disciplinary teams are frequently formed together with an advising group of faculty from the represented disciplines.

Students prepare a proposal delineating what, why, where, when, and how they will conduct the project. Frequently, MQPs involve engineering design so that specifications must be developed, the design conducted, and demonstration of achievement must be made. In this case, oral presentations are necessary in the weekly team meetings and, often, at the project conclusion. The report, itself, is one of the outcomes reflecting the objective. Additionally, written and oral communications are demonstrated as are other desired elements such as teamwork.

In addition, students must satisfy Distribution Requirements, a Social Science Requirement, a Residency Re-requirement, a Physical Education Requirement and achieve a threshold amount of academic credit. For students of engineering, the Distribution Requirement results in one year of study in mathematics and science, one and a half years study in engineering science and design, and out-of-department study stems, etc.

Global Perspective Program

The global economy, fueled by scientific discovery, technological innovation, and instantaneous communication, has produced fierce competition for financial, material, and human resources. Scientists and engineers will be confronted as never before with problems whose solutions require technical expertise and necessitate an ability to understand and work effectively in cultures other than their own.

Ten years ago, WPI launched its Global Perspective Program to provide students an opportunity to pursue projects concentrating on global issues. Presently, there are 15 Global Project Centers where students and advisors pursue project activity. Predominately, the focus has been on Interaction Qualifying Projects but recently Sufficiencies and Major Qualifying projects have been added and plans are underway to include graduate activity as well. Approximately 25 percent of the undergraduate students have participated in this program during the past few years. This percentage is expected to increase to 50 percent during the next few years. WPI minimizes the cost of participating in this program by charging no additional fees, extending full financial aid, and requiring "project fees" from sponsoring agencies. Local organizers arrange housing, board and transportation with an eye toward economy and also arrange projects and sponsors as well.

Change Process

Reflecting on the process of change at WPI, the outcomes that were achieved include:

Academic program planning shifted from faculty to students.

Students create programs of study tailored to individual interests.

Prescribed sequences of courses eliminated.

Focus shifted to outcomes rather than subjects or courses.

Project-based curriculum motivates students to learn both in and out of classrooms.

Significant oral and written communications embedded in projects.

1 Emphasis shifted to learning rather than information transfer. Revised academic calendar to enable flexibl-
ity, off campus projects, etc.

Establishment of non-punitive grading system.

Encouragement of cooperative learning.

The curricular changes at WPI grew out of dissatisfaction with traditional engineering education and concern that institutional direction was lacking. The change process was driven by faculty through a committee structure with administrative support. Since there are no schools at WPI, all faculty are involved in curricular change. Approximately two-thirds of the faculty ultimately voted to establish the WPI PLAN. In order to ensure successful establishment of the PLAN, an implementation committee was formed to facilitate the curricular changes. The "learning-curve" was very steep as the nature of projects was developed, as competency examinations were administered, and as academic advising matured. Initially, it was believed that the PLAN would be less costly than a traditional curriculum, but it was recognized that transitional costs would be significant. It is worth observing that faculty development was (and still is) an important component of the PLAN. To this end, numerous "retreats" and summer efforts were conducted to refine the curriculum, develop administrative procedures, and establish a strong advising system.

Outcomes

The WPI PLAN includes components which are inherently tutorial and time intensive for faculty. Courses, for the most part seven weeks in length, demand that students learn on their own and at a fast pace. Many students and faculty have initial difficulties with these formats. In recruiting faculty, WPI seeks individuals who can be comfortable with a non-traditional curriculum, who are openminded and adaptable, who are interested in the interrelationships of technology and society, and who are willing to spend a substantial amount of time in project and academic advising activities. Nevertheless, expectations for scholarly accomplishment and research productivity are high frequently causing a time allocation dilemma for faculty. Most faculty members successfully find equilibria which enable them to excel not only teaching in the context of the PLAN but also teaching graduate students and pursuing their research objectives.

References

In 1989, a cohort of 100 students were accepted into the experimental E4 program. In 1990 and 1991 second and third cohorts followed, as the preceding classes continued with the sophomore year of the E4 program and later joined the non-E4 cohorts in their pre junior year. The students entering the E4 program were randomly selected from volunteers having generally similar levels of academic preparation and achievement as the non-E4 cohorts. The success of the program resulted in the expansion of the E4 program to two cohorts of 100 freshman students in the Fall of 1992. The College of Engineering simultaneously began to examine the extension of the curricular revision to all five years with the first two years based on the E4 experience.

Furthermore, the University accepted the E4 principles as a model for curriculum revisions in disciplines across the institution. This formally recognized the applicability of the E4 principles to other professional disciplines, which facilitated the Biosciences Department to institute their own NSF funded program modeled after E4.

In addition, the Business and Administration College initiated curricular revision along the same lines. These developments clearly show that the E4 initiative at Drexel, which was subsequently reinforced by the Gateway Coalition, not only led to a drastic culture change in the College of Engineering, but also had a profound impact on the way faculty in other colleges across the University began to view their curricula.

In 1993, an analysis was performed on the retention rates, GPA, and completion to degree. These results clearly showed the positive effects of the new curriculum on student performance and success rate. Following the unanimous faculty approval of the completely restructured five year engineering curriculum based on E4, three cohorts of 100 students were accepted into the new program. In early 1994, the Faculty Senate approved the new engineering curriculum. Finally, in the Fall of 1994, E4 was formally "institutionalized" as the new Drexel Engineering Curriculum, and all 500+ engineering freshman were admitted to the new program. Subsequently, in Fall 1995 the program was evaluated by ABET and received full accreditation.

The Drexel Engineering Curriculum

The templates for the "traditional" and the new "Drexel Engineering Curriculum" are illustrated in Figs. 13, respectively. It should be noted that Drexel offers a full five-year Co-op program that requires 12 quarters of academic work and six quarters of Co-op assignments. Freshman and senior years require three quarters of academic work, while the sophomore, pre junior, and junior years consist of alternating 6 month periods (i.e., 2 quarters) between school and industry.

The core of the Freshman Engineering program is built on two themes: curricular integration and Engineering Design and Laboratory. Typical Freshmen take: Mathematical Foundations of Engineering (MFE), Physical Foundations of Engineering (PFE), Chemical & Biological Foundations of Engineering (CBFE), Engineering Design & Laboratory (ED&L) and Humanities. In the three year-long
courses, MFE, PFE and CBFE, topics of mathematics, physics, chemistry and biology are presented from an application and engineering perspective. For example, while dealing with static equilibrium, the relevance and application to bridge and structural design are invoked. While introducing the topic of electrochemistry, production of aluminum from bauxite is introduced. While presenting the topic of integral calculus, engineering design is often used as a motivator. The basic tenant of Drexel’s approach is that when fundamental concepts are put into engineering and practical applications context, the students find the topic to be more interesting therefore learn and retain better.

The humanities are integrated into the freshman curriculum. Humanities faculty coordinate the content of the course with all other course instructors. In addition to the typical freshman humanities course content, students write journals, essays and poetry related to science and engineering. They read about scientific discoveries, the practice of engineering, engineering projects and failures, and address the environmental and social impacts of engineering. Books to be read as part of the course are selected with science or engineering as a theme. During class discussion, a science or engineering faculty member participates in the class with the humanities instructor.

A significant element of Drexel’s integration theme is in the implementation. In nearly every freshman engineering course the students are exposed to instruction or recitation by an engineering faculty member. Such exposure enables discussion of engineering-relevant examples in class and provides a unique forum for students to interact with engineering faculty.

In the ED&L, a year long engineering design and laboratory course, students are given instruction to develop computer skills, experimental skills, design and presentation skills. The modules are organized to develop competency in the use of such software as CAD, Maple and others, conduct and report (written and oral) experimental investigations and to complete a design project ending with a formal presentation to the college and writing of a report. The design is conducted in groups of three to five students. The students either self-select or select from a list of projects/ faculty advisors. The design group works on the selected project over a four month period, straddling almost all three quarters. A large fraction of the students have reported very positive freshman design experiences which integrates the students’ freshman year both academically and culturally.

**Measures of Comparison for the E’ and Traditional Programs at Drexel**

E’ established a dramatically different approach to the engineering educational process than the traditional programs that were widespread and dominant for over the last forty years. One of the outcomes of the E’ program manifested itself in improved retention of engineering students, both within the College of Engineering as well as the University. The key factors which contributed to the improvement of retention may be listed as follows:

- A new and revolutionary academic paradigm was successfully created in which the general environment and all academic activities focus on the students as emerging professional engineers from the very beginning of the educational process.
- Engineering is up-front, with Engineering Design and Labs serving as the key element of experiential learning and integration of basic engineering sciences, engineering and humanities, based on projects that provide the context for engineering problem solving. Integration of theory and practice in engineering and science is perhaps the most critical factor in improving the retention rates by emphasizing the engineering experience early on.
- Faculty’s primary role as a mentor and a facilitator to establish a community of learners.
- Close faculty-student interaction through regular meetings of student cohorts with faculty teams. This creates a community feel and esprit de corps and strong identity as a "team of engineers". This is strengthened by the close interaction between the members of the engineering, science, math and humanities faculty team.
- The three quarter Freshman Design Projects which begin with a "first-week" design competition held in public with general participation. This reinforces the "engineering focus" and the "team project concept" in an exciting fashion.

The E’ program was evaluated with the voluntary participation of 800 students and 60 faculty members over a six year period. The first part of the evaluation process was based on a variety of quantitative methods and written instruments developed by the faculty and focused on the following elements: 1) student attitudes, level of preparation, abilities and maturity, 2) effectiveness of different curricula and methodologies, and 3) internal consistency among course objectives, subject matter, methodology and student ability. The second part focused on the understanding and measuring the complexities of change processes, which involved qualitative evaluation to capture the underlying processes of the students’ educational experiences. Student journals were examined, as well as in-depth interviews held for both E4 and traditional engineering students. The results of the evaluation were very positive and showed E4 students developed excellent to outstanding levels of communication, laboratory and computer skills. The E’ students also had, in general, higher grade point averages [Figs. 4-7], improved progress rates [Figs. 8-9], and higher retention rates [Figs. 10-14] than their counterparts in the traditional program. Perhaps most importantly, many indicated in their written commentaries that they had begun to sense that the practice of the "engineering profession" would be personally exciting, rewarding, and enjoyable.

A closer look at the quantitative measures compiled for the cohorts from the E’ and traditional tracks show a clear trend favoring the performance of the former. In these figures, Group 1 represents the freshman class of 1989, fol

*Realizing the New Paradigm for Engineering Education*
followed by Group 2 the freshman class of 1990, by Group 3 the freshman class of 1991, etc. It should be noted here that the Drexel academic calendar is based on ten week quarters, consisting of three academic terms in the freshman year (a free summer term), two academic terms each during the sophomore through junior years, and three academic terms in the senior year, for a total of 12 academic terms. Students rotate during the middle three years, between 6 month (two terms) Co-op assignments and academic periods, with approximately half the students being on campus while remaining half on Co-op during these periods (Fall-Winter and Spring-Summer cycles).

Figures 4-7 provide comparison of the compiled GPA’s for the two cohorts labeled E’ and Control. It is clear from these figures that the GPA for the experimental group is consistently higher (between 0.21 and 0.51) than the Control group having similar academic backgrounds, both while they were in their separate tracks (i.e., terms 1-5) and subsequently when the classes merged following the sophomore year. Figures 8 and 9 show that for the Class of 1994 (which includes the first E’ freshman cohort) and the Class of 1995, the "on track" progress to degree was significantly higher for the E4 students compared to the Control group (58% vs. 35% and 74% vs. 33%, respectively).

Figures 10-14 provide the retention rates by term (including Co-op terms), for the freshman classes of 1989 (first E’ cohort) through 1993. It is clear that the retention rates for all three freshman classes exhibit similar general retention trends for the E’ and Non-E4 cohorts. Comparison of the final retention rates for the freshman class of 1989 (i.e., graduating class of 1994) exhibit 23.4% higher retention for E’ students in engineering (68.4% vs. 45%), and 18.1% higher retention for E’ students in the University (75.5% vs. 57.4%). While the E4 students have significantly higher retention rates in both categories, it is noteworthy that the relative retention rates within engineering are even higher than within the University. It is clear that with some minor statistical variations these general trends were maintained for the later freshman classes (Figs. 11-14).

References

5. Quinn, R. "The Fundamentals of Engineering An Introduction to the Art of Engineering," Journal of Engineer-
Figure 1 Template of Traditional Curriculum, Pre-1988

Figure 2. The New Drexel Engineering Curriculum Adopted in 1994. Freshman and Sophomore Years
Figure 3. The New Drexel Engineering Curriculum Adopted in 1994. Upper Level

Figure 4. Comparison of GPAs of E4 students (1989) with Control Group
**GROUP 2 - CUM GPA**

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Figure 5. Comparison of GPAs of E4 students (1990) with Control Group

**GROUP 3 - CUM GPA**

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Figure 6. Comparison of GPAs of E4 students (1991) with Control Group
Figure 7. Comparison of GPAs of E4 students (1992) with Control Group

Figure 8. Comparison E4 students (1989) with Control Group
Figure 9 Success Rate of Students in Engineering, E4 vs Traditional Curriculum

Figure 10 Retention Rate of Students E4 vs Traditional Students; Freshman Class of 1989
Figure 11 Retention Rate of Students E4 vs Traditional Students; Freshman Class of 1990

Figure 12 Retention Rate of Students E4 vs Traditional Students; Freshman Class of 1991
Figure 13 Retention Rate of Students E4 vs Traditional Students; Freshman Class of 1992

Figure 14 Retention Rate of Students E4 vs Traditional Students; Freshman Class of 1993
Recovering from a Loss of Momentum in a Major Educational Reform: The Engineering Science Core at Texas A&M University

Karan Watson
Texas A&M University

Abstract

All of the engineering programs at Texas A&M University have now adopted aspects of a unified engineering science core. The adoption of this core, found in the second-year or sophomore curricula, also facilitated the rapid adoption of an integrated common curriculum for students in the first-year for all of the engineering curricula. These reforms in the first-year and second-year curricula for all majors in engineering incorporate pedagogical thrusts emphasized by the Foundation Coalition: 1) integrated curricula where students from all engineering fields work to understand the interdependence and relationship which exist across the foundation courses for engineers; 2) active and collaborative teaching styles and explicit instruction in teaming skills; 3) technology enabled classrooms where the students learn to utilize the most appropriate tools to solve complex problems; 4) assessment and evaluation for continuous improvement for the students, the instructors, the courses, and the curricula. This paper has a focus on the path to institutionalization of the second-year curricula. The utilization of techniques found in 'change management' and 'learning organizations' were essential to the successful institutionalization of the new curricula.

I. The Engineering Science Core

In 1988, with NSF support, Texas A&M University began a reform effort of the engineering science courses, commonly found throughout engineering curricula in their second-year. The goal of the effort was to present the engineering science courses in a manner so that students understood and valued the common aspects of the engineering sciences utilized by all fields of engineering, and, because of this common framework of understanding, the students can learn and retain the 'non-major' information they are presented as well as the 'in-major' information. Four courses [1], each a four semester hour course, were developed. These courses integrated topics in statics, dynamics, thermodynamics, materials, heat transfer, fluids, fields, and circuits in a framework that emphasized conservation properties in a defined system. Textbooks [2-5] were created and teaching materials prepared for offering these courses. Data was collected on the performance of students in these classes, as well as student performance in courses after modifications were made. Data on Fundamentals of Engineering test types supported that no skills or content understanding were lost in the new approach to the engineering science core. More significantly, the data collected showed that many skills and abilities were significantly enhanced, especially in students' abilities to solve complex and open ended problems. Nonetheless, programs were slow in adopting the new curricula [6].

II. The Momentum to Institutionalize

Figure 1 demonstrates the perception concerning the momentum surrounding the institutionalization of the courses for all majors that existed as the initial funding period of the NSF grant expired. While all majors would allow students to opt for these new courses, after 5 years only one program, Aerospace Engineering, felt the program offered enough advantages to make it a required course set in their curriculum. In addition, one program at Arizona State University was in the process of adopting the Engineering Science Core courses in their curriculum, and a few other programs around the country were reviewing the course materials. However, on the Texas A&M University campus it was clear that only a few of the engineering programs were even considering adopting the courses as requirements in their program.

The team of faculty involved in the development of the courses considered the apparent apathy of programs toward the adoption of the courses as an indication that the faculty in these programs had not seen, or did not understand the benefits offered by this new approach. Therefore, a major effort to introduce the courses and the data collected on the student performance in the course and beyond was initialized. Workshops and presentations were made. However, in spite of these efforts, a year later only two other programs, Agricultural and Civil Engineering, had adopted the Engineering Science Core as a requirement in the curriculum, and no other programs were considering adoption as a requirement. What was even more frustrating to the developers of the new approach was that in most cases the home department of those involved in the Core's development had not adopted the courses as requirements.

III. Recovering the Momentum for Institutionalization

At this point some of the team members from the Core department became involved in the efforts initiated
by the Foundation Coalition. These efforts incorporated other pedagogical changes beyond the integration of course work across disciplinary boundaries. As the Foundation Coalition initialized efforts to offer an integrated first-year curriculum it became more apparent than ever that a target set of curricula at the sophomore year must be assumed in the development of the first-year courses. The team decided to assume that the Engineering Science Core should be the target, even though only three of the thirteen undergraduate engineering programs had adopted the Core in their curricula. Other schools in the Foundation Coalition were also utilizing the Engineering Science Core as a guide for development of curricula for the sophomore year.

Several discussions were held with groups of faculty members from every program in the College to consider the Engineering Science Core, and the outcome of the meetings for some was a clearer understanding of the reasons why momentum toward institutionalization had been lost. Some of the facts, beliefs, and fears of faculty members concerning the Core included:

- The belief that the Core courses were too difficult for average students and should be taken by only honors students
- The belief that the Core courses had to all be adopted, or none should be adopted
- The restriction to one set of textbooks if this approach was adopted
- The dislike of the textbooks by some faculty members (note: for most of the authors this was the first textbook written)
- Many faculty did not perceive the old way of teaching the courses to need `repair'
- Most faculty members did not perceive the reason that their own mental model of how engineering sciences should be introduced, models based primarily on how they themselves had been taught and were teaching, were not the optimal approach
- The new faculty members who came in to learn to teach the Core courses found the course to be very difficult to prepare for
- As the NSF funding was removed from the Core, the incentive to make a transition to the new Core diminished.

Consciously or unconsciously the faculty involved in the change to a new Engineering Science Core were becoming more aware of one of the important aspects of the management of change in that they needed to pay attention to the resistance to change. As illustrated in Figure 2, an archetype of system thinking described by Senge [7] helped to understand the steps that might be more effective in regaining momentum for the institutionalization of the new Core. In the model illustrated, momentum toward institutionalizing the Core was enhanced by the NSF funding, the courses developed, and the positive results from the pilot programs testing the courses developed. However, simultaneously with the building of momentum, the development of a counter energy aimed at resisting change was building.

This resistance was fueled by some accurate facts about the new core as well as some misperceptions. By the end of the NSF grant the final thrust, namely 'we just can't afford this transition', had amplified the resistance to the point where no new data from the pilot programs was likely to regain enough momentum to move several programs toward institutionalization.

Thus, a new tack was taken on the institutionalization effort. The approach called for a concentrated effort to focus on reducing the resistance, and regain the mass (specifically the number of faculty) who supported the new approach. The following steps were taken:

- A new team of faculty was formed to consider the Engineering Science core. This team had very little overlap with the team that had originally developed the Core courses.
- A timeline for the decision about the Engineering Science Core was determined and publicized.
- More pedagogical changes were to be considered by the new team so that the Engineering Science courses aligned with the Foundation Coalition thrusts (course integration, active and collaborative instruction, technology-enabled instruction, new assessment and evaluation approaches).
- Consideration of the reasons for resistance to the Engineering Science Core should be addressed simultaneously with any new course developments.

This approach generated some of its own resistance, primarily from some of the faculty involved in the original development team for the Core and from some of the departments who had already adopted the Core. The new team made efforts to address these new resistances as they undertook their charge to design a Core that would be adopted by most of the programs in the College.

Two years later, in the Fall of 1996, all engineering majors in the College voted to adopt a new set of five, three semester hour courses which present the engineering science core in the common framework. Not every department adopted all five of the courses. The new sophomore year for engineering majors is sketched in Figure 3.

IV Conclusion

This quick change in momentum for institutionalization was accomplished by a sincere focus on the issues surrounding the management of change, not so much a focus on the issues concerning the course reforms. The principles of change management utilized included: understanding and reducing resistance to change, building broader cognitive support for the change, and training individuals to be change agents rather than champions for a change. Figure 4 summarizes the flow of the move toward changing the Engineering Science Core at Texas A&M University. The success in adopting the Engineering Science Core in 1996 was a strong aid to the successful adoption in 1997 of the Integrated First-Year curriculum developed by the Foundation Coalition.

Realizing the New Paradigm for Engineering Education
References


Realizing the New Paradigm for Engineering Education

Figure 1 Perceived Institutionalization Momentum of the Engineering Science Core in 1992

Figure 2 System Model of Momentum to Institutionalize the Engineering Science Core
Realizing the New Paradigm for Engineering Education

---

**Fall**
- ENGR 211 (Conservation Principles and the Structure of Engineering - Statics and Dynamics) 3 hrs
- ENGR 212 (Conservation Principles and the Structure of Engineering - Thermo/Fluid Dynamics)* 3 hrs
- MATH 251 (Calculus III) 3 hrs
- ENGL 210 (Technical communication) 3 hrs
- University core or Major core courses 4 hrs

**Spring**
- ENGR 213 (Properties of Materials)** 3 hrs
- ENGR 214 (Conservation Principles of Continuous Media)*** 3 hrs
- ENGR 215 (Principles and Applications of Electrical Engineering**** 3 hrs
- MATH 308 (Differential Equations) 3 hrs
- University core or Major core courses 4 hrs

*Not taken by ChE, but they have modified their course to fit the framework and use pedodogy
**Not taken by BioMed and CmpE, and EE takes their own material course
***Not taken by BioMed, CmpE, and EE, and ChE takes their own continuous media course
****BMed, CmpE, and EE all take a EE course (which is undergoing similar revisions)

Figure 3 Adopted Sophomore Year for All Engineering Majors

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**FACULTY ENGAGEMENT**
- Development team → New faculty trained → New team formed → Many new faculty

**PILOT EFFORTS**
- Pilot in Pilot in Repeat
- honors regular pilot courses courses

**CURRICAULA ADOPTION**
- Adopted
- Aero Civil, Ag
- Vote Adopted in all engineering majors
- Optional in others

Figure 4 Flow of Institutionalization of Engineering Science Core
Communication Infrastructure

Strategies for the Next Generation
June 5, 1998

Steve Miller
Technical Manager
Cross Product Architecture
Lucent Technologies
steve.miller@lucent.com

Communication Infrastructure - OUTLINE

- Customers and Technology moving toward “Convergence” of Voice and Data Networks
- Engineering Education Challenges
- Lucent Products that Enable Change in the University
Realizing the New Paradigm for Engineering Education

**What is Convergence?**

- Data
- Voice
- Transition & Convergence

- Data over Circuits
- Voice over Packets

**Changing Buying Behaviors**

- **Gradual Evolution**
- **Network Control**
- **Customer Driven Verticals**
- **Convergence**
  - Believe LAN architectures are foundation for enterprise communication within 2-3 years
  - HW and SW are separate buying decisions
  - Technology infrastructure places boundary conditions on business applications
  - Dominant SW companies have a large influence over the infrastructure needs
  - Servers are primary information vehicles
Infrastructure Convergence: Drivers and Enablers

Need for Greater Bandwidth
- CPU performance doubling every 18 months (Moore's Law)
- Storage capacity doubling every year
- Network bandwidth has remained stagnant

Increasing Complexity of Networks
- Multiple networks for voice, video, data, cellular
- High recurring costs of network O&M
- Need for LAN/WAN interop.

Emergence of Multimedia Applications
- 30% of desktops were multimedia-capable in 1997
- Proliferation of Internet-based multimedia applications

Multimedia Standards
- Voice over ATM
- ECMA (client/srvr telephony)
- Real-time traffic support in IPv6
- MPEG, M-JPEG

Infrastructure Convergence: Varying Customer Needs

End-Users
- Treat a phone more like a PC
  - Point & Click
  - Drag & Drop
- Treat a PC more like a phone
  - Real-time collaboration
  - On-the-fly interoperability

Network Managers
- Capacity & protocol handling of a LAN
- Guaranteed performance & administration of a PABX
- Usage-based accounting

Application Developers
- Uniform programming environment
  - HW & OS independent
  - Common APIs & toolkits across the infrastructure
- Robust programming capabilities

Chief Information Officers
- Expense reduction through network consolidation
- Enabling (multimedia) information flow throughout the organization
Realizing the New Paradigm for Engineering Education

Education Marketplace
Top Technology Issues

Technology
- Selecting and using effectively
- Keeping up with rapid change
- Setting the pace for the community

Networking and Computing systems
- Integrating heterogeneous systems and networks
- Linking the campus to remote students

Growth
- Rapid expansion to non-traditional markets
- New Applications
- Funding challenges

Rapid, complex service demands

Distance Learning
- Way of the Future; Opportunities for Industry/University
- Changes Required by Distance Learning
  - Technology-Equipped Classrooms ("Follow-me" camera eliminates camera person)
  - Students must be more motivated & Instructors must be more entertaining
  - Interaction Occurs Between Students and Instructors Outside of Class via E-Mail, Telephone and Fax
  - Team Projects Need to be organized in New Ways -- with Team Members at Different Sites
  - Site Coordinators / Managers Proctor Exams
  - Homework and Exams Delivered via FedEx, U.S. Mail, Fax, and E-Mail
Realizing the New Paradigm for Engineering Education
Enterprise Wireless: WAVELAN Data

In-Building
- ISM Band - Spread Spectrum
- 10 Mb per endpoint

Bldg-to-Bldg
- 5 miles w/out amplifier
- 20 miles with amplifier

CentreVu Internet Call Center

Customer Service:
- Prospective Students
  - Campus Tour reservations
  - Catalog Requests
  - Talk to a "real person"
- Student course selection
  - select course
  - ask questions via email, or voice
  - and get instant reply

- PSTN callback with Web browsing
- Internet telephony with Web browsing
- Leverage back-office systems to format answers, and push back to end-user.
Lucent Value Proposition

- Bring the reliability of voice to data and video networks and lower cost of ownership through
  - Investment protection
  - open standards
- Reduce the complexity of managing the network by building intelligence into the products, bandwidth when and where you need it, and providing a higher level of network management tools
- Deliver a broad range of network servers providing high value applications services
- Provide the most comprehensive customer support and professional services in the industry
- Offer choices to support your best path to a converged network

Internal Lucent Resources

- Higher Education Offer Manager: Charlie Fallon cfallon@lucent.com 908-953-8615
- Definity University Focus Group: Jeff Wyman 908-953-5128 jwyman@lucent.com
- Distance Education: Laurel Townsend 949-4013 ltownsend@lucent.com
- "CiniBlitz" Video Streaming Server, Nagan Raman 732-949-7932 fax 732-949-6868 nraman@lucent.com
- "Persyst" Virtual Classroom/Breakout rooms: Harvey Starin, 908 953 6180 hstarin@lucent.com
- Distance Education Consultation: www.lucent.com/cedl
Distance Learning Consultation

www.lucent.com/cedl

• Create a plan for meeting your organization’s distance learning needs
• Select distance learning technologies most appropriate to your instructional goals and organization resources
• Design facilities to be used for distance learning
• Develop effective strategies to manage distance learning personnel and activities
• Train distance learning personnel
• Evaluate the effectiveness of your planned and current distance learning programs
Role of Technology in Online Education and Training

Anoop Gupta
Microsoft Research
anoop@microsoft.com

Motivation

• How we teach/learn hasn't changed in a long time
  - pedagogically
  - institutionally

• Meanwhile, demands on education have changed
  - anytime, anywhere
  - modular, personalized, just-in-time
  - lower cost
Solution Components

- Re-thinking how we educate
- Re-evaluating role of traditional institutions
- Use of technology

- Bottom-line goals:
  - Access and scalability
  - Cost effectiveness
  - Education effectiveness

Rethinking How We Educate

- Emphasis on learner rather than teacher
  - Two definitions of distance education:
    - **Congressional Office of Technology Assessment**: "Linking of a teacher and students in several geographic locations via technology that allows for interaction".
    - **From South Africa**: "Distance education is the offering of educational programs designed to facilitate a learning strategy which does not depend on day-to-day contact teaching, but makes best use of the potential of students to study on their own. It provides interactive study materials and decentralized learning facilities where students can seek academic and other forms of educational assistance when they need it".
What this means is ...

- Online access to courseware and lectures
  - greater investment into high-quality courseware
    - capture and enhance great teaching
    - match individual learning style and situation

- Classroom discussions via email, bulletin boards, annotations, telephone/video conferencing, ... - both synchronous and asynchronous methods - small group interactions can be very valuable

- Private interaction via email, telephone, video ... - teachers as learning consultants

Do We Need to Sacrifice Quality

- No, in fact we may improve it

- Stanford Tutored Video Instruction (TVI) Experiment
  - four groups of students
    - on-campus
    - local TV
    - remote TVI (no tutor)
    - remote TVI (with tutor)

  - remote industry students did best
  - it helped the “at-risk” students even more

- Similar results for D-TVI version
Re-evaluating Traditional Institutions

- Cost of physical infrastructure
  - can we keep building for the growing demand?
- Separating the roles of:
  - content production
  - content delivery
  - one-on-one tutoring
  - learning through collaboration
  - community and personal growth
  - degree granting

- Many of these can benefit from technology
- Many can be left to the choice of the individual - e.g., popularity of NDOs at Stanford

Imagine a University with ...

- Little or no physical campus
- Highly leveraged courseware / lectures
- Dramatic improvements in quality and choice through "open competition"

- Teaching capacity re-deployed to individual interaction

- Educational access anytime and anywhere
Marketplace Perspective

- Two key factors:
  - Cost
  - Differentiation

- Together they provide the competitive advantage

- As in other markets, we will continue to see a diverse set of options available to individuals

“Cares of the University”

President Gerhard Casper, August 1997, Five-Year Report to the Board of Trustees and Academic Council of Stanford University

“Of all of the issues facing higher education at the end of the 20th century, none is more intriguing and more puzzling than the role of information technology in teaching, learning and research. ...”

“Just as the role of libraries has and will change, so will the function of the traditional classroom. Technology, again will increasingly change the way we communicate with one another, including the communication of complex thought and instruction. ...”

“Stanford’s ability to retain its position as a preeminent institution of higher education in the 21st century will depend to a significant extent on how the University employs technology in teaching and learning. ...”
Universities in the Digital Age

John Seely Brown and Paul Duguid, Xerox PARC

"The knowledge delivery view strikes us, however, as both wrong and misleading in a number of ways: it misunderstands how people learn, where they learn, and when they learn. In the first place, it takes students as empty vessels into which the university pours information." ..."
Education and Technology

- Two broad facets:
  - Technology for improved content
    - deep models of subject matter and student
    - active exploration of subject (simulations)
    - relate to students context/environment (situated learning)
    MOSTLY DOMAIN DEPENDENT
  - Technology infrastructure for:
    - course and student management
    - content creation
    - delivery / distribution
    - collaboration
    MOSTLY DOMAIN INDEPENDENT

- Both aspects are important and complementary

Technology Adoption Phases

- Phase-1:
  - digital version of non-digital process

- Phase-2:
  - value-added features appear in digital version

- Phase-3:
  - process re-design
Content Creation

- Critical bottleneck in these early stages
- Twin goals:
  \[ \text{End-User Value} \quad \text{Content Production Cost} \]
  \[ \text{Time} \]
- Diversity of effort
  - based on market size/value, longevity of content, ...
  - e.g., informal design review vs. Economics-101
- Diversity of media
  - text, images, audio-video, animations, simulations, ...
- Modular content and personalization
  - content granularity and structure

Many options today for text, images, html, ...
- numerous tools companies

Audio-video will be a key element
- follows from technology adoption phases
- capture the best; capture the informal
- Real Networks and Microsoft key streaming players

Our own effort:
- low cost capture of presentations and meetings
- smooth synchronous to asynchronous transition
- explicit support and automated index creation
- "living" content using annotations
Delivery and Distribution

- Infrastructure reasonable for presentations
  - intranets/campus-networks pretty powerful
  - Internet (web) good for text and images
  - Netshow/Real pretty good for streaming media
    - multicast; unicast; from local disk
    - scalable stream formats
  - compression is getting better all the time

- Infrastructure still poor for synchronous audio/video collaboration
  - text-chat just not adequate
  - both latency and bandwidth are killers
    - adoption of multicast only helps with bandwidth
  - continue to use telephone conferencing ???

Collaboration

- Asynchronous collaboration
  - major successes: email and bulletin boards
  - new addition: "in-context" annotations
    - annotatable web ==> e.g., notes in the margin
    - annotatable video ==> e.g., classroom discussion
    - annotations stored separately from content

- Synchronous collaboration
  - Feedback for "live" content
    - vote counting, pace I applaud I nodding-off meters, ...
    - back channel for questions, shared white boards, ...
  - Distributed Tutored Video Instruction (D-TV)
    - wired-together VCR controls; chat for discussion
    - may need to mix analog/digital technologies
  - "Awareness" tools
Work at Microsoft Research

• Annotation framework
• Collaboration for live presentations
• Distributed tutored video instruction
• Camera management
• MURL Seminar Series
Extended Flatland

- The whole session is recorded and compressed on-the-fly for on-demand access

- The on-demand media is further annotatable, making it "living" content

- Small group viewing possible in D-TVI mode

- Value-added features like time-compression and various indexes into the content

Concluding Remarks

- It's a hot and important topic, so lots is happening

- At this point, adequate technology base for takeoff - focus on new applications than new technology - asynchronous access will dominate

- Key challenges
  - taking value beyond cost
  - business model and bootstrapping issues

- Who will be the leaders in this new era?
Enhancing Problem Solving Skills in a Freshman Course with an Interactive Electronic Textbook

Timothy N. Trick
University of Illinois at Urbana-Champaign

Abstract

This paper discusses the development of an electronic textbook for a new freshman engineering course entitled, "Introduction to Electrical and Computer Engineering." One of the goals of the electronic format was to enhance the problem solving skills of the students through online interactive Web-based tutorials and exercises in which the students receive immediate feedback regarding the correctness of their work. A brief description of the course and the electronic textbook is presented. Student evaluations indicate that the project has been a success. The paper concludes with a brief discussion of a number of unresolved issues concerning the production, sale, and support of electronic textbooks.

Course Description

Two of the goals for our ECE 110 freshman engineering course are to excite students about the study of electrical and computer engineering by exposing them early in their education to electrical components and their applications in systems, and to enhance their problem solving skills through analysis and design. It is a lecture/laboratory course in which students learn about electrical instruments, motors, generators, diodes, transistors, amplifiers, digital circuits, and the microprocessor. In the laboratory the students experiment with various modules containing these devices, and in the final weeks of the laboratory they design a robotic vehicle. The enrollment in the course has grown steadily to several hundred students per semester, and it is still growing as more non-majors elect this course over the traditional circuit analysis course. This places a heavy burden on staffing.

Electronic Textbook on the Web

In the 1996 Spring Semester we made the decision to abandon textbook assigned problems which were manually graded by a teaching assistant (TA) and move to the highly interactive WWW-based learning environment. Our goal was to relieve the instructors and their assistants of mundane tasks and to create an interactive environment in which the student receives immediate feedback and assistance. There are many approaches to using multimedia and the WWW to create an asynchronously learning environment. At the University of Illinois at Urbana-Champaign we chose the computer program MallardTM [1,2], a WWW-based asynchronous learning environment. Mallard provides an asynchronous learning environment in which students can view interactive tutorials and take personalized on-line quizzes. Mallard grades quizzes submitted by the students and gives them immediate feedback about their solutions. Mallard also provides a number of useful features to help instructors maintain class rosters, post important announcements, keep track of student grades and progress, and develop appropriate teaching materials for their courses. Since its inception in the Fall Semester of 1995, Mallard has now been used by thousands of students in a dozen different courses. Courses that have used Mallard at the University of Illinois include courses in electrical and computer engineering, Italian, and economics.

In our freshman course the students do all of their homework on-line and don't submit any homework on paper for manual grading. Instead the students submit their homework to the Mallard server. Within seconds after submission a student receives his/her grade. If a student does not receive 100%, the student can be given additional feedback with clues about how to correct the problem. The student can also be given the opportunity to resubmit the problem a limited number of times with or without penalty. Hints can also be made available after an answer is submitted to guide the student towards the correct solution. The student's grade and number of attempts are recorded on a secure server. Cheating is less of a problem with Mallard than with textbook assigned problems, because problems and problem parameters can be randomized. Also, the homework is weighted as 10% of the grade; the other 90% of the grade consists of traditional in class examinations and performance in the laboratory.

In the 1996 Spring Semester the question types in Mallard were constrained to multiple choice, numerical, or simple symbolic answers. Sometimes we were too confined in the types of questions that we could ask the students. Yet the grading of more complex question types can put too much of a load on the server and can slow the response time unacceptably for the hundreds of students who are on line. We found Java applets to be a solution [3]. By means of Java applets students can draw a timing diagram in the browser window or draw a piecewise linear waveform on the screen. After the student has finished drawing the timing diagram or graph, the applet communicates the solution to the Mallard server, which grades the problem and gives the student feedback about his/her solution.

To grade design problems, Java-based simulators can be written. Last semester a Java-based microprocessor simulator was developed to teach the students about programming in assembly code. We have integrated the simulator with Mallard so that the students can be assigned simple programs to write. After the program has been run, Mallard
will be able to check the correctness of the program by checking the state of the processor.

Finally, we developed a Java-based whiteboard to allow the students to communicate synchronously with each other and with the TAs. The TAs have assigned office hours during which they will be monitoring the whiteboard to answer questions posed by students. In a session with the TA, students can upload circuit diagrams to the whiteboard and annotate them in order to show the TA how they are working a problem. The TA can respond immediately to the student's concern by drawing and/or typing a response to the student. In this way students can get help from their instructor or the TA over the Internet during office hours.

**Evaluations**

Each semester the students were asked to evaluate the lecture, laboratory, and the homework on a scale of 1 (poor) to 5 (excellent) with average = 3. The lecture is taught in large sections with an average enrollment of approximately 150 students. The laboratory is taught in relatively small sections with typically 24 students in a section. Naturally the laboratory is very popular and typically receives a rating of 4.1/5.0, whereas the lecture is much less popular and typically receives a rating of 3.1/5.0. When the homework was assigned from the textbook, the students rated the homework 3.3/5.0. Interestingly, when the textbook problems were replaced by Mallard quizzes, the rating increased to 4.0/5.0. Other faculty took note of the popularity of Mallard with the students, and they began to investigate the use of Mallard in their courses. There are now five courses in the department that use Mallard quizzes either partially or completely in the assignment of homework.

In addition, the Office of Instructional Resources has surveyed the students each semester with regard to their opinions on the use of web-based course material. Each semester a large majority of the students favored the use of web-based tutorials and homework exercises. The results are reported in more complete detail in [3].

**Electronic Textbook Issues**

There are a number of difficult issues associated with the production and sale of an electronic textbook. In time most of them will be resolved. The issues are:

- Cost
- Intellectual property
- Lack of uniform web browser and publishing standards
- Inexperience of publishers and universities in dealing with electronic textbooks.

**Cost** - There are a number of costs associated with the development, sale, and operation and maintenance of an electronic textbook. The most formidable of these is the cost of the development of the course material. Hollywood studios spend tens of millions of dollars to make a one hour animated film. For a three hour one semester course a professor must produce approximately forty 50-minute lectures.

In the traditional mode of teaching the cost to the university is in the range of a few thousand dollars to not more than a few tens of thousands of dollars each time the course is taught. The development cost for a multimedia course far exceeds this cost. Thus, to recover the development cost the volume (number of students that use the software over its lifetime) must be very high, and the cost of delivery must be less than the cost of delivery in the traditional mode of teaching. After a professor used a supercomputer to produce a one minute 3-D animated simulation for his course, the professor joked, “I think that I spent as much as the producer of the movie Rambo.”

Because of the enormous effort required to produce a multimedia course, another cost could be a non-tenured faculty member's career, if he/she does not use good judgment in prioritizing his/her time on the most appropriate goals to achieve a tenured position.

Other costs associated with web-based course material include the cost of multimedia development tools. The price of the tool is typically affordable, but these tools can be quite complex to use. The cost of training and retaining the employment of experts in the application of these tools is far more expensive than the cost of the tool.

In the use of these tools there is also the cost of the operation and maintenance of the server hardware and software, the cost of web access (low bit rate or high bit rate), and the cost of multiple software licenses (server/client, course material, and third party intellectual property). For example, a professor may use commercial clipart in his/her multimedia presentation, or may access a commercial graphical or mathematical equation solver software tool. If a professor's software contains third party intellectual property, then, before the professor can license the software to other parties, licenses must be obtained from the other parties.

**Intellectual Property** - As mentioned above there are third party intellectual property issues that must be negotiated, but also there are intellectual property ownership issues among faculty, publishers, and universities. Although universities are beginning to address the issue for electronic publishing of courseware, the issues are complex and not totally resolved in the minds of many faculty.

**Standards** - There are a number of standards issues. No two Web browsers display the contents of a multimedia presentation in the same way. It doesn't appear that this issue will be resolved in the immediate future. Presently, mathematical equations must be coded as an image in an html file, and there are multiple audio and video standards. Because of the enormous market potential of the internet, the standards issues will be slowly resolved.

**New Business Model Needed for the Electronic Textbook** - Universities and publishers lack experience in dealing with the production, sales, delivery, and operation and maintenance of an electronic textbook. Publishers deal in the delivery of hard copy. When I demonstrate my courseware to publishers, their immediate reaction is, "Can I produce and distribute a CD-Rom for you." On the other
hand, universities are reluctant to give departments additional funds for the operation and maintenance of electronic textbooks. The faculty, universities, and publishers need to develop new business models for the production, delivery, and operation and maintenance of electronic courseware.

Summary

The production of electronic textbooks is a very costly enterprise, and there are a number of issues that need to be resolved. However, the internet is a very powerful medium for communication, and, when it is coupled with the computer, it is a very powerful tool for both education and training. It will never totally supplant nor equal the quality of learning that occurs in the human interaction that takes place between a master in the profession and an apprentice, but computer-assisted instruction can be a strong enhancement to learning. The cost of human to human learning, and the amount of continuous learning that is required in the modern high tech job market, is creating a growing market for computer-assisted learning. The initial success of some of these computer-assisted internet learning ventures and the market potential of the internet will ultimately cause solutions to be found to the problems created by this fledgling industry.

Acknowledgements

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References

Why are the 1990's a Period of Major Change in Engineering Education?

Several forces combine to make this a period of unprecedented change in engineering education. The forces for change fall into two categories: changes in the nature of our world and changes in the nature of our knowledge base.

Three changes are particularly important to US engineering education. The first change is in the political arena. The dissolution of the Soviet Union, the return of Hong Kong to China, the normalization of relations between the US and Vietnam, the impending adjustments in Latin America when Fidel Castro retires from public life, etc. all create an environment that is significantly different than the world of the 1980's. Suddenly things are possible that were impossible a few years ago.

New political and economic alliances are emerging from this changing picture. The North American Free Trade Agreement (NAFTA), the Asian Pacific Economic Community (APEC), The European Community (EC), and membership changes in the North Atlantic Treaty Organization (NATO) are all examples of changing national alliances.

These changing alliances of governments are often paralleled by changing alliances of industries. At one time US and Japanese auto manufacturers only competed with one another; now they have many joint ventures in all parts of the world. The Boeing Airplane Company and Mitsubishi Heavy Industries recently announced the joint development of a new aircraft to be marketed all over the world. Nippon Steel and Inland Steel have combined to construct new state-of-the-art steel production facilities in the US. For commercial purposes, these emerging global corporations and corporate alliances make national boundaries less important now than they have been since national boundaries were first "invented" thousands of years ago.

A second major change in the nature of the world is the recurring revolution in telecommunications. CNN and other global, satellite-based communications networks have made a significant difference. The fact that information can be transferred instantaneously around the globe without the significant possibility of censorship has made a major change in the way the world operates. It is no longer possible to lie or misrepresent reality very long: others know the truth or see reality differently and can almost immediately refute anyone who attempts to misrepresent situations.

This change is pervasive. It not only effects politics and the business of nations; it effects commercial business, the equity and commodities markets, fashion, food, and feelings. We share the meetings of heads of state, the funerals of world citizens, and with my breakfast this morning, I watched summaries of the news from six world capital cities in real time. It is truly a time when a butterfly flaps its wings in the rainforest and El Nino shifts.

A third change is the proliferation of access to energy. For $2 million you can get delivery of a reliable 10 Megawatt generator set that will operate continuously for 30,000 hours in literally any conditions where man can survive. Couple it with a source of fossil fuel and you are in business. In business near the source of raw materials; in business near a supply of inexpensive labor; in business immediately adjacent to your market. In the past, industrial ventures that needed access to such significant supplies of continuous electric power had to be located in stable, established, first-world nations where tremendous capital investments had been made to create such fixed infrastructure.

I understand that there are severe limits on the extent of the world's fossil fuels; what I describe will not change that. My point is not that the "pool of oil" has gotten bigger; my point is that there are more spigots on the pipeline and that the pipeline has become a virtual one without the need for continuity from the source. Just as access to information no longer requires the continuity of the telephone line, access to energy no longer requires the continuity of the power line or the pipeline.

What difference does all of this make to engineering deans and faculty members? We are not industrial tycoons or politicians; we are teachers, researchers and curriculum designers. The reason it makes a difference to us is that we need to prepare our current students for a different working environment than the one we envisioned 20 or even 10 years ago. New engineering graduates will be expected to work productively in this global environment with essentially no boundaries except their own imagination and creativity. Many of the constraints placed upon previous generations of engineers have been removed or significantly modified. The remaining constraints have become amorphous and ephemeral: continuously changing shape, substance and hue. Our new graduates must be prepared to create, manage, direct and continually reshape the system that emerges from this foment. We cannot help them to achieve such sophisticated outcomes from their education using only the "fixed tooling" of the past.

The second category of forces for change in engineering education are changes in the knowledge base of mankind. Two aspects of our knowledge base prompt the need for change: the generation of new knowledge and the dissemination of that knowledge.

In 1963, in his book Little Science, Big Science... and Beyond, Derek Price claimed that more than
80% of the scientists and engineers who ever lived were alive at that time: that percentage is even higher today. This huge cohort of technical professionals has at its disposal significantly better and more productive “tools” than their predecessors. The result is a significant increase in the things we know and the things we can do.

We are generating "messages" to one another about this new knowledge at an alarming rate and that rate is accelerating at an astounding pace. An example may illustrate my point. The number of North American Internet users in January of 1993 was 1.3 million, by 1994 it had become 2.2 million, by 1995 it had grown to 4.8 million, by 1996 it was at 9.5 million, in 1997 it was 16.1 million and in January, 1998 it was estimated to be 25 million. These are annual growth rates ranging from 70 to 120% per year for those years. If you think of each of these "users" as a "publisher" you get sense of the real and potential situation. As Bill Gates of Microsoft describes it in The Road Ahead, the entry barriers to publishing are very low, essentially non-existent.

Put these two things together and we have a problem for learners. New things that need to be learned are being developed very fast. Those "new things that need to be learned" must be filtered out from a cacophony of background noise that is becoming deafening.

Put all of these things together and you have a significant problem for those charged with designing and operating an educational system to prepare young technical professionals for a practice that may well extend until 2050. Information explosion. Communications overload. Unlimited opportunities. Constant rapid change. What a mess!! Or- What a wonderful game for those who come prepared to play! That's our central mission: prepare these young people to play. Prepare them to play the new game, however the rules unfold.

Who perceives these environmental changes and who is defining the changes that need to be made in the US engineering education system?

The answer seems to be: nearly everyone. The difficulty of course is that each individual or group sees things from a different perspective or with a different set of biases. The "viewers" include: society in general, industry, engineering faculty members and deans, the National Science Foundation, ABET, and private foundations. Each of these entities is made up of many different people so it is difficult to characterize the views of each organization with great precision. Collectively, however, I think the following perceptions are shared by this group of interested observers.

• First, a realization of the changing world condition as described above. Nearly everyone accepts the emerging reality of a global market for nearly everything, including technical professional services.
• Second, acceptance of the burgeoning knowledge and communications base. There is agreement that the transfer of a body of knowledge as the primary value added by a technical education is no longer a tenable objective.
• Third, engineering colleges must accept the challenge of responsibility to reshape the engineering education system to prepare students for this future by defining and enabling the new outcomes our students need from their time with us in college.
• Fourth, there is agreement that we must assess and evaluate our programs to ensure that they create the outcomes we intend.
• Fifth, there is agreement that this is an iterative process that will continue forever, probably at a faster and faster pace.

What specific changes have been made to date?

Talk

Talk always seems to come first. Sometimes that is all that comes. Fortunately that is not the case with this situation. Nonetheless, there has been a significant amount of talk that preceded any substantive action. The "talk" included several seminal documents produced by the National Research Council, the National Academy of Engineering, the National Science Foundation, and the Engineering Deans' Council and the Corporate Roundtable of the American Society for Engineering Education.

Demands for Action

After the talk, there were demands for action expressed by public spokespersons and accrediting agencies. Persons who spoke on behalf of the public have been demanding accountability of various sorts for the past few years and have steadily become more and more assertive in their demands for assessment and evaluation of programs of all sorts.

More directly of interest to educational institutions, the regional accrediting agencies in the US began to demand more assessment of programs in their accrediting process beginning in the late 1980s. ABET followed suit in the 1990s with its revised accreditation standards embodied in the new Criteria 2000.

ABET's Criteria 2000 were the result of several years of meetings, conferences and workshops that included input from a wide spectrum of those involved in engineering education. Criteria 2000 is not just a different list of the things that a program must do to be accredited. Criteria 2000 heralds a shift from engineering education programs that were predicated on inputs to programs that are evaluated based upon their outputs. The old criteria were very prescriptive and provided a great amount of detail about what was to be taught and how much was to be taught and in what sequence it should be taught. The focus was on the inputs into the process. Colleges that deviated very far from this prescription put their accreditation at risk. The result was that most US engineering programs were very similar and they were designed to prepare graduates for the industrial world of the 1960s and 1970s not the world of 2010 and 2020.
The new criteria, Criteria 2000, are very outcomes oriented. That is, they ask colleges to demonstrate that graduates possess certain competencies rather than demonstrating that they have been exposed to certain experiences that should lead to those competencies. As George Peterson, the Executive Director of ABET recently said: "Accreditation under Criteria 2000 will be based upon what students learned, not what they were taught."

Changes in what agencies will fund
University level curricular development and pedagogical research in the US is funded almost exclusively on a specific program basis, i.e. institutions are not funded; specific activities are funded. Granting or funding agencies indicate a general area in which they will accept proposals and the proposals are then reviewed and funded based upon the extent to which the proposed activities forward the goals of the funding agency.

In the late 1980s and the 1990s agencies like the National Science Foundation, the Keck Foundation, the Kresge Foundation, the Lilly Endowment, etc. all expressed their interest in funding the following sorts of programs: programs they felt would lead to new and better outcomes for the graduates of US engineering colleges. The various agencies said they wanted to see programs proposed that would:

- Provide sustained and systemic changes in the engineering education process. The agencies did not want to fund things that were temporary or peripheral; they were interested in funding things that would last for a long time and things that were at the very core of engineering curricula.
- Involve industry. The agencies made it clear that they believed that engineering graduates would be important leaders in the world's industrial future and that the education they received should prepare them for work in this environment. The agencies also expressed a belief that there should be a closer relationship between industry and academe.
- Share resources across the university and between universities. Agencies indicated a clear preference for programs which brought the various segments of an individual university into closer cooperation and for programs that led to alliances of various sorts among different universities.
- Make engineering education more cost effective. Educational costs in the US have skyrocketed in the past decade, far exceeding the cost increases in most other sectors of the economy, and legislators, parents, and the various other funding sources of education have made strong statements that this cost escalation must stop.
- Provide access and support for underrepresented groups. This is a continuing demand, one that is always a component in Federally-sponsored programs, and one that is often a requirement of other governmental and nongovernmental agencies.

Changes in what people are doing
Engineering colleges have responded in a variety of ways to their own convictions about the need for change and the externally-voiced demands. A variety of alliances have emerged, most notably, the NSF-sponsored Engineering Coalitions. I will not attempt to chronicle all of these efforts in this paper but will concentrate, instead, on the specific changes at Rose-Hulman Institute of Technology.

Specific Changes at Rose-Hulman Institute of Technology
A central characteristic of the changes at Rose-Hulman in the past 15 years has been concurrent progress on several fronts. There have been marked changes in the outcomes expected for graduates, the roles played by various participants in the learning process, the physical facilities, and the technologies employed. Movement on only one or two of these fronts leads to frustration; it is absolutely necessary to consider them all when trying to implement change. The chart shown in Figure 1 attempts to capture these four streams of change and illustrates the parallelism required for genuine sustained, systemic change to occur.

Using the chart as a reference point, I will highlight the changes that have occurred at Rose-Hulman in the recent past. First I will describe "The Way It Was" in the 1960-1980's and then I will discuss the changes in each area at Rose-Hulman as we move toward 2000.

The Way It Was

Student Outcomes
Graduate engineers were once expected to be repositories of information: information on how to do various things and how to achieve various results. This expectation naturally led to the need for engineering students to learn a wide range of facts and memorize a number of "right answers." The facts included a host of conversion factors, numerical constants (how many decimal places can you recite for pi?), etc. Right answers constituted a slightly more sophisticated set of information and included knowing how to read the steam tables, integrate by parts, interpolate in the log tables, etc. These facts and right answers comprise a set of knowledge in which there is a correct answer; no human judgment is required in relating the information.

Of course, graduates were also aware of the need to understand the science behind the memorized facts or right answers so that the fact or the right answer fit the situation and so that new knowledge could be developed based upon current knowledge. Someone had to be the repository of this body of knowledge and set of skills and engineers were the class of professionals to whom this task fell.

Roles of the Players
The nature of the material to be conveyed to the student and the expectations of the graduates led to a pedagogy that was most effective for the transfer of a relatively fixed body of knowledge. The lecturer/listener mode is highly...
effective for such a task and that was, and unfortunately still is in many places, the dominant mode of interaction between teachers and students. Modest enhancements occurred as new media came into use and the teachers became presenters or coordinators of this process and students expanded their role a bit to use additional senses, albeit still playing a passive role.

Classroom Configuration

The classroom configuration described as Teacher in Front/Students in Rows is well suited to the pedagogy described above. As new media technologies entered the classroom, various things were added to the list of "Things in Front." The students, however, were still bound to their rows of seats which became even more confining with the anchoring effect of classroom computers.

Technology

Chalkboards have been the mainstay of the college classroom, almost literally, forever. Overhead projectors and the use of xerography to produce detailed transparencies has been a nearly universal addition since the 1960's. These "technologies" were primarily directed at making the process of teaching easier even though their visual nature also improved the situation for the student.

The Way It Is (or Ought To Be)

Student Outcomes

Everyone, including the graduates themselves, expects a lot more from today's engineering graduate than was expected even ten years ago. The rapid pace of the world is probably the greatest driver of this new set of expectations. The need for extensive teamwork, constant learning, problem solving skills, a global perspective, etc. are all driven by the quickened pace of both personal and professional life. The new outcomes like the development of various judgmental and transference abilities rest on a much higher intellectual plane than many of the older expectations.

ABET's Criteria 2000 expresses requirements for many of these new student outcomes and Rose-Hulman has also articulated its enhanced expectations of its graduates. New curricula like the Integrated First-Year Curriculum in Science, Engineering and Mathematics (IFYCSEM) is one of the ways in which Rose-Hulman is putting this into practice. IFYCSEM is a team-taught, 12 credit hour block of course work that combines all of the technical content of the first year of engineering studies into one course with integrated exams and one grade for the entire block. Various projects imbedded in IFYCSEM provide the opportunity for the development of teamwork, knowledge transference, and problem-solving skills.

A revised sophomore curriculum based upon the pioneering work of the NSF-sponsored Foundation Coalition partners, particularly those at Texas A&M University, builds upon the IFYCSEM program and leads into completely redesigned curricula at the upper levels. The final two years of Rose-Hulman's curricula in Electrical Engineering and Computer Engineering have been redesigned to take advantage of the enhanced student capabilities developed in the new first and second year programs. The curriculum in Mechanical Engineering is now in the process of change and Civil and Chemical Engineering are expected to follow suit in the near future.

The Roles of the Players

Teaching in a curriculum like IFYCSEM requires a different relationship between students and faculty members than the older curricula demanded. There is more of a player/coach relationship already in evidence among the Rose-Hulman faculty members and students involved in these classes. As the curricula mature and their downstream effects pervade the upper levels, it seems natural that a colleague relationship will begin to emerge between faculty members and students. The ultimate goal of making this an enduring life-long colleague relationship is a natural step ahead; new computer and communications technologies already enable this to become a reality.

Classroom Configuration

The fundamental change necessary in the physical environment must be predicated on the premise that the spaces should be designed to facilitate the learning process not the teaching process. The very use of the word "classroom" conjures up an image of "teachers in front; students in rows." At Rose-Hulman we have tried to revise our language to speak of Flexible Learning Spaces as the brick and mortar embodiment of the new large-group meeting places where learning is facilitated. They need to be flexible so that the physical arrangements of tables, chairs, computers, media devices, etc. can be reconfigured in minutes to accommodate changing learning needs. Our most recent attempt to reduce this concept to practice is the new Olin Advanced Learning Center on the campus. These spaces were designed by the faculty teaching the new curricula and using the new pedagogy.

Technology

The greatest changes in the learning process were probably brought about by the changes in the available technologies. The chart in Figure 1 shows an approximate chronology of the developments in instructional and computational technology between 1960 and today. In reality the force of the technological development is what finally accommodated and drove the process of change. Some of the new technologies made old student outcomes and pedagogical strategies obviously obsolete; others enabled innovative teachers and students to expand their expectations of one another and devote their time together to the development of more sophisticated outcomes.

The Real Secret

The real secret to the changes at Rose-Hulman is the fact that the changes in one area had to be made in con...
cert with the others. You can't just change the curriculum. You must also change the other components in the system. The parallel development of the new curriculum, the refocusing of the existing faculty and the hiring of new faculty sympathetic to the new curricula and pedagogy, the creation of new working spaces, and the injection of new technologies into the mix are all necessary components; none of them is sufficient alone to get the desired results. This is a short paragraph in the midst of a lengthy paper but it is the most important message. You must do it all and it must be done in a coordinated fashion and you must be committed to doing it over and over again.

At Rose-Hulman, the revision of our mathematics curriculum and the installation of classroom computers triggered the 10-year process of transformation of the learning environment. Once the computers were in place, our faculty were able to propose, develop and implement additional curricular changes to take advantage of the new capabilities of the students. The new curricula suggested the need for a revised pedagogy and the changes in the ways that faculty members and students interacted led to the need for differently configured facilities.

As the new facilities were under development, the possibility of affordable, student-owned laptop computers with the needed capability became a reality. At Rose-Hulman, the shift from college-owned desk-top computers to student-owned laptop computers was initiated with the class entering in 1995 and will be complete with the entering class in 1998. As an aside, I think it should be pointed out that I believe this signals a "sea change" for U.S. colleges in general and engineering colleges in particular: the days of college-owned computers for general student use has passed. Colleges should be getting out of the hardware business and focus their efforts and resources on providing access to network ports and other media sources. The end users, students in this case, should now own the hardware.

As I have suggested, the cycle of change is continuous. At Rose-Hulman we have been through a fairly identifiable cycle in the past decade: the curricula, the roles played by the people, the technologies employed, and the facilities have all changed in concert with one another.

If the process is indeed continuous, however, it should be possible to identify at least the beginnings of the next cycle. I think the first signs of the new iteration for Rose-Hulman are beginning in the area of student outcomes. In particular, the new student outcome that is surfacing is the requirement that each graduate have had some significant, externally-based, team-project work experience before graduation.

This is certainly not a new credential for engineering graduates. Many students have graduated with this experience as a result of their own initiative and/or good fortune. Several colleges even have a requirement for project work. What is new, however, is that we are beginning to expect that every student have this competency and that it must include each of the components.

• The experience must be significant, i.e. the work prod

Technology
- Computational
  - Hardware
    - Sliderule
    - Batch
      - Timeshare
    - Calculator
  - Software
    - Word Processors
    - System Software
    - Personal Software
    - Video Software
    - CAD/CAM
    - Graphics
    - CAS/SMS
    - Groupware
    - Applications
  - Notebooks
  - Applications
  - Teamware
  - Network Ports
  - Hypermedia
  - CD ROM

Instructional
- Chalkboard
  - Transparencies
  - Xerography
  - VCR
  - Satellite TV
  - TV-Computer
  - Proectors
- Interactive
- Video Disc
- Hypermedia
- Flexible Learning Spaces

Classroom Configuration
- Teacher in Front
  - Students in Rows
  - Teacher and Screen in Front
  - Students in Rows

Roles
- Student
  - Listener
  - Observer
  -Presenter-Coordinator
  - Resource Procuer
  - "Player"
  - "Coach"
  - Manager/Agent of Change
  - Facilitator of Continuous Improvement
  - Colleagues: Same Time-Same Place
  - Colleagues: Any Time-Any Place

Teacher
  - Lecturer
  - "Caretaker" of the Status quo
  - "Taker of the Status quo"

Administrator
  - "Manager of the Environment"
  - "Resource Procuer"
  - "Seeker of the Path"

Student Outcomes
- What Students Do
  - Memorize Facts
  - Learn "right answers"
  - Compare-Contrast
  - Use supporting evidence;
  - Learn how to Learn
  - Analyze, Synthesize,
  - Critique; Learn to think
  - for self
  - Learn to use Intellect
  - to shift from one context
  - to another
  - Speak Two or more
  - Languages
  - Transcultural aware

What Students Become
- Repositories of Information
- Understanders of Principles
- Discoverers of Knowledge
- Integrators of Knowledge
- Critical Thinkers
- Innovators
- Problem Solvers
- Team Members
- Leaders

Off-Campus Influences

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Figure 2

Figure 3

Figure 4
The Integrated Teaching and Learning Program: A Pioneering Learning Environment for 21St Century Engineering Education

Lawrence E. Carlson  
University of Colorado at Boulder

Jacquelyn F. Sullivan  
University of Colorado at Boulder

"Tell me, and I forget.  
Teach me, and I may remember.  
Involve me, and I learn.”  
Benjamin Franklin

Executive Summary  
The College of Engineering and Applied Science is in the sixth year of a bold, College-wide program that models the real world of engineering where skills in communication, teamwork, and leadership, as well as the ability and self-confidence to define and solve open-ended problems, are demanded. A team of faculty and students defined and realized an ambitious vision for undergraduate engineering education reform:  
"...to pioneer a multidisciplinary learning environment that integrates engineering theory with practice and promotes creative, team-oriented problem solving skills.”

The Integrated Teaching and Learning (ITL) Program integrates hands-on learning experiences throughout all four years and engages students in the design process from their first year. Cutting across all departments, the new curriculum vision demanded a new facility. The new ITL Laboratory, dedicated in April 1997, integrates leading-edge technology with the understanding and confidence borne of hands-on learning. The ITL team designed, piloted, implemented and continually refine a common first-year design course in which students work in interdisciplinary teams to design, build and test real products with real customers. Products such as an assistive glove that a quadriplegic student uses to grasp a soda can. While experiencing the design process first-hand, students define customer needs, sharpen their presentation skills, manage their time and budget their own money. Preliminary retention figures indicate that a remarkably higher percentage of students who take this course remain in engineering into their third year.

The team transcended departmental boundaries and made theoretical concepts come alive, developing over 35 experimental laboratory modules to augment sophomore and junior theory courses. The "mysterious" mathematics of Fast Fourier Transforms are more compelling to students when an electric guitar generates the signal. Modules are key curricular components of new interdisciplinary focus courses, now offered in the ITL Laboratory. Simple "hands-on home work" experiments using basic household supplies put engineering science principles into real-world context. Keeping honey on a spoon illustrates the rate dependence of fluid viscosity more effectively than a "chalk and talk" lecture alone could ever do.

The team won legislative approval of the ITL project as well as state funding for one third of the cost. In partnership with our students, the rest of the $17M ITL Program funding was raised by engaging alumni, industry and foundations sharing in our vision.

To support the curriculum reforms, a 34,400 sq. ft. Integrated Teaching and Learning Laboratory was created: a learning environment designed from the ground-up to support hands-on learning. The facility features first-year design studios, an active learning center, a computer simulation laboratory, an extensive computer network that integrates all the experimental equipment throughout two large laboratory plazas, capstone design studios to showcase student projects, group work areas to support student teams, shops where students turn their dreams into reality and interactive science-based kinetic sculpture galleries.

Unlike any other educational facility in the world, the ITL Laboratory itself functions as a living laboratory through exposed engineering systems and sensors integrated into the building, making its "pulse" accessible on the Internet as a technology and building systems resource.

Winston Churchill observed that "first we shape our buildings, then our buildings shape us." During the 1997-98 academic year, 58 faculty taught 41 courses to more than 1,720 students - shaping their learning and our future in new and exciting ways.

integrate (in' ti-gray) v. 1. To make into a whole by bringing all parts together; to unify.  
Imagine a Learning Environment...

- where first-year students design a tracking system to keep an elderly person from wandering
- where teams of sophomores "discover" dynamics by analyzing kinetic sculptures
- where undergraduate students are so committed to completing an assistive technology design project for their disabled "customer" that they request lab access during spring break
- where a team of aerospace, electrical and mechanical engineering seniors design and build an experiment that flies on the space shuttle, under their control
- where students explore the innermost secrets of a building system in real time, on-line
- where students actually enjoy the rigor of studying engineering
The Integrated Teaching and Learning Program

All of these are happening today at the University of Colorado at Boulder as part of the College of Engineering and Applied Science's Integrated Teaching and Learning (ITL) Program. The consensus among educators and practitioners nationwide is that engineering education must significantly change; the students, faculty and administration at CU agree. Through the College-wide ITL Program, CU has taken a bold approach to implementing systemic engineering education reform.

The engineering curriculum for the next century must be relevant to the lives of students and the needs of society. Reflecting the real world of engineering, we have expanded our teaching methods to exploit teaming, group learning, active learning and project-based design and problem-solving experiences in all four years of the curriculum. We have learned to value integration in addition to specialization.

The ITL Program is supported by the new Integrated Teaching and Learning Laboratory, a 34,400 sq. ft. hands-on learning facility that opened in January 1997. The architecture of this facility was driven entirely by curricular reform initiatives. It provides students with an interdisciplinary learning arena in which the principles of design are introduced during a student's first year; where theoretical engineering science courses in the middle two years are augmented with hands-on, open-ended discovery opportunities; and where interdisciplinary teams of seniors design, build and test real-world products.

College-Wide Curriculum Reform - The Process

Program Concept and Initial Planning - In early 1992, a small team of faculty, students and the Dean embarked on a bold venture - to completely revitalize the undergraduate curriculum by enriching it with hands-on, project-based learning, and to examine the traditional role of faculty. An interdepartmental curriculum task force solicited input from a broad customer base that included our own students, alumni and industry. Nearly 50% of the College's 150+ faculty provided input; most of the original task force members are still actively engaged in ITL.

Engineers from Martin-Marietta Corporation (now Lockheed-Martin) guided us in the use of a formal process to define the design requirements for our revised curriculum. Early and frequent dialog with the Hewlett-Packard Company culminated in a $3M equipment grant, one of the largest grants ever awarded by HP to a public institution, to outfit the ITL Laboratory with high-end computers, instrumentation and networking. The emerging ITL concept was also shaped by input from our Engineering Advisory Council, comprised of industry leaders who meet semi-annually to guide the College.

Curriculum Concepts Emerge - To illustrate the multi-dimensional and multi-level components of our re-vamped undergraduate curriculum, the ITL Program concept diagram, shown in Figure 1, emerged in late 1992. At its center are 2,300 undergraduate students pursuing bachelor's degrees in ten degree programs in six departments: aerospace engineering sciences; chemical engineering; civil, environmental and architectural engineering; computer science; electrical and computer engineering; and mechanical engineering. The inner ring represents the information technology component of the ITL Program: a computer network linking computers that support electronic lab notebooks, control of experiments, data acquisition and analysis, graphics and report preparation. Interdepartmental areas that focus on common fundamental concepts of engineering were defined: measurement and instrumentation, electronics and microprocessors, controls, heat transfer, fluid mechanics, structures and materials, manufacturing, and environmental engineering. The outer ring illustrates the curricular components of the ITL Program. These curricular elements support students' progress in becoming independent learners and effective team members - skills vital for lifelong learning and professional success. The curricular components include a first-year design course, integration of hands-on experimental modules and hands-on homework components throughout theory courses, and interdisciplinary capstone design courses.

Focus Areas Span All Departments - By late 1993, the work of the task force was augmented by the contributions of experimental focus area teams - groups of faculty from multiple departments interested in common, specific topical areas such as fluid mechanics, controls and manufacturing. The focus area teams defined experimental modules that serve multiple departments by providing hands-on experiences to augment theory courses. For example, four departments teach courses in fluid mechanics. While retaining disciplinary specialization at advanced levels, the focus teams identified common underlying concepts and specified modules and equipment to support hands-on reinforcement of basic theoretical principles. The first two interdisciplinary focus courses, in fluid mechanics and electronics, inaugurated the new ITL Laboratory using in-class demonstrations and hands-on laboratory and homework experiences. Faculty throughout the College developed more than thirtyfive experimental laboratory modules in various focus areas; all are exportable to other institutions.

Vital Student Support - Since the inception of the ITL Program, an essential and unique source of financial and intellectual support has been provided by the student body. In 1991, forward-thinking undergraduate engineering students, with a referendum support vote from their peers, chartered the Engineering Excellence Fund (EEF) to sponsor College-wide curriculum innovation. Every engineering student now contributes $100 each semester to the EEF, managed by a group of students, with the advice and approval of the Dean. This nationally unique educational excellence fund generates $700K annually; half of that is committed to operational support of the ITL Program. The other half is competitively awarded annually to faculty and students for curricular and laboratory innovations throughout.
the College, much of which is complementary to ITL.

Our students have also been intellectual partners in the evolution of the ITL Program. They lobbied both the Colorado Commission on Higher Education and the state legislature to support the ITL Program and to change the state legislative rules to allow a portion of EEF funds to be used for capital construction costs. Several students served on the curriculum task force, and numerous students provided input into the conceptual design of the ITL Laboratory.

**Successful Fund-Raising** - The curriculum task force was instrumental in helping to privately raise two-thirds of the $17M ITL Program funding. The team also led the project approval process through the state legislative system, which resulted in more than $5M in state support for the program. Foundations that have supported ITL include the David and Lucile Packard, U S WEST, Hewlett-Packard, AT&T, and Gates Family foundations. The Hewlett-Packard Company, Quantum Corporation, National Instruments and Lockheed-Martin Corporation also were significant contributors to the implementation of the ITL Program.

**The Vision Takes Shape - 1994** marked the offering of pilot ITL curriculum components, most notably the First-Year Engineering Projects course, as well as architectural design of the ITL Laboratory, which was entirely curriculum-driven. The ITL Program’s emphasis on cooperative teamwork and active learning formats demanded spaces different from traditional laboratory and classroom configurations. The initial design meeting was held at the San Francisco Exploratorium to inspire project architects by experiencing the thrills of people of all ages engaged in open-ended discovery. Design of the laboratory was conducted as a College-wide, participatory process. All students and faculty were invited to a number of open-house-style design charrettes to provide input. The potential to make the building itself a learning opportunity evolved as we engaged the architects and engineers in creative brainstorming sessions.

From the earliest phases of facility design through construction, the ITL co-directors provided strong project leadership, working collaboratively with Facilities Management and the external design and construction teams as partners. An all-day partnering session was held with the designers, contractors, and all major subcontractors to kickoff the construction phase. Imbuing them with the ITL vision and negotiating a process for collaborative and productive resolution of inevitable project conflicts, an environment for collaborative decision-making was established. In particular, the extraordinary complexity of making the building itself a learning tool required an unprecedented level of creativity and coordination between faculty, architects and contractors. Unquestionably, the exciting hands-on laboratory facility that emerged from this intense process reflects the collective creativity of dozens of students and faculty.

By late 1995, ITL Laboratory construction was underway, the First-Year Engineering Projects course was refined and gaining acceptance by faculty throughout the College, and the **Hewlett-Packard equipment grant was secured.** A College-level curriculum revision in spring 1996 guaranteed that the First-Year Engineering Projects course fits into all majors.

The process and investments paid off: the ITL Laboratory building - with more capabilities than we ever imagined possible - was completed ahead of schedule and within budget.

**External Review** - To provide meaningful and objective critique, beginning in 1994 the ITL team invited faculty from a number of forward-thinking institutions, including principal investigators from four NSF engineering education coalition institutions, to serve as external reviewers of the ITL Program. Annual meetings with this group provide valuable feedback and mutual exchange of ideas, many of which have been incorporated into the ITL curriculum and facility. For example, a portion of the University of Maryland’s Introduction to Engineering Design course provided inspiration for the design project portion of the First-Year Engineering Projects course. Likewise, the reverse engineering component of that course was adapted from Stanford’s mechanical dissection concept. Unanimously, our external review panel applauds the value of the mutual exchange of ideas.

**Celebrating Diversity in Learning Styles - CU’s**

Engineering College has long-standing programs to support diversity in gender, race and culture in its student body. The ITL Program now enables us to celebrate diversity in learning styles as well. Women students make up approximately 20% of the student body and 23% of entering first-year students. Underrepresented minorities account for 8%. The College has a clearly articulated goal of improving the recruiting and retention of women and people of color into our engineering program. The nationally-acclaimed Women in Engineering and Minority Engineering programs serve as advocacy organizations for both groups of students. The average retention rate (first to second year) for underrepresented minority students in engineering is a remarkable 70-80%, placing CU-Boulder among the top ten of all universities in the nation. The ITL Program, with curricular components that capitalize on group learning, experiential self-directed learning, and small group active-learning techniques, is designed to have a positive impact on retention of all students and should especially aid students who historically have felt isolated in the engineering education experience.

**Tour the ITL Curriculum and Laboratory**

Because the design of the ITL Laboratory was curriculum-driven, a tour of the facility provides an excellent way to describe the curricular elements that define the ITL Program. To realize the ITL curricular dream, several fundamental design concepts were incorporated into the laboratory design. Flexibility was vital to accommodate future, and unknown, teaching and learning methods. Because much of engineering is visually interesting, visibility was a key element in the design to stimulate students to study engineering by watching other students in action. Finally, the laboratory
needed to be interactive and stimulating in order to function as a learning environment for our students, as well as its many visitors. The interior spaces showcase engineering in ways very different from traditional laboratories.

Bridging to the Future-An overhead bridge links the Engineering Center to the ITL Laboratory. Flanking one side are ten group study rooms that students reserve for team work. Each space contains round tables and white boards, with a computer connected to the ITL network for access to data as student teams analyze experimental results and prepare presentations.

A Place for Art in Engineering Education - A gallery of interactive science-based sculptures provides both intrigue and educational opportunities for students. One audio-kinetic piece features a fascinating maze of spiraling tracks with balls zooming down, seemingly at random. Sensors incorporated into the sculpture allow students to measure aspects of dynamics such as velocity and acceleration, and compare them to computer simulations. Using a video camera and a computer, students track the repetitive bounces of a ball on a steel plate, measuring the coefficient of restitution. This experiment, and several others, is also available on the Internet as a virtual experiment accessible for distance learning (http://bench.colorado.edu). A Taylor column provides a captivating display of rolling cells in a pearlescent fluid. All the sculptures possess this multiple level for learning potential and are targeted to expose elementary-age children, as well as college students, to the challenges and excitement of science and engineering.

First-Year Students Try On Engineering - Just past the gallery with its commanding view of the laboratory plaza below, students enter one of two design studios dedicated to the First-Year Engineering Projects course where they experience the engineering design process in a hands-on way [1]. The design of the studios was based on two years' experience piloting the course, and represents a significant departure from the conventional classroom. Small tables facilitate team communication, while work benches and hand tools support product design and construction. A computer with a myriad of software is available for each team. These spaces are two of six smart classrooms throughout the building that use network connectivity and high-resolution video projection to capitalize on the growing role of educational technology in the learning process.

During the last 4/2 years, 36 sections of the First-Year Engineering Projects course have been successfully offered. The course is available to all first-year students in the College. In contrast to the often large, impersonal math and science courses, each section is limited to 30 students. The course goals include introducing students to the excitement of engineering and to the practical considerations of the design process, experimental testing and analysis, project management, oral and written communication, and working in multidisciplinary teams. Workshops on team dynamics, social style profiles, learning styles, and group communications progressively develop students' awareness and skills. Design reviews, presentations, written communications, cost considerations, and engineering design journals are key components of the first-year projects experience. The course also serves to cement the concepts first-year students concurrently learn in core physics, chemistry, and mathematics courses. Three main components characterize the course:

Mystery Artifact Challenge: In the first "icebreaker" challenge, student teams deduce the function of six unusual "mystery artifacts." Although valid scientific or engineering devices, their function is not immediately obvious. To solve the enigmas, students become resourceful and reach out to the engineering world and beyond, in part through the World Wide Web; they increase their knowledge and draw this knowledge into engineering. For example, a small steel cylinder studded with sharp trapezoidal projections turns out to be a hob for manufacturing spur gears. The student teams present their research and conclusions to the rest of the class.

Design Project: In the main eight-week design project, students experience the complete design-build-test cycle of product prototype development. Past project themes include:

• Rube Goldberg contraptions to perform ordinary functions in surprising ways;
• "Green" designs to make it easier for the campus recycling center to collect materials;
• Sensors that accurately measure a physical quantity, such as the amount of fuel remaining in a vehicle's tank, regardless of its orientation; and
• Assistive technology devices, e.g. a page turner for an adult with cerebral palsy [2].

• Interactive learning exhibits aimed at teaching an engineering or scientific concept to children, either in a middle school class, or as an exhibit in a youth museum.

Reverse Engineering: A three-week reverse engineering project encourages student teams to learn about realworld design by dissecting and analyzing a product of their choosing. Past examples include:

• Measuring the release force on automatic release ski bindings & correlating it with published data;
• Making an old rusty internal combustion engine breathe new life;
• Successfully creating light bulbs in the laboratory; and
• Dissecting rock-climbing hardware and engaging the designer via e-mail.

The outcomes of this course are tremendous. Entry-level students are introduced to tangible experiences in engineering that stimulate further exploration and demonstrate the context and need for further study in advanced topics such as electronics, fluid mechanics and materials. Students learn to work cooperatively in teams, significantly improve their written and oral communication skills, and gain confidence by completing challenging yet attainable creative projects. Most importantly, students are exposed to the challenging, integrative, and fun nature of engineering early in their college experience.
Preliminary retention figures indicate that nearly 80% of students who took this course during their first year have remained in engineering into their third year, a remarkably higher rate than our 55% average. Students overwhelmingly report that this demanding design course gives meaning to their physics and calculus courses, and frequently cite it as their initial reason for selecting CU, and then for remaining in engineering. Individual students have said, "the applications aspect of the course has kept me in engineering," and "it's using your mind, not plug and chug."

Recognizing the importance of hands-on experience, coupled with the large number of students who transfer into engineering after their first year, we are piloting a new sophomore version of this course in fall 1998. With financial support from the National Collegiate Innovators and Inventors Alliance, Innovation for the Community will focus on the invention and product development process. Students will design, build and test interactive learning exhibits for clients in the local educational community, experiencing first-hand the satisfaction achieved from meeting the needs of real customers with real products of societal value.

Opportunities for Open-Ended Discovery - In the past, sophomores and juniors studied heat transfer without feeling heat, or fluid mechanics without getting wet. The two 4,000 sq. ft. laboratory plazas at the heart of the ITL Laboratory change that. Dispersed throughout each plaza, designed to accommodate 60 students at a time, 15 custom-designed LabStations [3] - each an experimentalist's dream - can access and analyze data from mobile experiments (see Figure 2). Standardized connectors allow pre-wired portable experiments to quickly connect to the LabStation. Each LabStation features an oscilloscope, signal generator, counter, multimeter and signal analyzer, all controlled by two PCs running LabVIEW software [4]. Each plaza features a 260 sq. ft. "smart" break-out space where students gather with the instructor for a short, stand-up discussion of an important nuance, then retreat to their LabStations to continue their experiments. The key experimental and curricular ingredients that provide effective use of these lab plazas include experiential learning - the cornerstone of the ITL Program. Recognizing that the undergraduate curricula cannot accommodate a traditional laboratory component in every course, experimental modules provide enhancements to traditional theory courses. Modules are small experiments mounted on carts that are wheeled to a standardized LabStation. These portable, modular experiments were developed for the interdisciplinary focus areas shown in the concept diagram (see Figure 1) by faculty teams that span multiple departments; many were developed by undergraduate students as senior design projects. Modules are open-ended to encourage learning by discovery. For example, a functioning model of an automobile suspension with variable mass, spring rate and damping, controlled with LabVIEW software, allows students to design, model and observe optimum response characteristics.

More than 35 experimental modules are in various stages of development. They are designed to be:

- of multidisciplinary interest, crossing traditional departmental boundaries;
- suitable for open-ended exploration;
- stand-alone experiments requiring minimal supervision; and
- sequence-independent.

Examples of modules already piloted in courses include:

- Dynamic strain analysis of a mountain bike - a bicycle instrumented with strain gauges allows students to measure stresses in real time.
- Compressible flow modeler - uses water to simulate supersonic flow conditions in air.
- Photoelastic stress - visualizes stress patterns in complex structures.
- Remote sensing - simulates the way satellites sense the earth from space.

Interdisciplinary Focus Courses: Interdisciplinary courses combine hands-on experiences into core engineering theory subjects. One such offering is a junior-level course in basic fluid mechanics coordinated between civil and mechanical engineering. Fifteen experimental modules are utilized; some were developed at CU while others use commercially available fluid mechanics equipment. Fluids courses in aerospace and chemical engineering also use some of the experimental modules. Most of the experiments are open-ended, encouraging students to discover and understand fundamental fluid mechanics concepts by applying them. The College-wide Electronics for Non-Majors course relies heavily on the HP computers and electronic instrumentation.

Hands-on Homework - The assignment of laboratory experiments as homework problems provides students with an alternative mode of learning that permits practical reinforcement of theoretical concepts. Supported by a grant from NSF, hands-on homework (HOH) experiments augment theoretical courses. They are characterized by the use of relatively simple apparatus and materials that are typically available in the home. They generally involve solving a problem analytically, recreating the effect with a simple experiment, describing the experimental results qualitatively, or in an approximate quantitative way, and contrasting observations and analysis. Examples of concepts and simple materials used for exploration in HOH exercises in the area of fluid mechanics include:

- instabilities of viscous flow down a sloped surface using salad oil and a cookie sheet
- buckling flows using liquid detergent poured onto a flat plate
- standing hydraulic jump in the kitchen sink
- sequence-independent.

Thus far, 27 HOH are developed, 9 are in progress, and 16 are in planning stages. These experiments, because of their "low threshold, high ceiling" nature, are highly transportable to other institutions.

Seniors Struttin' Their Stuff - Capstone design projects form the ultimate integrating educational experience, allowing seniors to apply the knowledge they have acquired...
to open-ended design projects with no "right" answer. Adjacent to the lower lab plaza, four capstone design studies provide a highly-visible environment for long-term, in-depth projects with visual appeal. Observing seniors working on intriguing projects stimulates the interest of lower division students and makes them eager for their own design experiences. Each studio is equipped with a full complement of electronic instrumentation and a computer. Student teams compete for the limited space, which becomes their secure working environment for an entire term, or year, depending on the project.

Use of these design studios during the ITL Laboratory's inaugural year was diverse, including:

- "Things That Think", an interdisciplinary Computer Science course in which students created and tested small intelligent devices
- A racecar powered by a motorcycle engine that competed in the national Formula SAE competition in Detroit in May, 1998.
- The Robotic Autonomous Transport (RAT) - a robotic vehicle which can navigate an outdoor course delineated by two white lines and avoid numerous obstacles in its path. This unique vehicle won second place overall in a national competition in May, 1998.
- Human-powered submarine
- Remote micro surveillance airplane

**Modeling the Real World** - Analysis characterizes engineering design, allowing numerical models to accurately predict the behavior of a complex design before it is built. The Simulation Laboratory features 25 high-performance UNIX workstations with simulation software that students use to predict stresses in a complicated structure, estimate heat transfer behavior or model complex fluid flow phenomena. Moreover, students learn that simulation is an integral part of the engineering design and manufacturing process that goes hand-in-hand with testing in the laboratory. Three high-resolution color monitors face out from the lab allowing students to showcase their simulation and animation work.

**Active Learning: An Alternative to Lectures**

More effective than the traditional "chalk-and-talk" lecture format is the active-learning approach in which lecture is minimized and replaced with intense team-based student interactions. Students stay alert, are engaged, and learn more. The Active Learning Center is designed to support the needs of a more student-centered learning approach. Serving 65 students at a time, this reconfigurable "smart" space features oval tables to accommodate small-team interactions.

In fall 1996, the active-learning format was piloted in an Applied Data Analysis course. This required statistics class, with a reputation of being dry and boring, has historically yielded poor course evaluations. In the active-learning format, each 75-minute class period opened with a short Q&A period followed by a mini-lecture introducing new material and a brief example problem. Students then spent about 30 minutes in teams of four conducting hands-on workshops designed to reinforce the statistical concepts being studied. For example, students measured water temperature from drinking fountains, obtaining real data to subsequently compare and analyze with other teams' data to discover trends and correlations. They timed auto traffic outside the Engineering Center and compared their results to a Poisson distribution.

Another difficult required Chemical Engineering controls course was taught using the active-learning format last year. The professor, who had taught this course 19 times previously, received the highest student evaluations (A+) he had ever received. The professor's assessment was that, in addition to being significantly more engaged, students learned at least as much as prior classes.

**Create What You Dream - "It always works on paper."** But, as any practicing engineer can attest, the proof is in the fabrication and implementation of a design. Included within the ITL Laboratory is the capability to build mechanical and electrical components and systems. The manufacturing center contains a wide variety of computer-controlled and conventional machine tools for metal, wood and polymer fabrication, including rapid prototyping with engineering polymers directly from a CAD model. The electronics center allows students to breadboard and test electronic circuits. Technical staff helps students learn to safely fabricate their designs. These shops restore a hands-on manufacturing capability once prevalent in engineering education.

**A Living Laboratory - A modern building is an ideal example of the integration of multiple complex engineering systems.** A one-of-a-kind educational facility, the new ITL building itself is an interactive teaching tool, with the capability to expose, monitor and manipulate the many engineering systems inside. In a hands-on, real-world way, this capability helps to educate both engineering students and the general public about the multidisciplinary science and engineering technology found in today's structures, as shown in Figures 3 and 4 [5].

To demonstrate engineering principles and practice, building elements that are usually hidden above ceilings, behind walls or in equipment rooms are exposed. Interpretive signs highlight these features for the self-guided visitor. For example, the air handling unit that ventilates and cools the entire building is visible behind a glass wall. A prominent design feature of the laboratory is a five-foot diameter duct and its myriad of branches that carry the HVAC air supply throughout the three-story facility. Several types of concrete and steel structural framing are conspicuous, including a yellow 40-foot truss spanning a large bay. Even before its completion, the truss and large exposed ductwork have inspired many such questions from visitors. Numerous transparent "slices" reveal the building's infrastructure, including water flowing in a transparent pipe, the elevator shaft and equipment room, dampers inside a mechanical VAV box, etc. A peek into the wall separating the bathrooms reveals...plumbing, but little else! Reinforcing steel on the outside of one concrete column and beam illustrate and mirror the maze of re-bar hidden inside, making the building itself a tutorial in construction engineering.

From instrumentation placed in building compo

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ments, more than 200 precise measurements are taken in real time to monitor the status of the building systems, thermal environment, structural loading and electrical load profile. An extensive digital network controls the HVAC system and reveals its “pulse” on computer workstations in several locations. Also measured are temperature stratification in a three-story atrium, temperature distribution through five different wall sections, thermal performance of several different types of window glazing, outside soil temperature along the foundation wall, fin tube heater performance, etc. Steel framing and concrete caissons are equipped with strain gauges to measure stresses, and the use of optical fibers embedded in concrete to measure building strain is being pioneered. These data are sampled every minute, and will be accessible on the World Wide Web beginning fall 1998 in a variety of formats.

Manipulation of building systems presents unique learning opportunities. One of the two first-year design studios has conventional pneumatic temperature controls, while the other uses separately programmable direct digital control. Students testing different control algorithms can experimentally manage the climate in the second room. A parallel experimental computer network provides students the opportunity to experiment with network management without jeopardizing the laboratory’s main network.

It is clear that, in addition to its important role in engineering education for CU students, the ITL Laboratory will serve a broader role as a technological museum. In addition to educating visitors about engineering, it will hopefully motivate young people towards careers in engineering. Many “building-as-learning-tool” concepts were utilized in civil engineering courses during construction of the ITL Laboratory, and many courses throughout the College will use this rich capability as they come on-line.

ITL Program Assessment

The College is committed to assessing the total qualitative and quantitative impact on student learning of the tightly coupled facility, equipment, and curricula that represent the ITL Program. Assessment initiatives underway include:

- In-depth surveys, with in-person follow-up if requested, of the 58 faculty who taught in the ITL Laboratory during its inaugural year. Response was overwhelmingly positive, and many suggestions for improvements are being implemented to continuously enhance the learning environment. Students will also be surveyed during the coming academic year.
- Mid-semester group consensus feedback approaches are employed in all sections of the First-Year Engineering Projects course to better understand student needs and to provide input for mid-semester corrections.
- Students who took the First-Year Engineering Projects course are interviewed two years later through focus groups to assess the longer-term value of the course.
- The College engaged the expertise of Elaine Seymour, Ph.D., to evaluate College-wide plans to assess the effectiveness of the ITL Program. Author of the renowned study Talking About Leaving: Factors Contributing to High Attrition Rates Among Science, Mathematics and Engineering Undergraduate Majors, Dr. Seymour is regarded as a national expert in this area.

- Two semesters ago, College-wide questions were added to all the faculty course questionnaires to assess the course content for design, computing, communication, and teamwork components. We are using the results of these questions to chart and assess the flow of each of these elements through the four years of each of our major curricula. This information will next be used to guide departments in revising curricula, as needed, so that all students experience a steady stream of design, computing, communication, and teamwork experiences in each semester of their undergraduate program.
- A $20K "seed money" grant was recently secured for planning and instituting a longitudinal assessment plan to better understand the outcomes of the ITL Program.
- We assess students' attitudes, beliefs and knowledge before and after taking the client-based sections of the First-Year Engineering Projects course. This will help us to fine tune the class and to learn if students are gaining the experiences we expect.
- Mid-semester and end-of-semester qualitative and quantitative assessment are performed on those theory courses that incorporate hands-on, open-ended, experimental modules and hands-on homework to assess the added value of the experiential components.
- Three to five years after graduation, alumni will be surveyed to assess the relative value of various components of the ITL Program on their undergraduate experience. Suggestions to evolve the curriculum to make it more relevant to needs in the "real world" will be solicited.

K-12 Outreach: The Pipeline

The ITL Laboratory is used by University students primarily during the nine-month academic year. This leaves opportunities for summer outreach programs that extend hands-on learning experiences to K-12 schools in order to excite students and teachers about the future of a career based on a technological education. The ITL Program was recently awarded a prestigious $1.4M Program of Excellence grant from the Colorado Commission on Higher Education to foster outreach activities.

We exploit the ITL Laboratory during the summer months for K-12 outreach purposes to:

- develop and implement week-long hands-on science and math workshops for K-12 teachers (using the program design from the San Francisco Exploratorium as a starting point);
- offer a series of hands-on science and math summer camps for fifth, seventh, ninth and eleventh grade children throughout the state;
- develop and pilot an age-appropriate and fun week long fluid dynamics curriculum - "Go with the Flow" for middle school students, and train teachers to...
implement it;
• develop and offer a "Kinetics for Kids" workshop, capitalizing on the stimulating and engaging kinetic sculpture exhibits throughout the laboratory; and
• pilot the Success Institute, an intensive two-day introduction to engineering opportunities for 20 African-American middle school students (and their parents) from Denver.
• Offer an Upward Bound program for 50 Native American high school students, a six-week long program of computer skills, science, English composition, and traditional beliefs, in collaboration with the American Indian Science and Engineering Society (AISES)
• Conduct ongoing field trips and special tours for summer camps and science programs throughout the region.

The intent of the teacher workshops is to develop and export low-budget yet creative and integrative hands-on science and math experiments that can be replicated at low cost in local school districts and applied throughout the K12 curriculum. Improving the knowledge and confidence of K-12 teachers in hands-on math and science impacts many impressionable youngsters. The technology-rich ITL Laboratory serves as an excellent environment for exposing teachers and children to the possibilities that a technological-based future offers, and to make the world of science and technology seamless and approachable to learners from age five on.

The College is committed to developing this outreach program as an effective way to impact the "pipeline" of future scientists and engineers. School children, beginning with kindergarten, will enjoy the ITL Laboratory as a hands-on science museum as they explore the challenges presented by the myriad of museum-quality science-based sculptures.

Lessons Learned

The planning and implementation of a new undergraduate engineering program, and a state-of-the-art facility to support it, has been a tremendous learning opportunity for all of those involved. In order that what we have learned might help others, we offer some tips to bring about change:

• THINK BIG!
• Make it a team effort - practice teamwork
• Find passionate advocates and reward them for incremental change
• Commit for the long haul
• Demonstrate a passion for change
• Pilot curricular aspects early
• Assess impact and advertise early results
• Continuously improve
• Solicit external feedback
• Stay positive - believe that change is possible
• Provide Resources - People
• Broaden faculty horizons (e.g., ASEE, FIE, NCIIA)
• Treat curriculum reform as scholarly activity, and reward it financially
• Provide staff "enablers"
• Force collaboration - e.g., equipment must be used by at least three departments
• Encourage departmental cost-sharing
• Require curriculum development and documentation
• Let faculty determine priorities (within clear constraints)
• Solicit feedback
• Act on suggestions
• Continuously improve
• Recognize and value risk-taking
• Create a safe, trusting environment
• Share the success - give faculty visibility to Chairs and Deans
• Give praise and say thanks... often!
• Make progress every day
• Be clear about what you intend to accomplish
• Focus - like a laser
• Don't confuse effort with results
• Have fun!

Conclusion

The new ITL Laboratory culminates the vision and years of planning and risk-taking by a dedicated team. We first revitalized the curriculum, and then made our dream of a magnificent hands-on learning laboratory to support that curriculum become a reality. Both the curriculum and the laboratory are dynamic, evolving entities. We eagerly look forward to continuing what has driven us - the excitement of learning by doing.

The ITL Program continues to be a leader in undergraduate engineering education reform. The program and laboratory are well planned, well supported, and well understood. The ITL Program prepares students for meaningful engineering careers, both today and tomorrow. At a time when knowledge doubles every seven years, our graduates are better prepared to face the challenges of a diverse economy based on technological progress, international economic competitiveness, communications, and sustainable development. CU will continue to lead the way, and to demonstrate that, given a clear vision of the need and direction for change, a large public institution can take a national leadership role in engineering education reform and thus prepare students to build things that benefit society. We have just begun to tap the possibilities.

References

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Figure 1. ITL Program concept Diagram

Figure 2. ITLI LabStations provide powerful computer and data acquisition capabilities for two teams of students to conduct hands-on experiments.
Figure 3. The machine room is color-coded and visible behind a glass wall

Figure 4: Square D Power Logic monitors electrical system performance
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Summary of Workshop Sessions

E. W. Ernst
University of South Carolina

Preface

The conference organization included not only several plenary sessions for prepared presentations but also three workshops sessions. For the workshop sessions the conference participants were divided into five breakout groups. These breakout groups were together for each of the three workshop sessions. In each of the three workshop sessions all of the groups focused on the same question:

1. How can we use the challenges of the engineering workplace, ABET Engineering Criteria 2000, and the experiences of others to create change at my institution?
2. How can we use information technologies and the experiences of others to create change at my institution?
3. What can we do to implement engineering education reform, and what is my part in doing this?

For the last session of the conference, the leaders of each workshop group presented a brief summary showing the scope and thrust of the discussions for the three workshop sessions of their group. Discussions in each group covered a wide range of topics; discussions in each group included most of the topics discussed in other groups but often with a different perspective, scope, or conclusions.

An Executive Summary of the workshop sessions follows this brief Preface. An edited transcript of the presentations by the leaders of the workshop groups follows the Executive Summary.

Executive Summary

As the conference objectives emphasized realizing systemic engineering education reform, the fact that change and how to achieve change emerged as a major theme for the workshop discussions should offer no surprise.

Process of Change

One group offered a key question, How does the engineering education community move beyond the small fraction of faculty who are change agents to include the next 60%? The groups offered multiple responses to this question that, in summary, seemed to say, Create a culture for change. The process for doing this is not linear but, rather, cyclic and includes: a) develop a vision, b) select and implement innovation and change, c) invest in faculty development, d) collect, analyze and distribute data, e) market your successes, learn from your non-successes, f) broaden the buy-in, g) refine the vision, h) obtain external support to make major changes, i) recycle through the process.

Creating a culture for change and realizing your new paradigm for engineering education require seeking and using the key players for change and the key resources for change.

Key Players for Change

Faculty

Faculty have a central role in undergraduate engineering education. Their role in change and reform is no less central. Faculty need to become involved in the change process; they need to buy-in. In a very real sense the faculty must become the main champions for changing the way that we do engineering education. Proponents for change should serve on committees for the selection of faculty, deans and other administrators. They should not only serve on tenure and promotion committees, but also should seek to change the tenure and promotion processes and criteria. A faculty development program can help enlist faculty as supporters and proponents of change. This can involve mentoring to support developing faculty. Faculty development workshops and seminars should not be sporadic and unrelated but should be consistent and focused to have impact on systemic change. The process should, get the people to change or change the people.

The faculty reward system needs change. Teaching portfolios can be used as part of the assessment and evaluation process and should be linked to faculty compensation. Offer educational grants to encourage the use and the development of innovation. Recognize educational research as a valid scholarly endeavor. Link student, faculty and course evaluation along with other assessment to the tenure and promotion process. Integrate research, practice and teaching in research grants and in courses.

Deans and Campus Administrators

The Dean of Engineering is a critical player in reform and innovation of an undergraduate engineering program. Change agents should seek to enlist the dean in this endeavor at an early stage. Presidents, Provosts, and other campus level administrators are often strong supporters of change in undergraduate education. In some cases they have demanded changes.
Students and Parents

Students along with their parents are usually a very vocal advocate for change in the undergraduate engineering education program. In some cases they have taken a very active role as drivers for change. Students are often more "technologically literate" than faculty; these talents should be used. The structure for reform and innovation of the undergraduate engineering education program should include students. They should be engaged in the process for change.

NSF

NSF continues to exert leadership in reforming undergraduate engineering education. Perhaps they can lead other federal agencies to follow their example and extend their interest in engineering education to include not only graduate education but also undergraduate education. A NSF grant gives significant visibility on the campus to the efforts of an engineering college for reform and innovation of undergraduate programs. NSF funding supplies some of the money needed; campus sources and other resources should supply even more. NSF leadership is regarded as a "carrot." In addition to the funds NSF also provides respectability on campus for these efforts. What NSF has done, and continues to do, impacts a large number of engineering students from these will come many of our future faculty.

ABET

ABET is a major driver for changing undergraduate engineering education. It is a "stick" that focuses the attention of many players and causes them to talk about the need for change along with the need for assessment of what we do in undergraduate engineering education. ABET also provides a structure for involving faculty that may help reluctant faculty to see the need for change. The pressure for change from ABET as a result of ABET Engineering Criteria 2000 may be recognized as valid and accepted by some faculty more readily than the urging from their colleagues. The ABET criteria make us think about the outcomes we seek along with the feedback process we use to change and the kind of and role of assessment for our programs.

Key Resources. for Change

Experiences of Others

Those who have made significant change in their undergraduate engineering programs are a major resource for those seeking to make change at their institution. These paradigm shifters provide a roadmap that allow us to see that significant change can be brought about that it is not impossible. They also show us how they have overcome the difficulties they encountered as they made their paradigm shift, giving us confidence that we too can move beyond adversity to success. These experiences provide much relevant material. Some way should be found to make that material, those success stories, more accessible to others.

Lessons Learned and Problems Solved

The future can be described in terms of the possible, the preferable, and the probable. We know it's possible—we have seen that. We know it's preferable—that is the NSF action agenda. Now— we should make it probable. Let's do it.

Be patient; it's a long-term process. Be a good listener. Be a messenger. Be flexible.

A model for change: a) identify the institutional culture, b) identify the barriers, c) find the champions, d) define and implement a support system for change, e) institute assessment and reporting.

Be passionate. Organize change around themes such as Texas A & M's theme of conservation or Columbia's theme of information technology. Recognize undergraduate teaching.

Information Resources

Making change—changing your paradigm for undergraduate engineering education requires ideas and perseverance. It also requires a lot of information. Faculty, both those on your own campus as well as those from outside, can provide much useful information. Publishers are a regular provider of information for many of our endeavors. Our change efforts are no exception. Students are a significant source of information particularly about the use of computers and other information technology tools. Those on the university staff can help us learn about the use of technology and the use of new software. NSF in its role of leadership in reform of undergraduate engineering education has generated a significant amount of information and makes it available to us. The World Wide Web is a significant source of information not only about reform in engineering education but is also in terms of the information needed as instructional materials for conducting a revised program. Information about what others have done is crucial to moving ahead in reform of our educational programs. We should buy, beg, borrow, or steal whatever we can.

Assessment

Assessment data provides a means to enable change from what we are doing now as well as for the changes as we institute them. We should assess, assess and assess and compare the results with what we see elsewhere and what we have done before. The outcomes that we seek are outcomes of the reform. For example, when we seek reform of the faculty reward system, a revised faculty reward system is the outcome we seek. The current ratings for schools such as the U.S. News and World Report ratings and the Research Council Ratings consistently fail to give an accurate picture of the relative value of the educational program for students. We should develop ratings of undergraduate engineering programs for schools as alternates to these and other existing ratings.

Information Technology

Information technology is another driver for change. It will allow us to escape the physical boundaries of the cam...
pus and thus enlarge the number of people served and will enable us to reach the growth areas of continuing education, life-long learning, and non-traditional students. It also enhances the quality of learning and enables us to accommodate different learning styles more readily than we do now. Information technology itself cannot eliminate bad instruction. Bad instruction with information technology is just bad instruction more widely available. We have enhanced information technology tools. This allows us to use realistic problems in our instruction, to reach out to the different learning styles, and gives us access to a significantly larger information base. Information technology has been done in isolation in the sense that the various ways in which information technology has been used to improve engineering education have not been integrated. We should integrate the way we use information technology in our instructional programs to improve the impact of the information technology in these programs. We should examine the impact of information technology on learning. Several advantages for information technology are: just in time learning, animation and visualization, tutorial aids and drill work, database access, interactive learning. Information technology also brings with it some potential pitfalls: loss of face-to-face interaction (both student/faculty and student/student interaction), DO NOT use information technology as "do it for the sake of doing it." The lack of hardware and software uniformity provides some unexpected potential pitfalls.

Instructional Materials

We need more emphasis on using instructional materials developed elsewhere. The current emphasis seems to place an unwarranted level of emphasis on developing your own instructional materials. Dissemination of instructional materials that have been recently developed will be significantly improved if schools will seek out the materials rather than waiting for them to be offered to them by a provider. We should motivate the developers of instructional materials to make their materials available in a condition for use by others. NSF should require this for materials developed with NSF funding. Perhaps NSF should provide funds solely for this step in the development and use of new instructional materials.
We have printed everything from our workshop and have summarized the results of lessons learned. Basically it's "let's do it." We know it can be done. I'd like to relate to the talk I gave at the Action Agenda Workshop two years ago in which I framed things according to some work I had done at the Futures Institute at SRI. I said we can describe the future in terms of the possible, the preferable and the probable so I'll sum this to say, we know it's possible: we've seen it; we know it's preferable: that's the action agenda; but now let's make it probable. In terms of moving forward, these are some of our recommendations. The NSF has really taken a key leadership role in this whole process. They need to continue to do so but they should spread their vision to other government agencies that fund us (e.g. EPA, DOE, DOD). These agencies have more focus at the graduate level but it must be expanded to include the undergraduate level as NSF has done. Progressive changes in engineering education reform at the military academies may help drive change at DOD.

Industry is in a unique position to effect change using ABET EC2000 to push for change. There is a need to encourage industry to take a leadership role. We are listening more to them through our industrial boards. But, industry representatives on our team said industry has to be asked and we have to listen to them. We can play a role in deciding which faculty to hire and hire those open to change. In other words, "Get the people to change or change the people." And we have the power to do that.

"Thought leaders" or "change agents" (I'll be using that interchangeably) faculty need to serve on budget committees, review committees, and others. We could change the promotion and tenure criteria and evaluation processes. Let's really push the envelope to develop merit criteria for educational scholarship. Develop faculty evaluation criteria that address these reform efforts such as the integration of research and education. Find ways to align faculty research goals with educational goals so we're not doing double service. Some parts of what we are doing should be aligned along the same vector. "Change agent" faculty should get more involved in the selection of our deans and administrators. We can serve on those search committees and decide who become our deans and our administrators.

We also recognize (particularly with ABET allowing this) that students can be developed to be drivers for change. In the University of Colorado example it was actually the students that first walked into the dean's office to say, "we need change." That's a lesson to be learned. One major barrier to educational reform is the drive by deans to be ranked high in the external rankings, like US News and World Reports. These are heavily weighted toward research. Everybody criticizes those rankings but we haven't provided good alternatives. We have the Research Council's rankings of graduate universities. We need to develop alternate criteria for excellence in each of the Carnegie classifications to promote the best of class in each classification. This should lead to a "best in class" ranking system in which we give awards or rewards along each of these dimensions.

We need to find better material developed elsewhere particularly in the instructional technology side of it. The AIChE has CACHE and the Needs National Database is another archive that needs to be publicized more. NSF and the National Research Council are working on the National SMETE Digital Library that builds on these efforts. We need to include more problems and modular components in the databases, but we also need to make sure that, whatever faculty develop, they have the motivation to share their material, to put it into something like the Needs Database or the National Digital Library. NSF should require it and perhaps give supplemental funds to insure this. We need to agree that change is necessary, develop a shared vision of the future, and get commitment of top leadership for this vision including Provosts, Presidents and Deans. The Deans need to come from math, science, and engineering and work together to accelerate the integrated plan.

The key question is, "How to get beyond the 20 percent change agents that are here, who are believers and now move to the next 60 percent to influence change?" We concluded we really need to spread the word to other campuses that need help. We need a shared vision from the professional societies, NAE, ASEE, ABET. Individuals representing these groups should share the Action Agenda Vision and have universal credibility. The chair of this effort should have a very high profile. For example, Lew Platt, when he retires from HP, would be such a candidate.

Campus administrators and faculty are listening to ABET. The time is right to accelerate change. We need different forums to actually move the 60 percent.

In our first workshop session we talked about industry, ABET, NSF and other challenges and opportunities. We talked about industry looking for "quick-start" engineers. Those they can hire to start work and affect the bottom line of the industry. We discussed the issue of training versus education. Industry seemed to want relevance in the curriculum. So, is this education or is this training? And then we talked a lot about company size. Every time we have one of these meetings big companies are here, but where are the small companies? They might require a different engineer than the large companies require. We talked a lot about why
they are not here. Companies say they are hiring many of our engineers. Everyone agreed that ABET was a driving force. It is one of the things forcing faculty to discuss issues that we would never discuss before. So we said that ABET is helping us by making us think about outcomes, and also makes us think about the feedback, about how we do the assessing, and this brings us back to the curriculum. NSF limits the risk. We agreed that NSF would not provide all the money that we need. But at least it would provide some of the money so we can manage other things that we should be doing. Also, the visibility of a NSF grant helps us on our campus.

We have learned much from others. These role models show us what others can do. We also discussed the learning curve for doing something new. Starting these projects requires an initial jump-start and the experience of others can help you. We were talking about outcomes and what we mean by the outcomes. Are they student outcomes or what? Then we decided these should be outcomes from the reform. For example, reforming the faculty reward is an outcome. Also, we want to develop cost efficient ways for delivering courses. In all these reforms we must consider cost, the training of faculty and ways to get administration support. These were outcomes that we wanted.

The second day we discussed technology and how to facilitate change. Technology provides enhanced tools and we can now do realistic problems in the classroom. We can provide more information faster and we wonder whether that is good or bad? Technology provides universal access to the best information. Thus, you don't have to be one of the largest schools to have access to the best. And we talked about the learning styles; technology makes it easy to reach out to different learning styles in the classroom.

Who are the key players in the information technology arena? Information technology managers, companies, politicians, educators, those with money, publishing companies, artists. This suggests the crucial question, How do they interact? It seems they don't interact very well. Perhaps the lack of interaction stems from the lack of structure.

The last workshop—today. We asked, "What is your school doing or going to do?" For our summary we attempted to determine what is important. A lot of the baseline reform should be part of the strategic and business plans of either your department or your institution. A lot of us have been doing things but we have not been sharing them. In all schools we have our reform islands. We have multiple pockets of reform at the same institution, but they do not talk to each other. They do not share either within the institution or with other institutions. Many schools have developed many innovations, but are they institutionalized? When we go home, people plan to look at the resistance to change. Where is the resistance and how can I lower that? Use ABET EC 2000 as a driver. Texas and California are going through changes about affirmative action and other actions related to higher education. How do you deal with that in your reform? Many in our group want to reform the faculty reward system. We want to talk with our deans because this is really bothering us.

What have we learned? First, you have to be patient. This is a long-term process so you must have a lot of patience. You have to be a good listener. One of the things the team decided that patience was something learned by the presenters. You have to be a messenger and you have to be flexible while you are trying to change. We ended our discussion today with a model. We asked whether we saw a model in the presentations. First, identify your institutional culture. Then, identify the barriers to change. Second, you have to find the champions. Then you define and implement a support system. Last, you institute assessment and reporting on the whole process.

**Workshop Group Number Three**

Don Kirk, Facilitator (Presenter)
Dushy Sathianathan, Recorder

We decided to break it out in this fashion, to enumerate those that we saw as drivers and enablers and obstacles. In the process of discussing that we agreed that some individuals could be a member of more than one of those groups. The second area was the role of key players. The third and probably the most important thing, was the agreement of our group that we needed to be action agents. In the process of discussing that we agreed that those groups. The second area was the role of key players. The third and probably the most important thing, was the agreement of our group that we needed to be action agents in creating a culture for change. Finally, as the rest of you, we talked about "What I will do at my institution." As far as the drivers were concerned we started off talking about the employers and we saw the things that others saw. First, the workplace is changing because of the widespread and pervasive use of information technology. This occurs not only in the technical sector of the workplace, but also in the business sector. In many cases these are integrated with one another—or moving toward integration. Companies often tell us about their specific skill needs and we weigh training for the first job versus educating for a career. Though absent from our discussion the small businesses that employ more and more of our graduates often require those they employ to be much more flexible and not have very, very specific training. ABET, although recognized as a major driver, was referred to as the stick (in the carrot and the stick). We thought that these were the benefits that ABET was going to bring. Certainly ABET focuses the attention of a lot of the important players and forces them to talk about the need for change and the need for assessing what we do. In addition, the assessment data that we will develop provides the means to inform and enable the change. We recognize NSF and other funding sources as the carrot. In addition to the funding, we felt that they provide respectability on campus, a peer community of teaching scholarship. In addition to the impact of the NSF support on a very large fraction of recently employed students, some of those students will be faculty members of the future. We see that as a hopeful sign.

The experiences of others provide a tremendous

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amount of material and resources. We should find a way to make that material more accessible to people—perhaps in the form of a database. Examples of successes are out there and would help at our own institutions to reduce the “not invented here” syndrome.

Information technology forms another driver with attributes we felt information technology should provide. Two of these attributes concern escaping the physical boundaries of the campus. That is enlarging the number of people who can be served and also reaching the areas identified as growth areas: continuing education, life-long learning, and non-traditional students. In addition, technology can enhance the quality of learning and accommodate different learning styles. Other drivers include: students, faculty, and cost. Cost is a very big driver and will be increasingly important to us. We cannot ignore that. We must also demonstrate that we do well when we do any of these things and we are cost effective. University infrastructure is another very important enabler.

How about the key players and their roles? This is not in any priority order, but university administrators clearly have access to resources, they can provide incentives, they have something to do with the reward structure, they provide infrastructure, and they do a lot of other things. We saw the faculty as doing all of these things. With the common themes of our discussion today, maybe we should have had some of the devil's advocates here to help us sharpen our arguments and to see if we can be persuasive. Perhaps that can be considered for future efforts. Students are often out in front of the faculty in their knowledge of technology and we should really use them, both as advocates and to help those of us who are not as close to the frontiers of recent technology. In addition, we see the coursework provider as being a key player and it really starts with those who write the materials, the software and whatever. We discussed an interesting question, “Who is actually going to provide the coursework of the future?” One could assume it will be the publishers, but this is a very different environment. Publishers would need to perform a service role; this is one that they seem to not really do very well. The software companies may become major players.

We view creating a culture for change as kind of a cyclic thing. This assumes you start without the benefit of a major grant. You (one or a group of faculty) look at what materials are out there. Try to use what is there, don't rediscover the wheel. You invest in faculty development in several areas including: student learning styles and preferences on the basis that bad instruction used with the aid of technology simply makes bad instruction more widely accessible. Other areas of faculty development include the assessment of instructional effectiveness and the use of technology. This should include hands-on experiences. Further, to effect change, provide incentives for use and development of innovation, including information technology based materials.

Develop a partnership with industry to develop case studies that illustrate real-life-engineering applications. As

The last steps in this cycle for creating a culture for change start with refining your global vision. You then recycle through the process again with a goal of obtaining the external support to make major changes.

Finally, we discussed “What will I do at my institution?” The responses varied a little with the institution but included: 1) work to create a culture of change; 2) change my own courses, do what I can in my immediate environment, 3) identify faculty colleagues to work together when you implement these changes and seek major funding support, 4) for people already involved in this proceed on your current course to attain your vision. Some of those involved may be willing to reach out and help others not yet on the path.

Workshop Group Number Four

Jack McGourty, Facilitator
(Presenter) Pamela Mack, Recorder

We took John Prados' comments to heart and said: 1) we aren't going to talk about WHAT, 2) we know we are going to use ABET 2000. We are going to focus on practices that can really help systemic change. We will argue about those and identify both examples within the schools represented in our group as well as others we heard about over the past three days. Then we will talk about what will we do when we get back on Monday. Some conclusions followed. That is what I will share with you.

The first practice area was faculty involvement. We spent a lot of time and focused on how to get faculty buy-in, how to develop faculty in these areas. We identified a range of practices. Let me highlight a few. There are a number of mentor projects that were very supportive for developing faculty and getting them involved in thinking about teaching and innovation. I think Iowa State's Project Learn is a good example. We had a lot of discussion about faculty development seminars. A lot of people have/give seminars and workshops, but unless we find them to be consistent and focused, not just one here and one there, it will have little impact on systemic change. Some of our schools are already awarding special grants to engineering faculty for educational research and teaching. These range from small $5,000 grants to $20,000-$25,000 grants. We advocate using ABET EC2000, but in a specific context. This provides a structure for involving faculty in identifying and defining objectives and strategies and outcomes. This is a great way to get increased numbers of faculty involved. Also, it starts them talking about some of the real important issues. Use technology to intrigue faculty. We heard two extremely good examples that this is an excellent approach as the Columbia example demonstrated. And, finally, junkyard dogs. Some
body said today, "There are some people you just can't turn around." That is true, but we discussed some good examples for capitalizing on highly resistant faculty. These faculty provide a different perspective on what needs to be done, and you can create processes allowing them to debate the issue from the other side. We felt that we should try to harness some of that energy. Be positive.

Reward System. As you would expect, we had a difficult time with this. We had some good preliminary experience with the use of teaching portfolios in our group and the one thing from the conversation was they should be linked to compensation. The state of Florida has a mandated program. There were incremental dollars involved with good examples in the portfolios. The money was not enough to prevent certain schools from following a similar format. A number of people said they had something similar or professorships in the area of engineering education. We thought it was a good idea and sends a very strong message, another way to create change. Educational grants are another form of incentive for faculty: We talked about non-monetary type things, indirect compensation. Again, just like using technology to get them involved you can also use these as an incentive. One thing that Mort did not say was that Columbia, for example, wants the faculty to come in now and is encouraging them and rewarding the use of technology by connecting it with educational research. So there is a lot more of that going on. Finally, we noted that even though we had student course evaluation programs in place, there was no linkage to the tenure and promotion system. We need to re-evaluate how you use course evaluations toward the tenure and promotion process.

The use of information technology was another practice area. We must start thinking about how we are integrating technology. What we have been doing has been a bunch of disparate things, not in any systemic way. We are not getting the kind of impact we should. One of the things that we liked, what he said and we talked about, you could start breaking down the use in two different ways, both in terms of courses and learning and then also in terms of infrastructure. This seemed to also help us coordinate our discussion. A major portion of the discussion was, we really still have to examine some of the real effects of technology on learning. We don't really understand it, we don't have evidence and until we have that evidence it's going to be hard to get the kind of money we need to have the resources and equipment. We also realize in our own discussions and from our own experiences that faculty do not do a good job of integrating it into their courses and the curriculum. It is not mapped with educational objectives and we are not using it as well as we should. We should create processes to help faculty use the technology as our faculty is not that technologically literate. This is especially true when you talk about some of the more sophisticated technology. Columbia uses student technology assistance, using sophisticated students to create a consulting group to help faculty. Use technology to build a web site or as an enabler for assessment, incorporating technology as part of the assessment process.

We discussed integrating research-originally research and teaching, then we added practice, and you can look at some of these things. We felt it was very important to link research, practice and teaching in terms of grant work as well as the courses. We asked each individual on our team specifically what they are going to do when they get back on Monday. Here are some of the responses. Certainly, we all learned we need to market some of these success stories. We need to work with department heads as we felt they were important for creating change. Educate students on what we are trying to do. Work with deans to solicit real commitments. Change the composition of the search committees. We had a lot of conversation, and concluded the search committee seems to be a very good mechanism to get some new blood into the school and to get the kind of blood that you want. There is no silver bullet. We do not find any one practice that is going to make the change we want. You need multiple practices and they need to be integrated and we need to apply them consistently. Otherwise, the momentum will diminish as soon as you stop pushing. Finally, obtaining and marketing evidence is critical.

Workshop Group Number Five
Paul Yuen, Facilitator John Weidner, Recorder (Presenter)
Our discussions covered both change in general and information technology in particular. Although my presentation will be in general terms we had some nice discussions that focused on specific examples. In general terms, I will cover some of the advantages of information technology and some of the potential pitfalls of information technology that may arise. We considered questions about the key players involved in change, who they were and how they interact. Our discussions included lessons learned and problems solved and, finally, the part that we expect to play individually, and what our universities will do collectively.

At this point I can note the advantages of information technology succinctly. These include: 1) just in time learning, 2) animation and visualization, 3) tutorial aids and drill work, 4) access to databases and, 5) interactive learning. We conclude tutorial and drill work, for example, is a big advantage. It allows you to use less class time on drill work and allows time to develop some higher level thinking skills and be more efficient in the classroom. Although we felt there were no disadvantages to information technology, we did recognize some potential pitfalls. First, a loss of face-to-face interaction, either student to student or student to faculty. Do not lose this as we implement this technology. Don't implement information technology just for the sake of doing it. Information technology can't substitute for bad teaching. Make sure you are doing it for the right reasons. Make sure it supports your mission, and supports the ABET goals. For example, loss of the face-to-face interactions may negate some of the things that ABET asks you to accomplish.
with teamwork. There are also some pitfalls with a lack of uniformity in both hardware and software.

Our view of the key players in the change process is a bit different than you may hear from others. We concluded the main champion for this change would be the faculty themselves, and they are the ones to drive it. We identified three other groups as key players. One very vocal group includes the parents, students, and the employers of our graduates. This group are advocates of change. The financial resources available are key to driving the process and, finally some informational resources are necessary for the process of change. The financial resources include the administration to supply incentives for the faculty champions. NSF is another financial resource and industry can supply some funds. As learned from the University of Colorado, the students can supply some financial resources.

We have a lot of information available to help us change. Information resources we can use include: faculty from other universities or from within our university. We don't need to reinvent the wheel. Rather, we need to beg, borrow and steal from what other people have done. Our universities have computer resources and staff that can help us learn about the software or technology. Textbook publishers may be able to help us; they know how to deliver information. The Web is a great resource. For example, ASEE offers a tremendous resource on their web page. NSF can provide information, they can spread the word about the good things being done. NSF can also lend credibility to the process that helps the champions to move forward. Students often know more about information technology than anyone. We should use them as information resources.

Remember the advocates for change including parents, students, and industry. ABET is another advocate for change. Often, the reluctant faculty may realize that ABET requires change. That helps enlist them. At the very least, ABET is less a barrier than they used to be. Then, too, campus administration and government can often be very vocal in demanding change.

One of the lessons that we learned over the last three-days is to be passionate about whatever we do. We should organize around themes like Texas A & M, (organize around conservation principles) or Columbia University (organize around computer technology). Using a theme may help drive the process. Universities must continue to recognize undergraduate teaching and we heard examples of how that could happen. Of course, if we are administrators we can affect change, but as faculty members, as noted earlier, we are part of search committees, we are part of the tenure review process and we can strongly influence how undergraduate teaching is considered. We can learn from others, not only other faculty but, also external review boards, to help us implement change. Outside sponsors are important for supplying the multi-disciplinary teams we need. We need to engage the students in the learning process and also the process of making change. We need to participate across disciplines. We need to be able to make leaps that capture the imagination-sometimes the incremental ones are needed on a day to day basis-every once in a while we need to make large leaps to capture the imagination of other faculty and legislatures and sponsors and others. Also, we need to understand the local culture so that we know better how to make changes work.

Finally, we asked "What part we can play individually and collectively as a university?" Our part should be, Just keep an open mind to what is going on. Listen to people that are negative as well as those that are positive. Be a risk taker. Be an evangelist. Adopt and adapt to the changes that are going on. Do a good job personally (set a good example). If you are doing innovative things and doing a good job in the classroom, those things will spread. Pay attention to detail so that your changes don't suffer from lack of detail. Listen to all the feedback that you are getting, and be receptive.

As for what the institution should do, we felt developing a vision was very important. This lets you know where you are going. Bring in outside advocates (NSF or a consultant, or review boards). Embrace change. Broaden the buy-in. The University of Colorado demonstrated this, as they brought different people in (to serve on a committee) to broaden the support and not just have evangelists on these committees. Convince faculty that it is in their enlightened self-interest to change. Get administrative support. Broaden the acceptance of scholarly educational activity. Somehow, our community must recognize that educational journals can be (and are) as scholarly as disciplinary research journals. Finally collect, analyze and distribute data. This, of course, ties into the scholarly aspect. You wouldn't publish a disciplinary research paper that didn't collect and analyze data. We need to do a more scholarly job of assessing and evaluating our programs so they have scholarly creditability.
Edward W. Ernst
University of South Carolina

Introduction

Engineering education seems to prefer that engineering-what engineers do-speak for their work and have not created a large body of literature to help those new on the scene to understand what engineering education has been and how it has changed over the past century or more.

Engineering education has a long history of self-examination, seeking better direction and better guidance for the education provided engineering students. This self-examination has included conferences, studies, and reports. This review of engineering education selects reports of studies, proceedings from conferences, and other related documents to understand what the authors perceived engineering education to be doing and where the enterprise should be headed. The selection includes 39 documents from the period 1981 to 1997 as the literature portray a period of significant change with new directions and new thrusts emerging.

Attachment 1 lists these references. Attachment 2 includes a brief summary of each of these documents. The remainder of this paper focuses on the relationship among the documents. (th e slides for the presentation follow this paper.)

Several things happened to engineering education beginning about 1975. The plot in Slide 1, taken from [2] shows the changes in BS degrees in engineering from 1930 to 1978. The regression line indicates an increase of 1,200 degrees per year from about 1935. Except for the Post-WWII peak, a band of plus or minus 15 percent about the regression line bounds the variation.

The graph in Slide 2 uses more recent data and plots the BS degrees from 1966 to 1996. For the decade 1977 to 1986 BS degree production doubled from about 39,000 to about 78,000, an increase of over 4,300 BS degrees per year. This large annual increase was sustained longer than other increases of the past.

Another graph from [2] (Slide 3) shows the undergraduate enrollment in engineering doubling over the 1973-1980 timeframe with a faculty size increasing by only 10 percent. This rapid expansion in the student population without a corresponding increase in the size of the faculty was, in part, responsible for motivating the early examinations of engineering education used as background to this conference. However, the issues raised were broader and continue to echo in more recent examinations.

The shortage of faculty for engineering schools was one of the more visible and difficult aspects of the various items that were included in the description of the crisis in engineering education by the National Research Council (NRC) [6] and the American Society for Engineering Education (ASEE) [10]. Indeed for the NRC [6] the perceived crisis in engineering education was a strong factor in the motivation for undertaking the study. And while the NRC [10] indicated that the stress seemed to have been reduced and the situation was improving, it was nonetheless concluded that action for change in engineering education was needed. ASEE [10] perceived that the crisis emphasized the need for new directions in engineering education.

In two additional studies by the NRC [7, 9], the question considered was whether institutions should reduce enrollment to that appropriate for the faculty and other resources available or maintain the enrollment at the expense of the quality of the educational experience. Both reports concluded that quality should be maintained even though the numbers of students must be reduced.

Content and Context

Several studies, reports, and commentaries [6, 7, 10, 14, 16, 20, 24, 26, 31, 32] advocated a curriculum that offered significant breadth beyond the technical discipline. Even within the technical part of the curriculum, an NRC study [7] as well as a recent NRC report [32] urge flexibility and more attention to the use of the computer in engineering courses in addition to the call for better, more relevant labs.

Following the Grinter Report [1], engineering curricula included an increasing amount of engineering science that emphasized analysis and specialization of the technical content. Two sources [20] and [22] note this and recommend that integration be recognized as a central thrust of engineering and engineering education be designed toward this end. Indeed, the vision statement of NSF’s Directorate for Engineering [22] urges engineering to take the lead in integrating science and engineering. Representative George Brown supports this view when he makes an eloquent plea [26] for engineering education to develop a generation of Global Engineers who will impact not only the technical but also the economic, political, social, environmental-the context. They are to integrate not only content but also context.

The importance of context for manufacturing is noted by an early NRC study [5] but with less emphasis than in the later papers. Bordogna, Fromm and Ernst [20] note that engineering’s core lies in integrating all knowledge to some purpose. The NSF workshop [33] called for, "...comprehensive reform of undergraduate education...across the campus..." Another NSF workshop [34] urged,"...systemic, substantial, holistic curriculum reform..." and "...bold experiments in the educational enterprise..."

By 1985 many of the leaders in engineering educa
tion recognized career-long learning as fundamental for engineers. Rapid changes in technology demanded frequent updates just to keep up. Many also recognized that the technological knowledge base needed for an engineering career was so large that a student could not be expected to learn all that was needed for the diverse job market. Rather, learning throughout the career would be needed. An ASEE task force [12] supported this objective, with a slightly different slant when it offered that, "... The four-year undergraduate engineering program should be designed by engineering faculties to provide the knowledge base and capability for career-long learning..."

Conferences representing independent technological universities [16] and the engineering deans [31] added to the need for a knowledge base and capability the need for the graduates to have the motivation and the commitment for career-long learning.

ABET Engineering Criteria 2000 [39] expect graduates to have, "... a recognition of the need for and an ability to engage in life-long learning..."

For many years the question of whether the baccalaureate should be four or five years in length was debated. These reports [12, 24, 31, 32] seem to come down on the four-year side of the question. However, they all also counsel that most engineering graduates, including those seeking technical careers, should continue on to the masters degree. Most emphasize that the masters degree in question should be a practice oriented degree.

Realizing the New Paradigm for Engineering Education

Engineering Education Issues

There are several issues associated with engineering faculty. The NSF and the NRC [18, 22, 32] express concern that the present recognition and reward systems do not encourage faculty to participate nor strive for excellence in undergraduate teaching. Boyer [15] claims that current views of appropriate scholarship for faculty are much too narrow, focused on the scholarship of discovery. To this he adds three other forms of scholarship: integration, application, teaching. The data he gives showing the dominance of research (the scholarship of discovery) in the view of faculty is not surprising to many of us, even though we wish it were not so.

Boyer also notes that faculty renewal (development) is essential. In this regard, ASEE [10] notes that faculty development must be a structured process and states [12] that faculty development is the responsibility of the faculty member.

Two NSF workshops [33, 34] concluded that engineering education needs a new system of faculty rewards and incentives.

An ASEE study [12] asks whether the nation and the engineering profession would be better served if the resources available were devoted to fewer better schools. An earlier ASEE study [10] urged that new Ph.D. programs in engineering not be started but existing programs be expanded to meet the needs.

Discussion at an ASEE workshop [31] noted the need for an array of tools for assessing the quality of engineering education programs, reflecting the demands for accountability from various publics of engineering education.

The need for assessment and accountability for engineering education becomes much more visible with ABET Engineering Criteria 2000 and with similar expectations for outcomes-based assessment by the regional accreditation agencies [37].

This same ASEE workshop [31] noted the increasing fraction of graduate students who are foreign nationals as well as the increased fraction of the Ph.D. degrees awarded to foreign nationals. The NRC's Board on Engineering Education [32] suggests that more US citizens should be encouraged to enter graduate school and continue to the Ph.D.

One of the task groups reported in [31] offered a professional school of engineering as an approach for resolving many of the problems engineering education faces. This is not a new idea but the format suggested and the timing may make this worth more than passing interest.

At the ASEE workshop [31] the group on reinventing Teaching/Learning reported an emphasis on learning uncharacteristic of the early reports. Both ASEE [31] and the NRC [32] note the broad range of career opportunities available to graduates of engineering programs. That most engineering graduates do technical work (engineering work) for only a few years after graduation, or not at all, appears to have had little impact on the curriculum. What graduates do is broad in function including: technical, management, marketing as well as in disciplinary areas such as: medicine, law entertainment, finance, and the service industries. This is consistent with the view offered by [20] that engineering educators should, "...place primary emphasis on the development of students as emerging professionals..."

U.S. Economy Issues

An early NRC study [5] found that the difficulties faced by the manufacturing sector of the US economy just prior to 1985 caused much concern. Manufacturing had been doing so well that the need to recognize manufacturing engineering skills as high priority ones to be highly rewarded did not seem important. Manufacturing engineering is seen to demand both technical skills, usually found in engineering graduates, and business management skills, found to a much lesser degree in engineering graduates. ASEE recommended that "...the full scope of the manufacturing process be enhanced in its visibility, with research seen as an integral first step..."

Global Future

An NSF workshop [19] noted that, "...the deterioration of the nation's (civil) infrastructure is a serious problem with profound consequences..." Another NSF workshop [21] noted that in economic terms the US has a huge investment in infrastructure: $1 trillion in physical infrastructure and an additional $1.1 trillion in the infrastructure stocks of utilities. Each year about $50 billion is added to the public infrastructure stock. Human infrastructure is noted in...
An NSF workshop [14] presented engineering education as a key for retaining US technological preeminence and, hence, US competitiveness. Although Representative George Brown [26] notes that engineers as leaders are needed by the US, conferees drawn from technological institutes noted [16] the perception that engineers, upon graduation, do not aspire to nor attain major leadership positions.

The need for partnership among business, governments, and academia emerged as a common thread at the World Economic Forum [23]. Winfred Phillips, Dean of Engineering at the University of Florida, [30] notes the need for partnerships between industry and engineering schools. As a related matter, the concerns for manufacturing engineering education, as reported by the NAE [5], must be seen in the relationship of engineering and business schools, and industry.

The NSF workshop on systemic engineering education reform [34] makes a strong plea for partnerships involving engineering colleges/industry/government laboratories. The documents related to ABET Engineering Criteria 2000 [36, 38] as well as the criteria [39] imply and urge closer links between the engineering colleges and the employers of the graduates.

At the 1993 Industry Summit sponsored by the World Economic Forum [23] Throw notes that, "It is just as important to have a numerate public as a literate public." The report [32] from the NRC's Board on Engineering Education offers, "... it is essential that all members of society understand the nature of technology, how it has transformed the modern world, and what are the contemporary issues involving engineering that are significant for the future of our culture." The paper adds, "For engineering education to make a positive contribution to this issue, technological literacy must be adopted as a mission for engineering education by those in engineering education." Norman Augustine, CEO of Lockheed Martin, notes [24] that, in this increasingly technical world, our leaders must understand the technological and scientific issues involved if they are to make informed decisions. He notes further, "Can Americans choose the proper leaders and support the proper programs if they themselves are scientifically illiterate?" A report of the nations premier young researchers [18] suggests that, "...the US educational infrastructure is ill-prepared to meet the challenges and opportunities of the next century..." The report adds, "The faculty in higher education have a special and critical responsibility. Higher education provides the professional preparation of many of our nation's future business leaders, public officials, socially concerned citizens, and virtually all engineers, mathematicians, and scientists, including those who will become future faculty at all educational levels."

The world's environment was offered by Industry Summit [23] as a pillar that supports the ambitions of the world's industries and government and is, at the same time, a pillar that is threatened by these industries and governments. The NSF Engineering Directorate [22] includes protecting the environment among the nation's most pressing problems. The AAES Policy Statement on Engineering a Sustainable Future [27] notes that the guiding principles for a sustainable future anticipate a more assertive role for engineers, one that will require them to be more involved in political, economic, and social aspects of development. Support for this view is given by Frank Spallit of the National Engineering Consortium [17] when he notes that a sustainable future is threatened by the closely coupled Four E's: Environment, Education, Energy, and Economics.

The report of the 1993 Industry Summit [23] states that, "...a new distribution of economic and political power would be the cause of substantial structural transformation of industry over the coming years..." In [28] Allen Blinder was quoted as saying, "We should focus on human capital, not capital...there is mounting evidence that rates of return on human investments are high..." Central for Robert White, Chair of the National Academy of Engineering [25], is that technological advance has been the most powerful job creation mechanism society has devised. Historically, technological advance has created jobs faster than they have displaced them. The present stagnation in job growth is strongly influenced by economic, trade, and political forces, and much less so by technological change.

Academic Future

The NSF workshop [34], Engineering Criteria 2000 [36, 38, 39] along with the earlier NRC study [32] and ASEE workshop [31] all describe an engineering education enterprise much different than even the recent past with an academic culture that values integration as well as specialization, teamwork as well as individual achievement, and educational research as well as research in the engineering sciences. Enabling such a culture change is undoubtedly the greatest challenge facing engineering education reform.

None of the reports draws a picture of the urgent need for radical reform of higher education as sharply as the essay by Eli Noam [35]. The first two pages offer a bleak scenario for the future of the university. The last page offers a new scenario—a change of emphasis. "True teaching and learning are about more than information and its transmission. Education is based on mentoring, internalization, identification, role modeling, guidance, socialization, and group activity...In these processes physical proximity plays an important role...The strength of the future physical university lies less in pure information and more in college as a community; less in wholesale lecture, and more in individual tutorial; less in Cyber-U and more in Goodbye-Mr.-Chips College."
Realizing the New Paradigm for Engineering Education
Crisis

- Faculty Shortage
- Action for Change
- Quality vs. Quantity
Broad Education

- Breadth to include
  - Interdisciplinary
    * Non-technical
    * International
  - Curricular flexibility
    * Computer use
    * Laboratory segment
    * Coop

Content and Context

- Engineering: An integrative process
- Technical and
  * Economic
  * Political
  * Social
  * Environmental
Education: A Continuum

- Career-long learning
  * Rationale
  * In curriculum
  * Knowledge base and capability
  * Motivation and capability

- Four or five years
  * Baccalaureate
  * Masters

Faculty

- Reward systems
- Teaching excellence
- Scholarship
- Faculty development
Structure

• Number of schools, programs
• Assessment tools
• Foreign graduate students
• Professional schools

Students

• Focus on learning
• Broad career opportunities
• Emerging professionals
• Engineering and engineering technology
Manufacturing

- Important to:
  - Innovation
  - Business enterprise
  - Needs visibility
- Vital to US economy

Infrastructure

- Civil infrastructure
  - Human infrastructure
Interfaces

- US competitiveness
- Engineers as leaders
- Partnerships
  * Business, government, academe
  * Industry and engineering education
  * Engineering and business schools, and industry

Technological Literacy

- Public
- Leaders
- US educational system
- Higher education faculty
Global Future

- Sustainable future
- Environment

Economics

- Structural transformation
- Human capital
  - Job creation
"True teaching and learning are about more than information and its transmission. Education is based on mentoring, internalization, identification, role modeling, guidance, socialization, and group activity ...In these processes physical proximity plays an important role."

_Eli Noam_
Future

The strength of the future physical university lies less in pure information and more in college as a community; less in wholesale lecture, and more in individual tutorial; less in Cyber-U and more in Goodbye-Mr.-Chips College."

Eli Noam
References

Thirty-nine documents relevant to engineering education, manufacturing, and the environment were previewed to provide an overview of topical areas for conference participants. What follows is a chronological bibliography, and annotated summaries of the documents in the bibliography.


3. The Undergraduate Engineering Laboratory, Proceedings of an Engineering Foundation Conference, 1983.


23. Report on the 1993 Industry Summit World Economic...
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Forums, In Partnership with the Massachusetts Institute of Technology, Cambridge, MA September 9-12, 1993.


34. Systemic Engineering Education Reform: An Action Agenda, Ernst, Edward W., Irene C. Peden, John W. Prados NSF 96-63 (new)


Summary of Background Documents


The Grinter Report published in 1955 as the Report of the Committee on Evaluation of Engineering Education had a significant impact on engineering education for over thirty years. An appendix provides the complete text of the report.

Engineering Education: Aims and Goals for the ’80s
Proceedings of an Engineering Foundation Conference, 1981

The conference focused on key issues related to the perceived crisis in engineering education, developing for three years prior to the conference. These include a doubling of the number of engineering students with an increase of the resources by little more than ten percent.

The Undergraduate Engineering Laboratory
Proceedings of an Engineering foundation Conference, 1983

The laboratory segment of undergraduate engineering education was an important part of the crisis in engineering education. The conference explored the state of laboratory instruction and noted the changes needed if the laboratory were to be significant for the future of engineering education.

Mid-Course Corrections in Engineering Education
IEEE Centennial Education Forum, 1984

The forum, held as part of the IEEE centennial observations, explored the question, "How should traditional engineering education be modified to make engineering graduates more responsive to the needs of industry and government?"

Education for the Manufacturing World of the Future
National Academy of Engineering
National Academy Press
Washington, DC 1985

This is a report on a symposium convened by the National Academy of Engineering. The following paragraphs are selections from co-chairman Robert A. Frosch's observations and reflections on the symposium. While not a summary of the proceedings in a strict sense, these remarks are an attempt to capture the tone of the meeting that emerged in both formal and informal discussions among the participants, and highlight some of the major points expressed, suggested, and recommended by individual participants and working groups.

From the outset symposium participants appeared to be clearly frustrated about the state of manufacturing engineering and the status of manufacturing engineers. Apparently a major source of this frustration is a distinct (and probably correct) perception that the importance of manufacturing in the process of innovation and in the establishment of business competitiveness had been almost completely ignored for a long time. With the focus of business attention on fiscal and management areas, the art and science of manufacturing engineering have been allowed to decay and companies have not recognized manufacturing engineering skills as high-priority ones to be highly rewarded.

In spite of the considerable talk about the importance of manufacturing engineering, participants felt that relatively little change has occurred during the past several years in the status of manufacturing engineers and corporations, and that the status of manufacturing engineering is only beginning to change within the academic community. Indeed, another theme clearly expressed at the symposium was a good deal of uncertainty about what direction this change should take....

To complicate the matter further, the view was expressed that part of the problem stems from the lack of a good body of theory about manufacturing and manufacturing engineering, making it difficult to construct a curriculum and educational program. This is the case, and it results partly from the problem of how to define a manufacturing engineer, as well as how to answer the question: What body of theory can be constructed for what is not yet defined as a coherent body of experience and operation?

One theme touched upon several times in the discussion -the dichotomy or balance between the engineering and non-engineering problems of manufacturing - may help illuminate the question of theory. Engineering problems describe engineering in the strictest sense: the physical nature of machines, the processes by which machines create a product, the engineering systems that provide the physical designs for machines and processes and control the machines, and the means by which materials are moved and controlled.

Non-engineering problems concern the need to put the engineering side of manufacturing in an overall business context, so that engineering choices make economic sense and relate properly to social questions of health, environment, and the position and relationships of labor, management, and machines. Both speakers and discussants pointed out that a purely technical education in the traditional engineering sense is insufficient for a manufacturing engineer since so much of his or her effort deals with the business and social systems making the manufacturing system work.

Thus a view emerged in both the presentations and discussion that a much closer connection is needed between the technical engineering side and the business management side of education for manufacturing. However, dissatisfaction was also expressed with the existing base of knowl
In stressing another connection, representatives of both academe and industry agreed that the mechanisms used by students and faculty to obtain knowledge of the manufacturing reality and to construct and teach a theory based on that reality, respectively, were inadequate. They also recognized the inadequate understanding that industry people have of the educational process and of the opportunities to influence that process.

Thus the construction of new understanding and of a new curriculum for manufacturing engineering education must be seen in the context of a three-body institutional problem: the engineering and business schools of academia and industrial manufacturing. Indeed, the connections between industry and the university community must include both the engineering and business schools, and these connections may play a role in which these two academic forces work together effectively to produce new systems of understanding and methods for manufacturing.

**Engineering Education and Practice in the United States Foundations of our Techno-economic Future Committee on the Education and Utilization of the Engineer National Research Council, 1985**

This report is one of a set from the overall study by the Committee on the Education and Utilization of the Engineer. Some of the pertinent conclusions of the report can be summarized as:

When the National Science Foundation asked the National Research Council to conduct a study of the education and utilization of engineers, there were widespread concerns that the profession was under stress and that engineering education was in crisis. However, by 1984, data became available that suggested the situation might be improving.

Moreover, the engineering profession appeared to be healthy. It was no longer being subjected to the degree of criticism it had met with in the recent past. Engineers themselves were relatively well paid and enjoyed the lowest overall unemployment rate of any occupation. It appeared to the committee that the engineering community was addressing many of its problems on its own. Market forces and the professions traditional resiliency seemed to be having a salutary effect.

In reviewing these apparent trends, the committee then asked the questions, "Is action required, and, if so, what kind? Will the engineering enterprise in the United States retain its basic health in the absence of action?"

The committee concluded that inaction would pose risks that should not and need not be taken. technological, economic, and social change will continue to intensify and will place even greater stresses on engineering's ability to adapt.

The Executive Summary included 22 recommendations.

Some of these continue to reflect current concerns.

1. Engineering institutions, such as industrial concerns and engineering schools, have proven in the past to be remarkably adaptable, and individual engineers generally have been flexible in responding to change caused by new programs and changing technology. The Committee concludes that there is no need for actions that would fundamentally alter the functioning of this adaptable system. However, there are serious problems of support, of curricula, and of policy and practice that must be addressed if that adaptability and flexibility are to be maintained.

2. A shortage of highly qualified faculty continues to threaten the quality of engineering education. Universities must take steps to make engineering faculty careers more attractive than at present in order to fill vacant faculty positions.

5. If US engineers are to be adequately prepared to meet future technological and competitive challenges, then the undergraduate engineering curriculum must emphasize broad engineering education, with strong grounding and fundamentals in science. In addition, the curriculum must be expanded to include greater exposure to a variety of non-technical subjects (humanities, economics, sociology) as well as work orientation skills and knowledge.

To accomplish this expansion will require restructuring of the standard four-year curriculum by various means. The Committee recommends that extensive disciplinary specialization be postponed to the graduate level. Beyond that, individual engineering schools will have to closely examine their existing curriculum in order to ascertain how the curriculum can best be restructured to accommodate the other important educational needs.

6. The non-technical components of engineering education ought to include exposure to cultural and regional differences so they can design products that foreign markets require and will accept.

8. The Federal government and industry should recognize and support innovative programs in undergraduate engineering education in the second tier institutions (those that are primarily undergraduate-oriented), which annually supply half of the nations engineering graduates.

12. Computers, and computer-aided instruction in particular, should be recognized as powerful educational systems tools. These tools should be applied as rapidly and as fully as practicable in all academic programs in such a way as to enhance the quality of engineering education.

13. Engineers can be productive in engineering work over a longer period if they have access to effective continuing education.

17. While the fraction of women engineering students has grown considerably in recent years, it is still significantly

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lower than female representation in other fields of college study. Likewise, the proportion of women engineers is considerably lower than the proportion of women in other science/technology professions. Therefore, continuing efforts should be made to increase the participation of women in engineering.

18. The Committee recognizes the fine work . . . of the many colleges and organizations which support retention programs for minority undergraduate engineering students. Yet minorities continue to be underrepresented in engineering. Therefore, the Committee recommends that these efforts be broadened.

Engineering Undergraduate Education Committee on the Education and Utilization of the Engineer National Research Council
Washington, DC 1986

This report is one of a set from the overall study by the Committee on the Education and Utilization of the Engineer. The report notes the goals of undergraduate engineering education to be:

• To prepare graduates to contribute to engineering practice by learning from professional engineering assignments;
• To prepare them for graduate study in engineering; and
• To provide a base for life-long learning and professional development in support of evolving career objectives, which include being informed, effective, and responsible participants within the engineering profession and in society.

The Executive Summary includes 19 Findings and Recommendations. Most of these focus on: a) the engineering student pipeline - the number and kind of students expected to study engineering, b) the faculty pipeline - the number and interest of fixture faculty for engineering schools, and c) on facilities, including laboratory facilities. Some of the Findings and Recommendations do pertain to the topics for the workshop.

5. To increase elasticity in enrollment capacities and diversity of educational background of engineering enrollments, a pilot group of colleges and engineering schools should be funded to demonstrate effective structures for dual-degree programs ....

6. To increase their effectiveness and enhance their role, co-op programs need to be strengthened and made more attractive to students. A Considerably stronger commitment from industry is required to eliminate the "boom or bust" character of the programs that reflects a fluctuating economy ....

10. Engineering schools must create specific faculty development programs with shared institutional, industrial, and government funding.

11. Colleges of engineering and professional societies should promote the use of Professors of Professional Practice ....

12. The ability of engineering education to adapt to change depends on encouragement and toleration of curricular and faculty flexibility... The need for educational experimentation must be recognized and given institutional support ....

14. It is of primary importance that the role and significance of laboratory instruction in undergraduate engineering education be emphasized ....

15. A national program of government-industry-college matching grants is needed to address the problem of replacing outdated equipment and maintaining increasingly complex experimental equipment ....

17. Faculty must weave computer use into the fabric of engineering curricula. Administrators must treat this in corporation of computers as a "mainline" activity by allocating a percentage of the budget to the endeavor ....

19. Not only must engineering schools examine and use strategies that will maintain quality under the pressure of the demand for quantity, but they must also plan for the long term to maintain elasticity in the system by encouraging flexibility in faculty and other educational resources.

Undergraduate Science, Mathematics and Engineering Education
National Science Board NSB 86-100
This report is the outcome of a year-long study conducted by the National Science Board Task Committee on Undergraduate Science and Engineering Education. The report provides an analysis of the current (1986) condition and trends in U. S. undergraduate education in the sciences, mathematics, and engineering.

Engineering Technology Education Committee on the Education and Utilization of the Engineer National Research Council
Washington, DC 1986

The Panel on Technology Education prepared this report as a part of the overall effort of the National Research Council's Committee on the Education and Utilization of the Engineer. In its investigations, the Panel studied a number of aspects of technology education. The technical institute movement was examined, and recent developments were noted. The Panel also sought to distinguish between engineering education and engineering technology education, proposing definitions and delineating similarities and differences that might enable better program and curriculum development. As a result of its studies the Panel developed a number of recommendations for action to improve engineering technology education. Some of these recommendations are noted in the paragraphs that follow.

• The Panel proposed that college faculties and administrations should endorse national efforts to raise high school student achievement levels and subsequently raise college admission requirements for engineering technology programs by adopting more rigorous entry standards.

• Students should be advised and actively informed
about the similarities and differences between engineering and engineering technology. Those students who demonstrate superior ability in two-year engineering technology programs should be encouraged to continue their education by transferring into bachelor's degree programs in either engineering or engineering technology.

- Desirable academic and industrial credentials for engineering technology should be identified, and faculty development programs should be sponsored to achieve these standards. In addition, some institutions should accept the challenge of offering graduate education in technologies that will include research in the application and dissemination of technology, and faculty should be encouraged to publish their work on these topics.

- The Panel developed a number of specific recommendations on classes and labs...as a general rule, the Panel recommended that whenever quantity and quality compete, the major focus for change should be on quality.

In addition to the specific technology education recommendations, the Panel proposed the following actions on related issues:

- Cooperative education in all of its forms should be expanded through greater industrial, institutional, and governmental support, with faculty-industry linkages being encouraged.

- "Hallmark" programs in engineering technology should be identified, publicized, and supported nationally.

- Appropriate accrediting agencies should play a greater role in efforts to increase the quality of engineering technology programs.

- Manpower statistics on enrollment, degrees, and salaries should be maintained at the college, state, and national levels.

The Panel considered the impact of high technology to be of major importance in engineering technology education. Computers and computer technology should be recognized as one of the most powerful educational delivery systems now available and applied in all academic programs in engineering technology.

Quality of Engineering Education
Final Report of the Quality of Engineering Education Project American Society for Engineering Education September 1986

The nation's engineering educational system has functioned remarkably well throughout this century, but the accelerating rate of technological change and the emergence of vigorous new competition around the globe have placed system under increasing pressure to adapt. At the same time, recent years have seen enormous growth in engineering enrollments, a critical shortage of faculty in many engineering fields, a shortfall in the number of American students pursuing the Ph.D., and the rapid obsolescence and deterioration of engineering laboratory equipment and facilities. These stresses, taken together, have brought what many have called a "crisis in engineering education" and have threatened a breakdown in a system crucial to America's economic future....

Consultations with many employers of engineers and engineering educators confirmed the idea that the project should concentrate on the excellence of the faculty, the central ingredient in quality engineering education, and on some key aspects of the academic working environment. To accomplish this, the two year project got underway in September 1984 and four task forces were organized.

The Task Force on Preparation for the Teaching of Engineering

The task force was asked to examine the current modes of preparation of engineers for faculty positions, to determine the adequacy of that preparation, and to recommend changes, if indicated. In examining the preparation of engineering professors, the task force found it necessary to ask, first, what it is that professors are expected to do. Answering that question required in turn asking what it is that the professors principle products - engineering graduates - are expected to do.

Employers are generally satisfied with the basic technical preparation of today's graduates, but find them largely unaware of the steps needed to bring new products from the idea stage to the marketplace, and of the vital roles that engineers play throughout. An important reason is that faculty members often lack direct experience in industry or other engineering practice....

The task force believes that engineering education can help to strengthen U.S. competitiveness by placing greater emphasis on the entire process of developing and manufacturing high-quality, low-cost products. It recommends that the full scope of the manufacturing process be enhanced in its visibility, with research seen as an integral first step in that process. Faculty preparation for the teaching of engineering can play a primary role in bringing about this desired result....

Our existing system of engineering graduate schools is thus capable of expanding its production to meet any foreseeable need for engineering faculty, and the start-up of additional Ph.D. programs is not encouraged. Expanding existing Ph.D. programs will be a less costly and more efficient way to increase the supply of highly qualified Ph.D.s....

An aspect of engineering education that receives too little attention in today's crowded curricula is that which imparts an understanding of the international, product-oriented climate in which modern engineers operate. This includes such factors as: satisfying the customer; designing for quality, reliability, safety, cost, and producibility; satisfying societal needs such as conservation of scarce resources and preservation of the environment; effective communications; and ethical action. Cooperative education programs can have great educational value in imparting some of these values, not only because they expose students to actual practice, but because they help provide motivation and direction.

Task Force on Continuing Professional Development of the
The extremely rapid rate of change in engineering knowledge and practice makes it more difficult than ever for engineering faculty to stay up to date. A task force was charged to examine this situation and recommend improvements ....

The rapid emergence of new technologies over shorter and shorter periods of time exerts a constant pressure that affects the ability of engineering faculty to carry out their research and teaching functions with optimum effectiveness.

While performing their multifaceted jobs as teachers, researchers, and citizens of the academic community, faculty members have to try to keep abreast of: 1) progress in their specialties, 2) change in related specialties (new as well as existing), and 3) advances in the underlying knowledge base. They must also be able to anticipate the requirements of the future. This means they must attempt to equip both themselves and their students to adapt successfully to future change and to maintain at all times an integrated awareness of the constantly shifting whole that is engineering ....

The task force concludes that in today's world the continuing professional development of faculty cannot be left to chance. The primary missing ingredient, as we consider how to provide each faculty member with the opportunity to stay current, is a deliberate professional development plan for each faculty member at each engineering college. Faculty development should be a structured process. Yet no model program for such a process exists. Indeed, the task force asserts that no single program could serve as a model for all institutions.

The Task Force on the Use of Educational Technology

The task force was charged with identifying the technology base now available for educational applications, examining previous and ongoing experiments in this area, identifying the important issues, and recommending a viable approach toward integrating appropriate technologies into the nation's engineering educational process over the next decade.

Of the many changes in engineering practice over recent decades, perhaps the most dramatic has been the introduction of the electronic computer. The rapid rate of technological change and greatly enhanced communications (including access to extensive data bases) also strongly affect the way in which engineering students should be prepared for practice.

One of the forces driving the increased use of educational technology is the need to make the educational process more effective - in particular, more cost-effective. Thus, simulation is seen as an alternative to costly laboratory equipment; and electronic "multiplication" of faculty members increases their teaching productivity. The need to make continuing education more accessible further encourages the use of educational technology ....

The task force explored the problems and promise associated with use of educational technology by examining the major issues related to students, faculty, graduates, curriculum, and logistics. Among the many issues raised are:

- How to define computer literacy for the engineering graduate.
- What kind of computing environment should be provided for engineering students.
- The slow pace at which curricula change to incorporate new technology.
- Whether or not advanced technologies are being used extensively enough in upper division courses.
- The need to develop an appropriate reward system for faculty involved in developing and using educational technology.
- Distributed delivery of continuing education to engineers in practice.
- Whether educational technologies are likely to be too unevenly distributed across the engineering educational system.
- Portability of software and courseware.
- Institutional cost of using educational technology.

Task Force on the Undergraduate Engineering Laboratory

The task force was charged with the responsibility for assessing the current and future role of laboratory instruction in engineering education and recommending ways to ensure that laboratory instruction contributes fully to the engineering education process. For at least two decades there has been considerable concern on the part of practicing engineers, educators, and administrators as to whether the undergraduate engineering laboratory even comes close to meeting the various purposes of the laboratory that many engineers and educators expect it to serve.

There are two primary deficiencies in today's undergraduate engineering laboratory programs. The one mentioned most frequently is the lack of appropriate kinds and adequate amounts of equipment. Ample evidence suggests that equipment deficiencies (obsolescence, postponement of equipment purchases, continuing technological advancement, state and federal program cutbacks), along with a lack of appropriately equipped space, have become a problem of the first rank. Operational and maintenance costs of modern laboratory instrumentation have escalated, and yet they are not recognized in university resource allocations. The cost of technician support and related maintenance items such as parts, supplies, and service contracts is often higher than the cost of the original equipment.

The second deficiency is the low level of participation in laboratory instruction by qualified engineering faculty. Laboratory instruction presents two features that make it unattractive to faculty. First, teaching laboratory classes is perceived to require more time for the corresponding teaching load than does teaching lecture or discussion sessions. The time required to develop new experiments, for class preparation, for report grading, for interaction with students, and for scheduled direct student contact is significantly greater than for other types of assignments that carry an
equivalent teaching load. Second, an increasing fraction of the faculty perceive that the time and effort devoted to laboratory instruction will do little, if anything, to advance their professional careers. Indeed, they frequently see such efforts as counterproductive for promotion and tenure.

In seeking to describe the characteristics of excellent laboratory programs, the task force identified several goals and objectives for the undergraduate engineering laboratory:

- First, the student should learn how to do experimental work expected of engineering professionals in the discipline.
- Second, the laboratory can be a place for the student to learn new and developing subject matter.
- Third, laboratory courses help the student to gain an understanding of the real world of engineering, and how to work as part of an engineering team.
- Fourth, the laboratory can provide an opportunity for development of the student’s ability to communicate effectively.

The enthusiasm, capability, and interest of faculty members involved in teaching laboratories are among the most significant factors for a successful laboratory program. Laboratories that appear to be worthwhile, successful and meaningful for the student tend to be those that are handled by faculty who are experimentally oriented, interested in laboratory instruction, and encouraged by their college administrations.

**Engineering Education Answers the Challenge of the Future Proceedings of the National Congress on Engineering Education ABET, 1986**

The congress addressed the many engineering education issues that have surfaced and that have been subjects of reports and studies during the prior decade. These included Faculty Issues, Curriculum Issues, and Issues on Laboratories, Computers and Educational Technology.

The **National Action Agenda for Engineering Education Report of an ASEE Task Force**

American Society for Engineering Education Washington, DC
November, 1987

This study reviewed a number of (then) recent reports that examined the state of engineering education in the United States. The task force selected from the diverse array of topics considered in these reports a number of issues of the greatest importance and urgency to the future of engineering education. In each of these broad areas the task force identified and recommended specific actions. Several of these recommendations pertain to the topics for the workshop.

I. The Overburdened Curriculum

Recommendation-The four-year undergraduate engineering program should be designed by engineering faculties to provide the knowledge base and capability for career-long learning. It should include the appropriate sciences and mathematics and the fundamental concepts of analysis and design....

2. Practice oriented Graduate Programs

Recommendation: At the graduate level, advanced degree programs focused on engineering practice should be vigorously developed by engineering faculties in a variety of technological specialties to complement the currently available research-oriented advanced degree programs in the engineering disciplines. The majority of baccalaureate students who wish to pursue careers in engineering practice should be encouraged to complete such programs on a full-time basis as the appropriate route to a working depth of knowledge and skill.

3. Design/Manufacturing/Construction

Recommendation: The National Science Foundation should continue and expand its current programs in support of design projects. The American Society for Engineering Education, through its divisions, should organize projects to develop and test courses in the methodology of engineering design applicable to both single and multiple engineering disciplines....

4. Instructional Laboratories

Recommendation: Engineering faculty need to re-think the objectives of laboratory instruction and experiments and find innovative ways for satisfying these objectives....

6. Professional Development for Faculty

Recommendation: Professional development and career planning should be recognized as an ongoing responsibility of every faculty member. University administrators should provide an environment which assists faculty members to increase their capability and become more proficient in their technical areas, including both teaching and research.

7. Career-long Learning

Recommendation: Universities, technology-based industry, technology-dependent government agencies, and professional engineering societies should recognize their shared responsibility to develop an integrated system for providing educational services to engineers throughout their professional careers. Such services must be time-effective and cost-effective. Individual schools of engineering, industrial companies, and professional societies need to combine their efforts to ensure an adequate infrastructure and better quality of career-long educational opportunities.

The report raises a concern about the quality of academic engineering programs in the U.S.. Among about 300 schools offering accredited engineering programs, there is a wide range of quality. The question naturally arises whether the nation and the engineering profession would be better served if current resources were devoted to fewer, better schools. The pressure in local communities to create additional engineering schools is frequently almost irresistible to the political structure. Yet a disservice to the community
Report of the Committee on Career-Long Education for Engineers
National Academy of Engineering
Washington, DC 1988

The ability to compete in the international marketplace is determined in critical ways by a nation's resources of engineering and scientific intellectual capital. The high quality of recent graduates from engineering colleges in the United States provides a strong base for formation and growth of this capital. A combination of circumstances, however, may cause the supply and quality of engineering intellectual capital of be United States to be insufficient to meet future goals for economic growth, security, and improvements in quality of life. These circumstances include the fierce worldwide economic competition, rapid technological advancement, the changing pool of people in the United States from which our future engineering personnel is likely to come, serious questions about the quality of public education for young people in mathematics and science, and increasing needs and opportunities for engineers and organizational functions where they previously were seldom found.

Investment in post-baccalaureate, career-long education of practicing engineers can help overcome shortfalls of engineering intellectual capital. Indeed, compared to the investments already made in the resource, the increment for career-long education may be modest and strongly justified. Benefits to the nation and to employers from enhanced programs of career-long education appear to be considerable.

Equally important as a national need is the need for individual engineers to participate in continuous career development. A career typically last 35 to 40 years. The value of professional engineering expertise depreciates rapidly in many areas, so that obsolescence may become a serious problem as soon as three to seven years after completion of formal education. Career-long education helps an engineer perform more effectively on a current job, prepare for a new job, and gain greater personal satisfaction from work.

In the committee's judgment, investment and participation in career-long education remain below desirable levels. This is attributed in large part to the structural reality of a system in which cost and benefits are not always closely tied to one another in space or time.

The committee's principle recommendations are as follows:
1. A nationwide coalition should be formed to coordinate, monitor, urge, and advocate action for career-long education for engineers.
2. The engineering community as a whole must exercise leadership in communicating the concept that engineering education is an integrated system. It must clarify the desired characteristics of the career-long portion of the system and improve the accessibility at other fea
tures of career-long education.
3. All private companies and other organizations that employ engineers ... should design infrastructures that encourage, support, and sustain a policy of career-long education from the highest level of the enterprise through managers and supervisors to the line engineer.
4. Engineering schools should reassess their role as professional schools with regard to the educational demands placed on the B.S. engineering professional by technological advances and other influences, and they should include the career-long education of engineers as part of their mission ....
5. The federal government and state governments should recognize the growing importance of career-long education for engineers and begin to assume more responsibility for it....
6. Engineering professional societies and other independent groups should assume an even stronger leadership in the outreach to individual engineers.

Report on the National Science Foundation Disciplinary Workshops on Undergraduate Education Workshop on Engineering (pages 51-55)
April 1989

Engineering education is of great importance to the well being of the United States. It is a key to avoiding a possible crisis caused by the erosion of U.S. technological preeminence. National action must taken now to reverse this erosion and to reflect current and new realities . ...The goal is to ensure that this nation's system of engineering education yields engineers capable of surpassing our economic and technological competitors in the 21st Century ....

Emerging technologies carry civilization forward inexorably, presenting opportunities and problems of increasing scale and complexity .... The economic implications are immediate. Today's current and emerging technologies soon become commonplace and diffused worldwide . ...As new ones emerge and outstrip the old at a heightening pace, the nation confronts a new version of the adage: "The race is to the technologically swift and commercially astute."...

The principle admonishment of the 1986 workshop report was: "NSF's role will be to encourage and support the intellectual effort necessary to restructure the curriculum and teaching methods in the light of present day and near future technical realities." From this, a vision of undergraduate engineering education through the start of the 21st Century can be based on the notion that the engineer's essential role in organized society is an integrative process, i.e., an emphasis on "construction of the whole," if you will. The primary goals of this educational process are therefore to develop, in as individualized way as possible, each student's:
- Integrative capability,
- Analysis capability,
- Innovation and synthesis capability,
- Contextual understanding capability.

The workshop recommendations are intended to drive sweeping changes in engineering curricula - interpreted in
In defining the scholarship of integration, Boyer gives scholars a chance to make connections across the disciplines and place the specialties in a larger context. He gives scholars a charge to make connections across the research - engineering educators might find the most interest in his discussions of integration and application. We appear to do integration rather poorly or not at all, and we have long been involved in discussions concerning just how applied our research should be.

While Boyer gives some new insight into the meaning of teaching and discovery - the latter being a somewhat expanded view of what we traditionally call research - engineering educators might find the most interest in his discussions of integration and application. We appear to do integration rather poorly or not at all, and we have long been involved in discussions concerning just how applied our research should be.

In defining the scholarship of integration, Boyer gives scholars a chance to make connections across the disciplines and place the specialties in a larger context. He even suggests that we have a responsibility for educating nonspecialists, too.

In his treatment of the scholarship of application, he takes a traditional virtue, service, and expands it to involve an essential link between theory and practice, each feeding and enriching the other.

Once Boyer defines the framework for the reconsideration of scholarship, he provides a lot of information about what academics think of themselves and invites us to, perhaps, reshape the academy.

At the end of Chapter One Boyer writes: We conclude that for America's colleges and universities to remain vital a new vision of scholarship is required. What we are faced with, today, is the need to clarify campus missions and relate the work of the academy more directly to the realities of contemporary life. We need especially to ask how institution

tional diversity can be strengthened and how the rich array of faculty talent in our colleges and universities might be more effectively used and continuously renewed. We proceed with a conviction that if the nation's higher learning institutions are to meet today's urgent academic and social mandates, their missions must be carefully redefined and the meaning of scholarship creatively reconsidered.

New Challenges in Educating Engineers
Report of a Conference presented by Illinois Institute of Technology
June 10-11, 1991

Conference discussions focused in seven panels. A brief summary of each panel attempts to give a sense of the report.

Developing Leadership Through Engineering Education

The following issues were identified and discussed, with the resultant findings and recommendations described in the text to follow: It is a widely held perception that engineers upon graduation, continuing through their development, do not aspire to nor attain major leadership positions, most particularly in the industrial sector. The focus of discussion was the current character of engineering curricula and its underlying philosophy, and whether such as it accentuates or pre-directs the fundamental skill and attitude differences thought to exist between the practitioners of engineering technologies and those who strategically direct and manage the manufacture, marketing, and sales of the resulting products, in a competitive, rapidly changing world environment.

Restructuring Engineering Education: Disciplinary versus Interdisciplinary

Engineers usually become interdisciplinary because their job requires it. A particular product may require design skills from another discipline, which the engineer must now learn. If a company has enough such products, interdisciplinary competence may become a strategic need of the company. On a larger scale, societal needs arise, frequently within a single generation, which call for a new breed of engineers capable of bridging disciplines. An interesting facet of widespread interdisciplinary activity is that it soon leads to a new discipline. Within the university, curricular change whether caused by evolutionary trends, market forces, societal strategies or technological breakthroughs - is not the only route to interdisciplinary education. Significant interdisciplinary can occur also through extra-curricular learning in campus clubs and in social circumstances.

The Engineer as a Professional

Professionalism should receive greater emphasis in engineering education. Building the image of the engineer as a professional will increase the interest of young people, women, and minorities in the field. Universities should take the lead in including women and minorities in professional activities and play a role in expanding the public understanding of engineering as a profession. Time should be allo
Gated in the engineering curricula for formalized training in ethics. Ethics across-the-curriculum is a novel approach for implementing this goal. Students should be taught the meaning of professionalism and the need for lifelong learning to maintain professional competence.

The Value of Career Readiness in Engineering Education

Industry has become an increasingly dissatisfied customer of the university. Employers charge that too often engineering graduates require excessively long apprenticeships. And, in addition to providing such job-specific training, employers find they must address such significant gaps in an engineering graduate's education as a lack of understanding and crucial skills in teamwork, effective communication, the design process, the manufacturing process, and design for manufacturability. Nor do new graduates appreciate the importance of product quality, safety, integrity, and cost. Also at issue is the apparent dislocation or discontinuity in value systems between academia and industry; that is, little correlation seems to exist between test scores/grade point averages and subsequent on-the-job performance. A wide-ranging partnership between industry and academia is required to solve the problem. Both partners need to view education as a continuum. Universities - instead of trying to cram even more technical courses into an already overburdened four-year curriculum to keep pace with the information explosion - must take a more contextual approach, developing in their students an ability to understand the "big picture" and to learn how to learn. Education should also aim to develop in students a commitment to life-long learning and an attitude of adaptability that will keep graduates continually "career-ready" regardless of how particular disciplines change.

Liberating the Engineering Curriculum

The panel considered the challenge of developing engineering curricula for the 21st Century by focusing discussion on five key issues. First, the identification of those things that we are currently doing well, and those that are in need of improvement is prerequisite to any serious action. Second, the function of engineering design in the curriculum was addressed, with emphasis on its permeation throughout the engineering program. Next, the role of liberal arts in an engineering curriculum was confronted, with special consideration being given to the "integration" of the liberal arts component with the rest of the curricula. Fourth, the accreditation process and its role as a driving force for curriculum change was discussed, and suggestions were made for evolution/revolution. Finally, the impact of increasing numbers of non-traditional students in engineering programs was addressed.

Alternatives to Traditional Education: New Approaches and New Delivery Systems

Progress over the past decade in computing and telecommunications has paved the way for a new era of lifelong continuing education in which an engineer undertaking a new project can call up courseware on demand just as he or she might previously have withdrawn a book from a library. The course will be taken on a self-paced basis on a multimedia educational workstation and transmitted from the "courseware library" to the student's workplace via any of the several evolving broadband telecommunications technologies. The student will communicate with his or her professor via a teleconferencing system. While the university remains the natural center from which to support this new era of Just-in-Time Education, its priorities and structure will be fundamentally changed. Faculty will develop and publish courseware just as they presently publish textbooks, and curricular development will be funded and rewarded just as we presently fund and reward research projects. The required technology for this new educational era is either in place or under development. What is needed, however, is to develop the infrastructure in industry, government, and academe to support it.

K-12 Preparation for Science and Technology

We briefly summarize the present inadequate status of science, mathematics and technological education in the kindergarten through twelfth grade classes in American schools. The needed revolutionary change can be made by introducing experiential hands-on learning into the classrooms; by training and retraining teachers in science content and in these techniques; by the introduction of performance-based assessments; by using student portfolios in place of standardized tests for acceptance criteria into science and engineering colleges; and by updating the present 19th Century organization of schools, to use the new technological developments in the classroom and in their operation. These changes will succeed only if the leadership role is undertaken by science, engineering, and education colleges and universities to develop a community of action at the Federal, State, and Local levels. This community must include the whole society making a firm commitment to the importance of every child's education.

Creating our Common Future
Frank G. Splitt
National Engineering Consortium
Chicago, Illinois
September 29, 1991

The clear, present and future danger faced by the world in general, and the United States in particular has to do with two polarities. The first is the ecologic polarity between human activities and the life sustaining capacity of the earth. The second is between the haves and the have-nots - the so-called North-South economic polarity. These polarities are strongly interrelated as they both involve the closely coupled Four Es: Environment, Education, Energy, and Economics. In combination, these ecologic and economic polarities threaten the security of the world at large.

To move beyond today's problems, and to ensure evolution toward a secure and sustainable future for all humanity requires the individual and collective realization that
we are living in a time of transition, sometimes characterized by great chaos and crisis - a time of correspondingly great opportunity - what could be the opportunity of earth's life-time. Successful seizure of the opportunity requires recognition that we are both part of the ecologic and economic polarization problems and a major part of a workable systemic solution.

America's Academic Future
A Report of the Presidential Young Investigator Colloquium on U. S. Engineering, Mathematics and Science Education for the Year 2010 and Beyond
National Science Foundation, January 1992

Numerous reports and studies have expressed serious concerns that the U. S. educational infrastructure is ill-prepared to meet the challenges and opportunities of the next century. The low level of scientific and technological literacy in our society is deplorable, and the trickle of talent flowing into careers in engineering, mathematics, and the sciences from all segments of society is deeply disturbing. The poor condition of our educational infrastructure is not the result of a few isolated, independent, or discipline-specific problems. Its condition mandates fundamental, comprehensive, and systemic changes in the way all of us go about the business of education.

The success of the current national efforts to revitalize engineering, mathematics, and science instruction depends on the commitment and collaboration of a number of communities, including industry, schools, colleges, universities, government at all levels, and the public. Mostly, however, it depends on the faculty in our nation's schools, colleges, and universities....

The faculty in higher education, however, have a special and critical responsibility. Higher education provides the professional preparation of many of our nation's future business leaders, public officials, socially concerned citizens, and virtually all engineers, mathematicians, and scientists, including those who will become future faculty at all educational levels - elementary and secondary schools, community colleges, and colleges and universities themselves. Thus, the faculty in higher education and their commitment to teaching are absolutely critical to the quality of instruction in engineering, mathematics, and the sciences provided to both majors and non-majors on our colleges campuses and also to the quality of instruction in K-12 classrooms through the future teachers they prepare.

We believe strongly that higher education in general, and our institutions in particular, must be committed to assuring high quality instruction for all students in all segments of the American education pipeline. It is crucial that growth, change, and creativity that are so integral to research become equally integral to teaching. Thus, our vision of higher education in the year 2010 and beyond is that faculty in all our nation's colleges and universities will be truly recognized for their individual leadership and achievement in support of broad institutional missions involving instructional scholarship, public service, and research excellence, and for their commitment to provide a quality education for all students at all educational levels.

To assure high quality pre-college and undergraduate instruction in engineering, mathematics, and the sciences for all students and citizens in the year 2010 and beyond, U. S. higher education in general, and the National Science Foundation in particular, must:

1. Encourage and reward teaching excellence, instructional scholarship, and public service as well as research.
2. Increase substantially resources for instructional innovation and curriculum renewal, especially for undergraduate education.
3. Assume primary responsibility for public understanding of science and technology, principally through high quality pre-college teacher preparation and lower division undergraduate instruction.
4. Assure adequate career participation in engineering, mathematics, and the sciences by all segments of society, particularly careers as pre-college or college faculty.
5. Encourage the development of discovery-oriented learning environments and technology-based instruction at all educational levels.

Civil Infrastructure System Research
Report of a National Science Foundation Workshop
April 15, 1992

The purpose of this one day workshop was to determine the need for a national focus in civil infrastructure systems research (CIS) and, if appropriate, to develop a base document for a civil infrastructure research initiative within the engineering directorate at NSF. The issues were discussed in five separate groups. The paragraphs that follow include a brief summary of the report from each of the groups.

Structural Systems Group

Structures provide the skeleton upon which the civil infrastructure operates. As such, issues related to the planning, design, construction, maintenance, condition assessment, and rehabilitation of structures are central to the problem of revitalizing America's infrastructure systems. Because of the complexity of these systems, their special needs for durability and reliability, and the lack of consensus on effective methods for designing, assessing and repairing such structures, research related to these structural issues will have a significant and direct impact on the effectiveness of efforts to rebuild the civil infrastructure. At the same time, it must be recognized that the decision making process related to the infrastructure involves numerous political, economic and social considerations, and that these aspects, and their relation to more traditional engineering concerns, must be incorporated as a fundamental part of an overall research effort aimed at improving the infrastructure.

Geotechnical Systems Group

Geotechnical engineering concerns engineered facilities and natural hazards which involve the surface or sub
surface of the earth's crust. This field includes consideration of the solid, as well as the air and fluid phases of the crust. Examples of the problems that fall within the realm of the geotechnical engineer include: a) landslides and earthquakes, b) embankments, tunnels, and building foundations, and c) ground water transport. The most recent decade has seen a shift in emphasis of the geotechnical engineer towards environmental issues, such as: a) landfills and waste containment facilities, b) contaminated ground water flow, and c) remediation and isolation of contaminated sites. All of these application areas obviously bear on the civil infrastructure, and it is logical that research on this subject involves geotechnical engineering.

The geotechnical group discussions focused on what types of generic areas deserved attention rather than attempting to define specific research topics. Thought was also given to whether or not the market in a certain area was already developed by foreign governments and industries. Many recent innovations in geo-construction have been developed overseas, such as reinforced earth, wick drains and chemical grouting. In such cases it was thought that technology transfer would be important to prevent unneeded duplication of research. Geotechnical engineering has an added significance in view of new technology which expands the use of soil as a construction material, and the growing impact of geo-environmental issues.

Construction and Materials Group

This group recognized that the solutions to infrastructure problems are probably five-percent technical and 95 percent social, political, environmental, and economic. Engineers might be tempted to ignore the 95 percent as something they can do little about, and concentrate on trying to do some good via the five-percent that falls into their technical specialties. Instead, this group recommended addressing the 95 percent head-on. The program/institute should find out why the general public and elected representatives have so much trouble with infrastructure projects and actively oppose them. Some reasons are fairly obvious: high and uncertain direct costs; the disruption and cost to neighborhoods and businesses while work takes place; the impact of completed projects (e.g., a freeway) on familiar environments and valued lifestyles; the effects on the natural environments. Technology could be better targeted to address these concerns and provide positive rather than negative impacts. For example micro-tunneling has proven far less disruptive than open trenching for installing utility lines. Research on lowering the cost of large bore tunneling could permit transportation corridors to be economically moved underground. In other words, while 95 percent of the barriers to solving infrastructure problems may be social, economic, environmental, and political, technology could provide much more than five-percent of the solution if the real issues of concern to the public were identified and addressed directly.

Life-Lines/Utility/Public works Group

The group endorsed the general goals as expressed in a self-study, but noted lack of a definitive objective. The research focus needs to be sharpened. Suggestions made in the structural systems report are applicable to most, if not all, of the life-line systems. The importance of system integration was emphasized to the point of observing that instead of talking about many infrastructure systems, we should refer to civil infrastructure as one system - albeit it is very large and very complex.

Government/Industry/Professional Coordination and Management Group

The group reached general agreement on the following points in the discussion sessions.
1. Research is required in civil infrastructure systems which emphasizes system integration.
2. The complexity of the problem and the intellectual challenge should not be underestimated.
3. The National Science Foundation has a unique role to play in infrastructure research.
4. There are significant barriers to improving the state of the present infrastructure and to constructing more durable infrastructure in the future. One of these is the difficulty of implementing existing knowledge.
5. The deterioration of the nation's infrastructure is a serious problem with profound consequences for the wealth and quality of life in the U.S.. It will take many years to rehabilitate the infrastructure and it is imperative that a research program is commenced without delay to facilitate the process. This program must not only address the performance of individual components, but also the systems aspect of infrastructure construction and operation. It is also important that the needs of future construction are addressed so as to improve the longevity, quality, and reliability of all new infrastructure systems.

Engineering Education: Innovation Through Integration
Joseph Bordogna, Eli Fromm, Edward Ernst

The several reports and papers of the past decade suggesting paradigm shifts in engineering education are shown to reveal a common theme, to wit: engineering is an integrative process and thus engineering education, particular at the baccalaureate level, should be designed toward that end.

Suggesting a change in intellectual culture, the roots of contemporary collegiate education in the United States are traced to their origin and attention is given to discussing the current emphasis on reductionism vis-A-vis integration or, said another way, a course-focused education compared to a more holistic approach in which process and knowledge are woven throughout the curriculum.

Thus, the intellectual mission of educators must include the cultivation of each students ability to bridge the boundaries between disciplines and make the connections...
that produce deeper insights. The complexity and co-mingling of many engineering, industrial, economic, environmental, political, and social problems demand individuals with the technical skills and professional competence in the integrative approach to defining problems with care, seeking alternative solutions for them, and participating in their ultimate application. In other words, there is a need to focus on creating a holistic education for students, particularly undergraduate students, because engineering's core as a profession lies in integrating all knowledge to some purpose.

This context suggests that emphasis in engineering education programs should shift from dedication to course content to a more comprehensive view, focusing on the development of human resources and the broader educational experience in which the individual parts are connected and integrated. This would place primary emphasis on the development of students as emerging professionals with the knowledge base and capability for life-long learning, and make the study of engineering more attractive, exciting, and fulfilling throughout.

**Public Infrastructure Research**

A Public Infrastructure Research Agenda for the Social, Behavioral and Economic Sciences

Report of a Workshop held by the National Science Foundation

Washington, DC
April 21-23, 1993

American's have made and continue to make a huge investment in infrastructure. In 1989, the net stock of physical infrastructure amounted to $1 trillion, and the infrastructure stocks of utilities added another $1.1 trillion. This accounted for 23 percent of the $9 trillion in fixed reproducible wealth in 1989. And each year, roughly $50 billion more is added to the public infrastructure stock by all levels of government. Intelligent management of this huge infrastructure stock and these major continuing infrastructure investments are central to the vitality and productivity of the nation's economy.

**Infrastructure Productivity**

Key objectives of infrastructure productivity research are to determine how infrastructure capital affects economic growth, to identify the future investments that will yield the largest payoffs, and to determine how existing infrastructure can be used to the greatest advantage. There is little agreement in the research community on this important issue of public policy. This provides a powerful motivation for further research on the impact of infrastructure investment on economic and social outcomes.

**Human Infrastructure**

Civil infrastructure systems are central to the economy, but they are only part of the nation's infrastructure. The stock of human infrastructure is less readily expressed in dollar terms, but it is no less important. Annual expenditures on education exceed $350 billion, with expen

**Institutional Effectiveness**

Infrastructure facilities are typically shared by a large number of users. The benefits of infrastructure frequently extend well beyond the immediate user community, and infrastructure facilities frequently extend across local and state boundaries. Infrastructure services are often provided by government; where they are not, perceived scale economies often lead to their provision by one or a few private suppliers. These features of infrastructure bring public institutions to the fore in investment decisions, construction, financing, maintenance, replacement, allocation of benefits among competing users, rationing access to congested facilities, and oversight and regulation of private providers.

**The Long View**

National Science Foundation
Directorate for Engineering
September 1993

In partnership with society, engineering creates, integrates, and applies new knowledge across ever-changing disciplines to create shared wealth, protect and restore the environment, and improve the quality of life. Advancements in the quality of education will give tomorrow's engineers a broader command of science and technology, as well as a rich and holistic context for solving societal problems and creating new products and processes. Our engineers will reflect the rich fabric of life, with all its diversity, and will, therefore, have a better understanding of the world and its people. They will be able to assume stronger leadership roles in government, industry and academe. Continued disciplinary strength and added attention to disciplinary interfaces where, increasingly, new knowledge is created will generate fresh ideas and directions for engineering education and research and boost the synergy between them. Innovative partnerships among universities, industry, and government will help to exploit new discoveries, applying engineering solutions to the nation's most pressing problems, such as renewing the nation's civil infrastructure, revitalizing manufacturing and the service industries, improving health care, and protecting the environment.

There is realization that scientific leadership does not translate automatically into economic and industrial success. There are calls for the academic research community to be more responsive to the nation's needs and to be more accountable to the public. ENG must embrace this change by making its programs more attractive to policy makers and the public. This must be done by enhancing ENG's mission of fostering excellence, quality, and innovation in engineering education and research. Changing operational para
digms and accelerating costs will intensify university focus on the nature of the mix of research and teaching. In the engineering schools, the traditional engineering disciplines are changing, the boundaries becoming increasingly blurred. Schools will become more selective in nurturing their research capabilities and bolder in educational innovation....

In concert with the engineering community, ENG will seek to identify needed changes in engineering education and research and then use its resources and prestige to help the community to progress to jointly identified goals. Change will result in both incrementally steady improvements and "paradigm shifts" such as:

- The cultural (and reward system) of universities to place renewed value on quality education and curriculum innovation in the context of education and research being viewed of equal value and as complementary parts of an integrated whole.

- Changing the role of faculty in the reward system to value the integration, synthesis, and application of knowledge as well 2 the discovery of new knowledge ....

- Quality engineering education is the development of intellectual skills and knowledge that will equip graduates to contribute to society through productive and satisfying engineering careers, as innovators, decision makers, and leaders in the global economy of the 21st Century. Quality engineering education demands a process of continuous improvement of and dramatic innovations in student, employer, and societal satisfaction, by systematically and collectively evaluating and refining the system, practices, and culture of engineering education institutions. The studies, workshops, and papers of the past decade display the following set of dilemmas facing engineering education:
  - Emphasis on analysis/reduction over synthesis/integration in the curriculum.
  - Emphasis on the research mission of academe over teaching and educational innovation.
  - Slow integration of research results into the engineering curriculum.
  - Limited undergraduate involvement in challenging projects in research.
  - Inadequate knowledge of industrial problems, capabilities, and approaches.
  - Introductory courses that cause student attrition, rather than enthusiasm.

Addressing these dilemmas suggests a change in the paradigm underlying engineering education. Most importantly a balance must be struck between the current focus on engineering science by discipline and a fresh focus on the integrative nature of engineering....

As we move into the swifter current of the 21st Century the world grows more exciting, more complex, and more connected. Solutions to tomorrow's problems will require the contributions of many disciplines and points of view. For example, engineering research on renewing the civil infrastructure will have to incorporate knowledge on the human, economic, and institutional context. The same is true for research aimed at protecting the environment, improving health care, and making manufacturing more productive. Because engineering's core as a profession lies in integrating all knowledge to some purpose engineering must take the lead in drawing together the science and engineering disciplines.

Report On The 1993 Industry Summit
World Economic Forum
In Partnership with the
Massachusetts Institute of Technology
Cambridge, MA USA
September 9-12, 1993

The World Economic Forum's first U.S. industry summit confronted the key trends which are changing the structure and competitiveness of industry worldwide.

The 700 participants from business, government and academia divided among 11 industry sectors, ranging from automotive to textiles. These industry-specific sessions among peers provided the core of the summit agenda, and the opportunity to address critical issues at a micro level.

The participants voiced their ideas on innovative programs and technology, with an eye towards globalized world business and settling on "the right mix" of government. In the opening plenary, World Economic Forum President Klaus Schwab told participants there were two reasons for this special summit: First, a new distribution of economic and political power would be the cause of substantial structural transformation of industry over the coming years as the GNP of DECD nations fell below 50 percent of the world's total; second, while world business has become increasingly globalized, world economy has become increasingly unsynchronized.

The need for cooperation and partnership within and among businesses, governments and academia, in the midst of a competitive world and global market place, emerged as a common thread which ran through many of the industry sectors as well as through interactive sessions. John Gibbons, Assistant for Science and Technology to the U.S. President, spoke in favor of the federal government taking a stronger role with the private sector to stimulate industrial restructuring. He referred to the building of an "information highway" as an example of a key area in which the government should work with private enterprise to help the U.S. compete in the 21st Century.

Percy Barnevik, President and Chief Executive of Asea Brown Boveri, called for limits on government's active roles, citing costly subsidies and quotas which result in the loss of jobs. He urged a focus on creating a better climate for business by supporting training and education. "Those countries with the best education will become winners."

One pillar which both supports the ambitions of the world's industries and governments and at the same time is threatened by them, is the world's environment. Ecology as a global concern was introduced by Harvard President Neil Rudenstien at the summit's second plenary. It is an important problem which travels, "We can't just hope for a mar...
Socioengineering

Norman R. Augustine

Remarks: University of Colorado Engineering Centennial Convocation
October 1, 1993

The history of engineering is in many respects the history of the progress of the human race. Today, we take for granted that telephones work, skyscrapers don't fall down, airline travel is boringly safe, automobiles start, electric lights go on when you flip the switch, computers do not make errors in tracking your bank account, and televisions not only bring you more than 100 channels of programming but do so in virtually perfect color and at an enormous data rate.

But despite the many positive contributions of our profession, and despite all the amazing technological innovations that are constantly being produced, many of the greatest challenges for engineers today come from non-engineering sources....

To a not inconsiderable segment of the public, the word "technology" congers up images of Chernobyl, Bhopal and Thalidomide; Exxon Valdez, Challenger and atomic bombs. Too often technology is perceived as the problem rather than the solution, as something to be avoided rather than something to be embraced.

The lesson from this new age is increasingly evident: in this modern era engineers must become as adept in dealing with societal and political forces as they are with gravitational and electromagnetic forces - and, candidly, up to this point I would not give us a passing grade. Tomorrow's engineers must recognize that they are no longer constrained simply by the laws of nature as was generally the case in the past, but also by the laws of the land....

In a sense, we were fortunate in the past, for we became accustomed to being measured by nature itself an unwaveringly fair, unforgiving and consistent judge. Today, in contrast, we are also judged by humans - with all the vagaries, special agendas and inconsistencies that entails....

Socioengineering - the very word to some will seem to be a non-sequitur - combines the elements of a traditional engineering education with the far broader skills needed to prosper in the 21st century, ranging from written and oral communications to political science and from economics to international relations....

More than 30 years ago, C. P. Snow was appalled at the lack of technological understanding on the part of much of the public. ...Only five of 435 members of the U.S. House of Representatives hold engineering degrees. There are none in the senate and none in the cabinet. Of the 50 governors, only three hold engineering degrees.

The danger to all when those to whom we entrust our well being do not understand even the rudimentary technological aspects of critical issues was eloquently noted by the late Isaac Asimov, who wrote, "Increasingly, our leaders must deal with dangers that threaten the entire world, where an understanding of those dangers and the possible solutions depend on a good grasp of science. The ozone layer, the greenhouse effect, acid rain, questions of diet and heredity - all require scientific literacy. Can Americans choose the proper leaders and support the proper programs if they (themselves) are scientifically illiterate?....

What are the key ingredients of an engineering education for the 21st Century? I believe there are ten important
have access to foreign markets, to lower costs or competitive situation, which in turn generates the need to technological forces underlie the intense global communications and air transportation that enable the integration of the global economy. It is modern indirect ways. Indirectly, technological forces underlie the employment both positively and negatively in direct and forces. Technological change affects domestic solely or even largely attributed to technological change. At the time of the Luddite riots in England, (1811) 73 percent of the workforce in the United States was employed in primary agricultural production. At the turn of the century it was down to 36 percent. At present only three percent of the U.S. is so employed. Manufacturing employment as a percent of the workforce reached a peak of about 34 percent in 1960 and has declined since while manufacturing output continues to rise. In the United States employment in the service industries is now about three times that in manufacturing. No testament to the effectiveness of technology as a job creation mechanism is as powerful as this change in the employment characteristics of the workforce in the United States. The present stagnation in job growth cannot be solely or even largely attributed to technological change. As in manufacturing, it is the domestic job displacement in the services industry resulting from technological advance that may be more worrisome... For those that are highly dependent on transactions that can be handled by computer -industries like insurance and banking - the paperless office is no longer a future concept. It is a reality with significant layoffs of employees. Historically, technological advance and the associated economic growth have created jobs faster than they have displaced them. Is it possible that we are facing a historical shift in our expectation that the employment situation will right itself in a time-frame compatible with other social and political adaptations, as it has in the past?... The questions for society are profound. We are witnessing the collision of philosophies and beliefs about economic growth, social equity and technology. As engineers and technologists we are in a better position than most to appreciate the enormous power of technological advance to create new industries and the associated jobs. We should be clear as we weigh in on the jobs issues to assert our beliefs. We will be judged, both as engineers and as a society, by how we respond to the gathering pressures related to technological advance and job displacement. How we respond will determine whether there is a pot of gold at the end of the technological rainbow.

George Brown presents a challenge facing our society and encourages engineers to accept this challenge. This will require a new breadth of insight and knowledge for engineers along with competencies and capabilities not usu-
ally associated with engineering or engineers. The challenge to engineering educators is clear: Educate a new generation of global engineers. Selected paragraphs from his presentation to the National Academy of Engineering Symposium on New Directions in Science and Technology Illustrate his message.

Those new directions (in science and technology policy) must move us from the myriad serendipitous paths of where we are capable of going, to the strategic paths of where we must go if the planet and its increasing population is to survive ....

We know that the global economy, and economic issues in general, will increasingly be the focus of international relations in this new ‘post cold war’ era. The highest priority in this new era must be to redress growing economic disparities in the world, to recognize that each nation needs to share in the global march toward an improved human condition...

There is no question that one of these goals must be environmentally benign technological development. The growing centrality of economic issues on the global agenda has strongly focused the debate on how to achieve economic growth without sacrificing environmental quality...

Undoubtedly, we are at the very beginning of the learning curve for sustainability - a life-pattern that promotes economic and social survivability while preserving the planetary habitat that supports our activity. We must, however, be wary. Sustainable development cannot become distorted to mean each nation sustaining its current standard of living. Poor nations are not interested in sustaining poverty...

There is no question that we need new models for economic development both here and abroad that honor continued growth, but not for the few at the expense of the many, or for any of us at the expense of the environment...

The ideal of industrial production without major environmental abuse, colloquially termed green technology - is not only achievable, it can be made profitable...

Business and industry are making... changes to remain competitive. In the not-to-distant past these changes would have had two drivers - technology and economics. Today, these changes have three drivers - technology, economics, and the environment...

The German poet and philosopher, Goethe, helps us to understand how engineers fit into this new direction. He said, “Knowing is not enough; you must apply. Willing is not enough; we must do.”

This is a role for... (engineers). Engineers are doers, ... problem solvers; your skill is applying knowledge. As such, you become important navigators down the strategic path toward a sustainable future ...

...Engineers know that once a product moves from design to production its characteristics are, for the most part, fixed -including its environmental characteristics...

It is, thus, engineers who will be called upon to consider the environmental impacts of each component of a new design or process before it is added to the production process. We also know that 85 percent of engineering graduates go to industry where they will be the primary designers of industrial systems.

Just as it is easier and more cost effective to reduce waste before it enters the waste stream, so to is it easier and more educationally effective to teach green design throughout engineering education than to retain new engineers in the workplace...

...Addressing this quality issue will require some restructuring of engineering curricula, not just for better quality design but also for environmental design... Engineering schools have a crucial role in moving society toward sustainable activity...

Engineering programs also have a critical responsibility to their customers, both students and the eventual employers and U.S. industry and government, to educate for employability . ...The leadership must come from engineering educators.

So this task of “renovating” engineering education to teach design from the systems approach of industrial ecology may not be accomplished with ease. And yet engineering education is the foundation for achieving a sustainable society. Engineering schools will educate students for the frontier job markets...

As engineers and engineering educators, your task will be to train a new generation of global engineers who will be able to do more than retrofit existing factories with green design, or create new green manufacturing systems for plants yet to be built. They must also possess an holistic orientation to sustainable development so that they will be equipped to influence social change as well as implement technical change...

As engineers you have both the opportunity and the responsibility to influence cultural as well as technological change. There are few professions that have such a clear and direct route for impact on the global community of nations. I hope that each of you will take up that challenge as a personal task. It would be a grand and eloquent service to all mankind.

**Engineering a Sustainable Future**

**An AAES Policy Statement**

Sustainable development has been defined as development or progress that "meets the needs of the present without compromising the ability of future generations to meet their own needs." Articulated in the report of the World Commission on Environment and Development in 1987, this definition was confirmed at the UN Conference on Environment and Development in 1992. Because engineers play a critical role in development, the American Association of Engineering Societies has adopted a policy statement that defines the challenge to engineers and sets forth a series of "action principles" to guide them.

The guiding principles anticipate a more assertive role for engineers, one that will require them to be more involved in political, economic, and social aspects of development. "These concerns require a new thinking about the
nature of development, and demand an expanded role for engineers as part of the decision-making process itself and as agents for change," says the statement, which was approved by the AAES Board of Governors in the spring of 1993. And the principles convey a sense of urgency: "Because the continuation of current development and resource consumption trends may well foreclose opportunities for a sustainable future, we must greatly accelerate the implementation of new sustainable technologies and manufacturing processes."

The AAES statement calls on engineers to educate themselves and the public about the potential impact of what the profession does. It also encourages them to think in terms of integrated systems and find new ways of analyzing environmental and economic relationships. Creating sustainable technologies and processes is the most practical step engineers can take to address the challenge in the near future. Multidisciplinary partnerships are considered essential to achieving sustainable global development: "Public/private partnerships that forge cooperative relationships and place the long term viability of technology in the mainstream of social policy and resource decision-making are a necessary precondition to building a viable future."

(Summary from ASEE Prism, October 1993, Page 13)

Studying for the Future:
Life-Long Learning in Europe, the U.S. and Japan
Leenamaja Oatala
ASEE Prism, October 1993, Page 23-29

The link between a country's education and training systems and its industrial productivity and competitiveness is attracting increasing attention in industrial nations. Allen Blinder, an economics professor at Princeton, was quoted last year in Business Week (July 27, 1992) as saying, "We should focus on human capital, not capital...there is mounting evidence that rates of return on human investments are high. A ten percent increase in the amount of capital per worker would boost productivity three percent. But a ten percent increase in labor quality would gain us seven percent."...

But training to do better in the present job is no longer enough, especially in engineering. In some fields, 20 percent of an engineer's knowledge becomes obsolete every year. In terms of economic competition, it seems safe to say that companies that learn the fastest will win. Employees need continuing education that provides them with strategic as well as operational capabilities if they are to learn the tasks and skills essential to tomorrow's workplace. Faced with rapidly changing technology, engineers need continuous training and education alongside work. That is life-long learning.

Life-long employment with a single company is a declining trend in all countries, even in Japan. Recession, frequent downsizing and mergers, and other economic developments shorten business focus and increase turbulence. Although life-long learning is a major industrial policy in all industrial countries, few countries have a policy for developing technical competence, and even fewer have a policy for life-long learning. In the U.S. the key responsible partner is the individual who invests in his or her better future. In Japan life-long employment focuses training on company needs. ... With the remarkable market changes currently taking place in Europe, there are more life-long learning players than elsewhere, and a reapportionment of responsibilities is taking place.

Today's tough economic situation makes the profitability of training investments a more important issue than ever. ...Finding the correct focus and gaining the best return on training investments are common demands that change company training and will soon impact public education.

While the demand for return on investment and quality of training occurs first in business, shrinking government budgets will change attitudes among universities and in public education. Demand for effectiveness, total quality management, and business-orientation among academics is likely to grow.

Life-long learning in industry has mainly been developed by large enterprises. The development of long-term competence in smaller companies remains a problem. ...Difficulties aside, small and medium sized enterprises play an important role in all industrialized economies and in the creation of new jobs. In the U.S., 2.6 percent of industrial companies have more than 500 employees; 87 percent of companies have fewer than 100 employees. In Japan 89 percent of companies have fewer than 100 employees. Many of these smaller companies result from the initiative and technical inventions of engineers. ...

Because general continuing education usually has more value to an individual than a company-specific program, educational institutions should find they have a new market and a new demand for educational services. If short-term thinking prevails in the uncertain business environment, competence may increasingly become an asset of individuals, who only lend it to current employers. The career plan is increasingly a competence-development plan. ...

If continuing education, life-long learning, and the development of strategic capabilities are organized by society, that is a challenge for universities. Life-long learning needs continuity, which conflicts with the current business trend of flexibility. Universities, usually more stable than companies, can distribute expertise across national borders and across competition barriers, providing a structure for life-long learning.

Re-engineering Engineering Education
W. M. Spurgeon
Frontiers In Education Conference, November 1993

Evidence is abundant that engineering education needs reform. There are far too many cases of uncontrolled floods, water unfit to drink, air unfit to breath, increasingly dangerous bridges, power outages, car recalls, roads that don't last - the list goes on and on. Why must it be this way?
There are many reasons, one being that engineering education has not kept up with the times. There has been an exponential increase of knowledge. Much of the new knowledge is not yet incorporated in our curricula. We do not teach much systems engineering. We do not teach much about the innovation process, which provides new products that lead to new jobs. We do not teach students how to work effectively with political leaders, legal experts, and finance people. There are many knowledges, skills and attributes that are essential for engineering practice but not included in our curricula. An old aphorism tells us why. You can't teach what you don't know. We are not teaching our young faculty what they need to know.

Requirements for tenure and promotion should be changed to require demonstrated competencies in both instruction and engineering. These changes will not be easy to effect, but will go far toward renewing America's technology.

Taking the Lead
Winfred M. Phillips
ASEE Prism, December 1993, Page 52

...Many characteristics of post World War II engineering programs went largely unchallenged until the late nineteen fifties when sputnik put a new focus on engineering science and analysis while increasing interest in engineering...

In the nineteen eighties, Japanese economic successes caused the status quo to be questioned, and management views began to change. Chemical and aerospace engineering programs were once again challenged by cyclic down turns in their industries, and a subsequent reduction in enrollments that lasted into the nineteen nineties. After the Reagan administration reassigned responsibility for urban renewal and infrastructure to the states, infrastructure renewal slowed. A fortunate shift to environmental concerns mitigated the impact on employment and student interest in civil engineering. Meanwhile, telecommunications industry exploded.

Engineering education will need broad shoulders to carry the responsibilities being assigned to it today. Somethings we brought into the nineteen nineties are now seriously challenged, and some are changing. Institutions are taking another look at the four-year undergraduate curriculum that typically takes five years, presents design as a separate (albeit integrating) topic, offers discrete classes and gatekeeper courses, and teaches physical science and math separate from and before engineering. The classroom itself, and the way students learn, is changing. Even the undergraduate professional degree is being questioned, as are discontinuous undergraduate-graduate programs.

Most of us avoid confronting the future by preoccupation with the day-to-day crisis and clutter of the modern university. It is a time, however to look above the desk. What can we expect to see in the future?

• Outcomes assessment.
• Computer prompted learning, along with computer-generated evaluation tools and problem solving.
• Self-paced instruction; teachers as program planners and advisors.
• International issues.
• Continuous quality improvement and ISO 9000.
• Economics and statistics.
• Systems integrations; interdisciplinary approaches, including traditionally "soft" subjects.
• Design throughout the curriculum; environmentally sensitive design.
• Multiple curricular paths and multiple outcomes.
• Stronger chemistry-based and more biology-based programs.
• Three-two undergraduate/masters degree programs.
• A market-driven curriculum; public-private partnerships in the curriculum.

Can U. S. engineering education change to meet the real challenges of the future? Absolutely, yes. The dramatic changes over the past 20 years in electrical engineering alone are sufficient evidence of the responsiveness of engineering to new science, new information and the new challenges of industry. And the engineering college is certainly the university's leader in responding to industrial needs. We must continue this tradition.

But while engineering education has always responded to the need for change, the traditional approach of waiting for a discrete crisis is no longer acceptable. In the new technological world, with its information explosion, instant connectivity, and global markets, industry and engineering education must become partners in the process of change. It is time for a critical examination of the challenges and the delivery, by the partnership, of a plan for meeting them. Our customers demand no less.

ASEE Workshop
Engineering Education in a Changing World
February 24-25, 1994

This workshop responded to the suggestion that engineering education needed to examine the principles that had been guiding its evolution. Although engineering education in the United States has served the nation well, there is broad recognition that it must change to meet new challenges. These challenges include the need to attract a greater diversity of students, as well as the shift from a technology policy strongly focused on national security to one aimed more diffusely at international economic competitiveness, communications, and sustainable development. Moreover, with technology playing a growing role in both professional and public policy decisions, it is important that engineers be prepared to participate actively in decision making processes. Engineering education programs must be Relevant, Attractive, and Connected:

• Relevant to the lives and careers of students, preparing them for a broad range of careers, as well as for life-long learning involving both formal programs and hands

The workshop participants were charged to address the curricular content and the broad academic framework of an engineering education which is responsive to the new challenges of an increasingly interdependent global society. This report is an integration of the reports, the perspectives, and the concerns from the discussion groups at the workshop. An appendix includes an annotated bibliography of 26 papers and reports of the previous decade.

Electronic and the Dim Future of the University
Eli M. Noam

This three page essay paints a bleak picture for higher education if we simply extend the present to the future. He also outlines a happier prospect. Eli Noam is an economist from Columbia University.

"True teaching and learning are about more than information and its transmission. Education is based on mentoring, internalization, identification, role modeling, guidance, socialization, and group activity...In these processes physical proximity plays an important role...The strength of the future physical university lies less in pure information and more in college as a community; less in wholesale lecture, and more in individual tutorial; less in Cyber-U and more in Goodbye-Mr.-Chips College."

The Vision for Change: A Summary Report of the ABET/NSF Industry Workshops

This document is a brief summary of three workshops held during the summer of 1994 about ABET Engineering Criteria 2000 and the implementation process.

Frameworks for Outcomes Assessment, July 1996, Commission on Higher Education, Middle States Association of Colleges and Schools

This 60 page document is designed to assist colleges and universities to meet the outcomes assessment requirements of the Commission on Higher Education and to enable colleges and universities to respond to new expectations for accountability being expressed in public forums.

Engineering Criteria 2000: A Bold New Change Agent
George D. Peterson
ASEE Prism, September, 1997, p. 30-34

A brief overview of Engineering Criteria 2000. These criteria respond to the need to promote the innovation and continuous improvement in engineering education required to meet the challenges engineering education faces.

Accreditation Board for Engineering and Technology

This document includes the general criteria for all programs in engineering as well as the program criteria for
each of the several engineering disciplines.

REALIZING THE NEW PARADIGM FOR ENGINEERING

June 3 - 6, 1998
Omni Inner Harbor Hotel
Baltimore, Maryland

Conference Co-Chairs:
Edward Ernst
University of South Carolina
&
Irene Peden
University of Washington

Engineering Foundation Conferences
345 East 47th Street, Suite 303
New York, NY 10017
T: 1-212-705-7836; F: 1-212-705-7441
e-mail: engfnd@aol.com; www:
http://www.engfnd.org
Wednesday, June 3, 1998

1:00 p.m. - 6:00 p.m. Registration

6:00 p.m. - 7:15 p.m. Dinner

7:30 p.m. - 9:30 p.m. SESSION I
Session Chair: Irene Peden
University of Washington

Brief welcoming remarks
Henry Shaw, Engineering Foundation
Marshall Li, National Science Foundation

Review of reports, studies, conferences on Engineering Education 1984-1996
Ed Ernst
University of South Carolina

John Prados
University of Tennessee

9:30 p.m. - 10:30 p.m. Opening Reception

Thursday, June 4, 1998

7:00 a.m. - 8:15 a.m. Breakfast Buffet

8:30 a.m. - 10:00 a.m. SESSION II
Session Chair: Irene Peden
University of Washington

Keynote Presentation
Joe Bordogna
National Science Foundation

10:00 a.m. - 10:30 a.m. Coffee Break

10:30 a.m. - 12:00 noon SESSION III
Session Chair: Ernest Smerdon
National Science Foundation

Drivers for Change I: Accountability (ABET & NSF), Engineering Workplace
Bill Wulf
National Academy of Engineering;
Art Glenn
General Electric Corporation;
Ed Parrish
Worcester Polytechnic Institute

12:00 noon - 1:15 p.m. Lunch

Realizing the New Paradigm for Engineering Education
Thursday, June 4, 1998 (continued)

1:15 p.m. - 3:00 p.m.  
SESSION IV  
Session Chair: John Prados  
University of Tennessee

Paradigm Shifters #1  
Paul Penfield  
Massachusetts Institute of Technology;  
Richard Phillips  
Harvey Mudd;  
Barbara Olds  
Colorado School of Mines

3:00 p.m. - 3:30 p.m.  
Coffee Break

3:30 p.m. - 5:00 p.m.  
SESSION V  
Workshop #1  
How can we use the challenges of the engineering workplace, ABET Engineering Criteria 2000, and the experiences of others to create change at my institution?

5:00 p.m. - 6:00 p.m.  
Social Hour

6:00 p.m. - 7:30 p.m.  
Dinner

Ad hoc sessions / evening on your own

Friday, June 5, 1998

7:00 a.m. - 8:15 a.m.  
Breakfast Buffet

8:30 a.m. - 10:00 a.m.  
SESSION VI  
Session Chair: Ed Ernst  
University of South Carolina  
Paradigm Shifters #2  
Ed Parrish  
Worcester Polytechnic Institute;  
Nihat Bilgutay  
Drexel Institute;  
Karan Watson  
Texas A&M

10:00 a.m. - 10:30 a.m.  
Coffee Break

10:30 a.m. - 12:00 noon  
SESSION VII  
Session Chair: Henry Shaw  
New Jersey Institute of Technology  
Drivers for Change II: Information Technologies  
Communications Infrastructure  
Steve Miller  
Lucent Technologies
and Anoop gupta
Microsoft; ASL
Infrastructure Tim
Trick University of
Illinois

12:00 noon - 1:30 p.m. Lunch
1:30 P.m. - 5:00 p.m. Ad hoc sessions and/or afternoon on your own
6:00 p.m. - 7:30 p.m. Dinner
7:30 p.m. - 9:30 p.m. Session VIII

Workshop #2 How can we use information
technologies and the experiences of others to create
change in my institution?

Saturday, June 6, 1998
7:00 a.m. - 8:15 a.m. Breakfast buffett
8:30 a.m. - 10:00 a.m. Session IX

Paradigm Shifters #3
James Eifert
Rose-Hulman; Mort
Friedman Columbia
University; Jacquelyn
Sullivan Lawrence
Carlson University of
Colorado

10:00 a.m. - 10:30 a.m. Coffee Break
10:30 a.m. - 12:00 noon Session X

Workshop #3 What can we do to implement engineering
education reform and what is my part in doing this?

12:00 noon - 1:30 p.m. Lunch
1:30 p.m. - 2:30 p.m. SESSION XI

Chair: Irene Peden
University of Washington

Conclusions and Recommendations

2:30 p.m. Conference Adjoumment
Engineering Foundation Conferences

Realizing the New Paradigm for Engineering Education

Omni Inner Harbor Hotel
Baltimore, Maryland
June 3, 1998 to June 6, 1998

Participants List

Ackley, Richard A.
328 Lorena Road
Rome, NY 13440
Tel: 315-337-5649; Fax: 315-337-2941
E-mail: r.ackley@ieee.org

Agogino, Alice M.
Associate Dean
University of California
5136 Etcheverry Hall
Berkeley, CA 94720
Tel: 510-642-6450; Fax: 510-643-5599
E-mail: agogino@needs.org

Anderson, Carl L.
Associate Chair & Director
Michigan Technological University
ME-EM Department
1400 Townsend Drive
Houghton, MI 49931
Tel: 906-487-2551; Fax: 906-487-2822
E-mail: Gander@mtu.edu

Awoniyi, Samuel
Associate Dean
Florida A &M University
College of Engineering
2825 Potsdamer Street
Tallahassee, FL 32310
Tel: 850-487-6423; Fax: 850-487-6486
E-mail: awoniyi@dingo.eng.fsu.edu

Bailey, J. Ronald
Dean of Engineering
University of Texas
Box 19019
Arlington, TX 76019
Tel: 817-272-2571; Fax: 817-272-2548
E-mail: bailey@UTA.edu

Baum, Eleanor
Cooper Union
School of Engineering
51 Astor Place
New York, NY 10003
Tel: 212-353-4285; Fax: 212-353-4341
E-mail: baum@cooper.edu

Beaufait, Fred W.
Coalition Director
Greenfield Coalition
1400 Oakman Boulevard
Detroit, MI 48232-2881
Tel: 313-494-4499; Fax: 313-494-4558
E-mail: beaufaf@focushope.edu

Behbehani, Khosrow
Associate Professor
University of Texas
Biomedical Engineering Department
P. O. Box 19138
Arlington, TX 76019
Tel: 817-272-2055; Fax: 817-272-2251
E-mail: kb@uta.edu

Bilgutay, Nihat
Professor & Department Head
Drexel University
Electrical & Computer Engineering
32’d & Chestnut Streets
Philadelphia, PA 19104
Tel: 215-895-6806; Fax: 215-895-1695
E-mail: bilgutay@ece.drexel.edu

Bordogna, Joseph
Acting Deputy Director
National Science Foundation
4201 Wilson Boulevard
Suite 1205
Arlington, VA 22230
Tel: 703-306-1001; Fax: 703-306-0109
E-mail: jbordogn@nsf.gov

Realizing the New Paradigm for Engineering Education

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Bothwell, Michelle K.
Assistant Professor
Oregon State University
Bioresource Engineering Dept.
116 Gilmore Hall
Corvallis, OR 97331-3906
Tel: 541-737-6313; Fax: 541-737-2082
E-mail: bothwell@engr.orst.edu
Bradley, Daniel J.
Dean
Montana Tech
College of Engineering
1300 West park Street
Butte, MT 59701
Tel: 406-496-4254; Fax: 406-496-4417
E-mail: dbradley@pol.mtech.edu
Butcher, William S.
Senior engineering Advisor
National Science Foundation
4201 Wilson Boulevard
Room 505
Arlington, VA 22101
Tel: 703-306-1308; Fax: 703-306-0289
E-mail: wbutcher@nsf.gov

Callahan, Anita L.
Associate Professor
University of South Florida
4202 East Fowler Avenue
ENB 118
Tampa, FL 33620
Tel: 813-974-5577; Fax: 813-974-5953
E-mail: callahan@eng.usf.edu

Caplovitz, Abigail
ICIS Research Assistant
ICIS
Civil Infrastructure Systems
269 Mercer Street, Room 204
New York, NY 10003
Tel: 212-995-4165; Fax: 212-995-4165
E-mail: apc211@is8.nyu.edu

Carlson, Lawrence E. University of Colorado CB 427 Boulder, CO 80309-427
Tel: 303-492-7698; Fax: 303-492-3498

Carpenter, William C. Chairperson
University of South Florida 4202 East
Fowler Avenue M/S ENB 118 Tampa, FL 33620 Tel: 813-974-2275; Fax: 813-974-2957 E-mail: carpente@eng.usf.edu
Carr, Stephen H.
Associate Dean of Engineering
Northwestern University
2145 Sheridan Road
Evanston, IL 60208
Tel: 847-491-7379; Fax: 847-491-8539
E-mail: s-carr@nwu.edu
Chuang, Steven
Department Chair
University of Akron
Chemical Engineering Dept.
200 East Buchtel Common
Akron, OH 44325-3906
Tel: 330-972-7341; Fax: 330-972-5856
E-mail: schuang@uakron.edu
Chukwu, Godwin A.
Professor
University of Alaska-Fairbanks
Petroleum Engineering
437 Duckering Building
Fairbanks, AL 99775-5880
Tel: 907-474-7748; Fax: 907-474-5912
E-mail: ffgac@uaf.edu

Davis, Daniel C.
Associate Dean
New Jersey Institute of Tech.
5700 GITC
Newark, NJ 08873
Tel: 973-642-7239; Fax: 973-596-2316
E-mail: davis@admin.njit.edu

Davis, David W.
Director/Distance Education
University of Texas
P. O. Box 19077
Arlington, TX 76019-0077
Tel: 817-272-3299; Fax: 817-272-5630
E-mail: ddavis@uta.edu

Realizing the New Paradigm for Engineering Education
Kirk, Donald E., Dean of Engineering
San Jose State University
College of Engineering
San Jose, CA 95192-0080
Tel: 408-924-3800; Fax: 408-924-3818
E-mail: dkirk@email.sjsu.edu

Lam, Marca
Professor
The Cooper Union
51 Astor Place
New York, NY 10121
Tel: 212-353-4393; Fax: 212-353-4341
E-mail: mjlam@cooper.edu

Landinez, Rosa
Engineering Foundation
345 East 471 Street
Room 303
New York, NY 10017
Tel: 212-705-7836; Fax: 212-705-7441
E-mail: engfnd@aol.com

Lih, Marshall M.
Division Director
National Science Foundation
4201 Wilson Boulevard
Suite 585
Arlington, VA 22230
Tel: 703-306-1380; Fax: 703-306-0326
E-mail: mlih@nsf.gov

Litzinger, Thomas A.
Director
Penn State University
Leonard Center
202A Rider II Building
University Park, PA 16802
Tel: 814-865-4015; Fax: 814-865-4021
E-mail: ta12@psu.edu

Lyons, Jed S.
Associate Professor
University of South Carolina
Mechanical Engineering Dept.
300 Main Street
Columbia, SC 29208
Tel: 803-777-9552; Fax: 803-777-0106
E-mail: Lyons@engr.sc.edu

Mack, Pamela L.
Professor
Morgan State University
School of Engineering
5200 Perring Parkway
Baltimore, MD 21251
Tel: 410-319-3073; Fax: 410-319-3843
E-mail: pmack@eng.morgan.edu

Malave, Cesar
NSF Foundation Coalition
University of Alabama
Box 870200
Tuscaloosa, AL 35487
Tel: 205-348-4090; Fax: 205-348-4088

McCarthy, Joseph J.
Assistant Professor
University of Pittsburgh
Chemical & Petroleum Engr.
1249 Benedum Hall
Pittsburgh, PA 15261
Tel: 412-624-9630; Fax: 412-624-9639
E-mail: joe@chem-eng.nwu.edu

McGourty, Jack
23 Vreeland Road
Florham Park, NJ 07932
Tel: 201-593-0072; Fax: 201-593-0172

McGuire, Joseph
Professor
Oregon State University
Bioresource Engineering Department
116 Gilmore Hall
Corvallis, OR 97331-3906
Tel: 541-737-6306; Fax: 541-737-2082
E-mail: mcquirej@engr.orst.edu

McShane, William R.
Vice President
Polytechnic University
Six Metrotech Center (RH 217)
Brooklyn, NY 11201
Tel: 718-260-3550; Fax: 718-260-3063
E-mail: bmcshane@poly.edu

Meyburg, Arnim H.
Director
Cornell University
Civil & Environmental Engr. School
Hollister Hall
Ithaca, NY 14853
Tel: 607-255-3690; Fax: 607-255-9004
E-mail: ahm2@cornell.edu

Realizing the New Paradigm for Engineering Education
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Sechrist, Chalmers F.
Florida Gulf Coast University
12767 Yacht Club Circle
Fort Myers, FL 33919-4589
Tel: 941-454-0640; Fax: 941-454-3383
E-mail: c.sechrist@ieee.org

Shaw, Henry
Professor
New Jersey Institute of Technology
Chemical Engineering Dept.
323 Martin Luther King Jr. Blvd.
Newark, NJ 07102
Tel: 973-596-2938; Fax: 973-802-1946
E-mail: shaw@admin.njit.edu

Skull, Kenneth R.
Assistant Professor
Northwestern University
Materials Science & Engineering
2225 North Campus Drive
Evanston, IL 60208-3108
Tel: 847-467-1752; Fax: 847-491-7820
E-mail: k-skull@nwu.edu

Smerdon, Ernest T.
Senior Education Associate
National Science Foundation
4201 Wilson Boulevard
Suite 585
Arlington, VA 22230
Tel: 703-306-1380; Fax: 703-306-0290
E-mail: esmerdon@nsf.gov

Storvick, Truman S.
Professor
University of Missouri
Chemical Engineering Dept.
W-2024-Engineering Bldg. East
Columbia, MO 65203
Tel: 573-882-3215; Fax: 573-884-4940

Sullivan, Jacqueline
Director University of Colorado ENG Center Room CE 102
Boulder, CO 80309-0421 Tel:
303-492-3972; Fax: 303-492-1347
E-mail: sully@cadswes.colorado.edu

Swaszek, Peter F. Associate Professor
University of Rhode Island Electrical Engineering Department 119 Kelley Annex Kingston, RI 02881 Tel:
401-874-5802; Fax: 401-782-6422 E-mail:
swaszek@engr.uri.edu

Trick, Timothy N.
Professor & Head
University of Illinois
Electrical & Computer Engineering
1406 West Green Street
Urbana, IL 61801
Tel: 217-333-2301; Fax: 217-244-7075
E-mail: trick@ece.uiuc.edu

Vohra, Promod
Northern Illinois University
College of Engineering
DeKalb, IL 60115-2854
Tel: 815-753-1442; Fax: 815-753-0362

Watkins, Charles B., Dean
City College of New York
Convent Ave. at 138th Street
New York, NY 10031
Tel: 212-650-5439; Fax: 212-650-5768
E-mail: watkins@soe-mail.engr.ccn.cuny.edu

Watson, Karan
Associate Dean
Texas A & M University
204 Zachry
College Station, TX 77843
Tel: 409-862-4367; Fax: 409-847-8654
E-mail: watson@teesmail.tamu.edu

Weidner, John W.
Associate Professor
University of South Carolina
Swearingen Engineering Center
Columbia, SC 29208
Tel: 803-777-3207; Fax: 803-777-8265
E-mail: weidner@engr.sc.edu

Weilerstein, Phil
Program Manager
Nat'l Collegiate Inventors
Hampshire College-LM
Amherst, MA 01002-5001
Tel: 413-582-5309; Fax: 413-582-5834
E-mail: nciia@hampshire.edu