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ABSTRACT

This document integrates reports, perspectives, and concerns from four major discussion groups that participated in a June 1994 workshop on restructuring engineering education. Discussion groups focused on four topics--students, faculty, curricula, and experiential learning. Four major recommendations emerged from the meeting: (1) engineering education must encourage multiple thrusts for diversity; (2) engineering education needs a new system of faculty rewards and incentives; (3) assessment and evaluation processes must encourage desired expectations for both faculty and students; and (4) the changes needed for engineering education require comprehensive change across the campus, not just in the engineering college. Background information on change and restructuring is presented to support the recommendations. Appendices include: the workshop agenda, an interpretive summary of six keynote addresses, a list of workshop participants, a summary of key issues, and summaries of background documents. (DB)

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Restructuring Engineering Education: A Focus on Change

Report of an NSF Workshop on Engineering Education

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Division of Undergraduate Education
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Restructuring Engineering Education: A Focus on Change

Report of an NSF Workshop on Engineering Education

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Georgia Institute of Technology

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Division of Undergraduate Education
Directorate for Education and Human Resources
National Science Foundation
April 1995

Disclaimer: The opinions expressed in this report are those of the workshop participants and do not necessarily represent NSF policy. Their recommendations are under review at NSF.

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NATIONAL SCIENCE FOUNDATION
DIRECTORATE FOR EDUCATION AND HUMAN RESOURCES

January 15, 1995

Dr. Neal F. Lane, Director
National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230

Dear Neal:

I am pleased to submit the report from the workshop on restructuring engineering education. The workshop was developed with leadership from the Division of Undergraduate Education of the Directorate for Education and Human Resources in cooperation with the Division of Engineering Education and Centers of the Directorate for Engineering.

During June 6-9, 1994, 65 participants, representing engineering faculty, engineering education coalitions, engineering societies, industry, and students, met. The purpose of their meeting was to explore issues important to the continuing development of high quality engineering curricula which are relevant to the needs of our society as it moves into the twenty-first century. During the three days, participants worked in groups representative of the various constituencies to develop recommendations that will provide a basis for future activities and projects designed to improve the quality of undergraduate engineering education. Through their joint efforts, and with expanded support from NSF and others, academia and industry can work together to achieve comprehensive reform of undergraduate engineering education. The reform of undergraduate engineering education will better prepare graduating engineers for entering a variety of professions and provide expanded access to the contextual richness of engineering coursework for non-majors.

Sincerely,

Luther

Luther S. Williams
Assistant Director

LETTER OF TRANSMITTAL

January 8, 1995

Dr. Robert F. Watson, Director
Division of Undergraduate Education
National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230

Dear Dr. Watson:

I am pleased to submit the report from the workshop, *Restructuring Engineering Education*. The leadership and support provided by NSF's Division of Undergraduate Education in the planning and execution of the workshop was greatly appreciated.

Held June 6-9, 1994, the workshop developed recommendations for improving the ability of engineering education to better meet the needs of the twenty-first century. The 65 participants represented engineering faculty, engineering education coalitions, engineering societies, industry, and students.

Workshop participants were organized into four working groups: students, faculty, curricula, and experiential learning. Each participant was assigned to two working groups to assure maximum interaction and communication.

On behalf of the members of the planning committee, the chairs and scribes of the working groups, and all other participants, I submit this report to NSF in the spirit of cooperation, collaboration, and optimism for the future of engineering education. I encourage NSF, in cooperation with other federal agencies, academia, engineering societies, and industry to take a leadership role in implementing the recommendations in the report.

On behalf of all participants in the workshop, I wish to extend thanks to Drs. Norman Fortenberry, Don Kirk, Chalmers Sechrist, and Jack Waintraub of the Division of Undergraduate Education at NSF. Your continued commitment to engineering education and your recognition of the potentially central role of engineering education to comprehensive reform of undergraduate education, particularly the preparation of future teachers, is applauded.

Sincerely,

Carolyn W. Meyers

Carolyn W. Meyers, Ph.D.
Workshop Chair
Georgia Institute of Technology

PREFACE

Within the context of seeking to understand better the programmatic implications of the broad changes needed for engineering education, the National Science Foundation's Division of Undergraduate Education (DUE) in cooperation with the Division of Engineering Education and Centers (EEC) organized the *Workshop on Restructuring Engineering Education*. The workshop, held June 6-9, 1994 included 65 selected participants representing individual investigators, engineering education coalitions, Technology Reinvestment Program coalitions, engineering societies, the National Research Council's (NRC's) Board on Engineering Education, the American Society for Engineering Education (ASEE) Engineering Deans' Council, industry, and students. The charge was to address the curricular content (including experiential/contextual learning activities) and the broad academic framework of an engineering education which is responsive to the new challenges of an increasingly interdependent global society.

The workshop was organized around four working groups each with 14 participants. Each group focused on one of four topics: students, faculty, curricula, and experiential learning. Workshop participants were assigned to two working groups each to promote maximum interaction and cross-fertilization of ideas. It was explicitly recognized that the issues related to engineering education do not separate neatly but are interwoven among the topics. Not only must curricula be integrated but also much of engineering education must be integrated. The far ranging scope of the discussions in each group was reflected in the reports from the scribes and the chairs of the four groups.

This report of the workshop is an integration of the reports, the perspectives, and the concerns from the four discussion groups. An attempt to summarize a report on students or faculty or curricula or contextual learning would fail to convey the nature of the discussions. In these discussions, the interfaces between the designated areas received as much attention as the areas themselves. Nevertheless, the workshop generated items on which consensus developed. These are presented in the Recommendations and the Executive Summary with the body of the report providing the background.

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RECOMMENDATIONS

1. **Engineering Education Must Encourage Multiple Thrusts for Diversity.** Even though engineering and engineering education are more diverse now than in the past, challenges to our society demand even more, in both kind and degree, including:
   - Educational and professional diversity among faculty;
   - Ethnic, racial, and gender diversity among faculty and students;
   - Diversity in academic backgrounds and experiences among students; and
   - Diversity in planned educational experiences that respond to the demands of a diverse workplace including integrative laboratory experiences which promote inquiry, relevance, and hands-on experience in a variety of contexts.
2. **Engineering Education needs a new system of faculty rewards and incentives.** Faculty perceive the present system to focus on disciplinary research and publication; this focus must be expanded to include teaching, research, advising, and service in a way that includes all faculty as valued colleagues.
3. **Assessment and evaluation processes must encourage desired expectations for both faculty and students:**
   - New approaches to assessment must judge faculty contributions across the expanded spectrum;
   - Methods for evaluating student efforts must promote student learning; and
   - Careful assessment of teaching and learning is needed to identify successful educational innovation and encourage adaptation/adoption by others.
4. **The changes needed for engineering education require comprehensive change across the campus, not just in the engineering college.** As reflected in the previous items, colleges and universities must take new approaches toward students, faculty, and curricula. These changes can not credibly be limited to engineering colleges, but will necessarily entail a comprehensive reform of undergraduate education.

EXECUTIVE SUMMARY

The recommendations delineated on the previous page indicate several broad foci of the workshop discussions. Restructuring engineering education requires that we examine the enterprise from a different point of view, with new measures, and with new expectations.

Diversity for all aspects of engineering education seems to be a cornerstone of the restructured enterprise. To encourage diversity requires rewards and incentives compatible with the diversity we seek. Similarly, changes in our expectations for diversity and in the reward structure underscore new approaches to assessment and evaluation of faculty, students, courses, curricula and programs in engineering education. The recommendation for comprehensive change across the campus recognizes that engineering education must function as part of the larger campus setting.

Workshop discussions focused, not on the recommendations per se, but on four aspects critical for engineering education: students, faculty, experiential learning, and curricula:

Students are central to the educational process. As such, they should be active participants in the educational transformation process. The educational experience should develop the motivation, capability, and knowledge base for lifelong learning.

We must encourage **faculty** to assume a more active role not only in the implementation/delivery of the educational experience for the student, but also in the innovation and continuous improvement necessary for engineering education to meet the challenges. Changes in the reward structure and the assessment process are more critical for encouraging faculty changes than for other areas.

The **learning experience** must move from the lecture as the dominant mode to include a significant level of active learning approaches. Laboratory and internship experiences should provide the broader contexts within which to view trade-offs in the design, development, and implementation of engineering systems. These experiences should encourage world class design, development and implementation processes for engineering systems. Cooperative learning approaches and other contextual experiential learning must be integrated within the classroom.

Engineering **curricula** should be broad and flexible, preparing students for both leadership and specialist roles in a variety of career areas. Each curriculum should be designed to develop graduates who are life-long learners and contributors to the profession, fully capable of succeeding in the current and future global, multi-disciplinary marketplace. The learning experiences for which the curriculum is the central part should accommodate and serve students with various learning styles. Further, engineering education should provide an opportunity for non-majors to study engineering topics and concepts and should work to make these studies accessible to non-majors.

Restructuring Engineering Education: A Focus on Change

Background

Over the past 50 years a succession of studies [1-9] has probed engineering education. Each has acknowledged the enterprise to be a vital part of the nation's higher education with many strengths and contributions. Each also noted changes to strengthen engineering education and some offered challenges for broad changes. Over this half-century period engineering education has changed and, although most of the changes can be noted as incremental, the continuous change sums to changes of significant proportions. In this last decade of the 20th century, the need for sweeping changes in engineering education appears more credible than at any time in the past several decades. Most recently, forums have been sponsored by the National Research Council's (NRC's) Board on Engineering [10] and the American Society for Engineering Education's (ASEE's) Engineering Deans' Council [11]. Each re-emphasized and expanded upon earlier calls for change. Each also advised, among other things, increased attention by the federal government to the needs of engineering education.

Within the context of seeking to understand better the programmatic implications of the broad changes needed for engineering education, the National Science Foundation's Division of Undergraduate Education (DUE) in cooperation with the Division of Engineering Education and Centers (EEC) organized the *Workshop on Restructuring Engineering Education: A Systems Approach to Integrated Curricula* which was held June 6-9, 1994. The participants represented individual investigators, engineering education coalitions, Technology Reinvestment Program coalitions, engineering societies, the NRC's Board on Engineering Education, the ASEE Engineering Deans' Council, industry, and students. The charge was to address the curricular content (including experiential/contextual learning activities) and the broad academic framework of an engineering education which is responsive to the new challenges of an increasingly interdependent global society. The participants were organized into four overlapping discussion groups: students, faculty, curricula, and experiential learning. This report is an integration of the reports, the perspectives, and the concerns from the discussion groups.

Vision and Challenge for Change

Our society faces significant challenges including international competition, the global environment, an increasingly diverse population, and a rapid growth in information technologies. Industry, government agencies, and educational institutions all have important roles in meeting these challenges. Higher education, in general, has the role of providing the professional preparation for the next generation of business leaders, technical professionals, government officials, and educators at all levels. Engineering education, in particular, will have a central role in our increasingly technologically-based society. The education of engineers must prepare them for the full disciplinary nature of the problems they will face.

Reports and presentations about engineering education over the past decade document the growing need for change in the way we do engineering education. Sweeping changes in the context for engineering accompanied by significant changes in the challenges offered by the engineering workplace bring an urgency to the need for broad change in the education of engineering graduates [12-13].

There is a growing realization among engineering faculty that a new vision for the education of engineers is evolving, a vision based upon the needs of engineering in the 21st century. The philosophy that forms this vision differs from the current more rigid and more uniform basis of today's curricula. This vision welcomes and encourages all motivated and talented students to become engineers. These students discover engineering from the beginning of their academic career and enjoy a nurturing environment throughout their university education. They find flexible curricula that recognize individual learning styles and diverse career paths. Guided by advisors and mentors, students choose electives for career preparation in support of educational goals and a strong foundation in the fundamentals of engineering.

The new paradigm depicts engineering education as broad and forward looking. It describes an engineering education that:

- offers a broad liberal education that provides the diversity and breadth needed for engineering;
- prepares graduates for entry into careers and further study in both the engineering and non-engineering marketplace; and
- develops the motivation, capability, and knowledge base for lifelong learning.

Faculty accept responsibility as mentors, with a focus on the development of the student as an emerging professional, building the student's self esteem and competencies, and accepting responsibility for the intellectual growth of the student. The engineering faculty adopts technological literacy as a mission for engineering education.

The contents of the new curricula reflect this vision, and courses include a broad range of concerns: environmental, political and social issues, international context, historical context, and legal and ethical ramifications of decisions. For this vision to become reality requires sweeping changes not only in engineering education, but also in the environment for the engineering education enterprise.

A new engineering education philosophy in conjunction with profound cultural changes should provide the environment for the new curricula. The most important means for change include improved pedagogy, revised curricula content, and a process of continuous assessment and continuous improvement. The overall goal of engineering curricula should be to develop engineering graduates who are professional contributors and lifelong learners capable of succeeding in the current and future global, multi-disciplinary markets. Further, engineering education must help develop technologically literate graduates of non-engineering programs.

Although the technical component will continue to be the core of an engineering education, economic/political/social/environmental contexts of engineering will be explicitly addressed. Emphasis will be placed on the critical need for the motivation, capability, and knowledge base for lifelong learning. The capability for learning effectively and efficiently benefits an engineering graduate as much as any capability and should be provided by an engineering education. Changes that help students develop this capability for self-learning and provide increasing opportunities during their academic program for practicing this skill are needed.

Engineering education must be flexible enough to support the diverse career aspirations and needs of our students as well as agile enough to enable rapid transformation in response to emerging social demands. Necessary characteristics include:

- new and highly flexible degree options for students who intend to practice engineering;
- new educational pathways for students who need or want a significant technical component to their education, but who intend to pursue non-engineering degrees;
- a broader service role within the university community with some engineering courses included in the general education requirements for non-engineering students; and
- continued effort to understand and respond to diversity in learning styles and their implications for student learning.

We need processes whereby curricula within existing departments can be renewed more rapidly. In addition, we need processes for more dramatic change, enabling curricula to adapt quickly to societal needs, analogous to "flexible and agile" manufacturing techniques. Just as we need mechanisms for quickly assembling new programs we need mechanisms for disassembling them when their time is past. See Figure 1.

Comprehensive Restructuring

The challenge for change described in the preceding paragraphs focuses on the college of engineering. Yet meeting this challenge requires comprehensive change in the university, including changes in non-engineering academic units with which engineering students interact as well as changes to the campus culture with even broader impact. The engineering college is not an island in the campus ocean.

Instituting the changes requires a comprehensive restructuring of undergraduate education. On each campus, the engineering college must take the lead in this comprehensive change that benefits all of undergraduate education and requires participation by many sectors across the campus. The goal is a better prepared more competent and more fully contributing graduate fully capable of and confident with life-long learning. The diversity of the enterprise must be celebrated and not just tolerated.

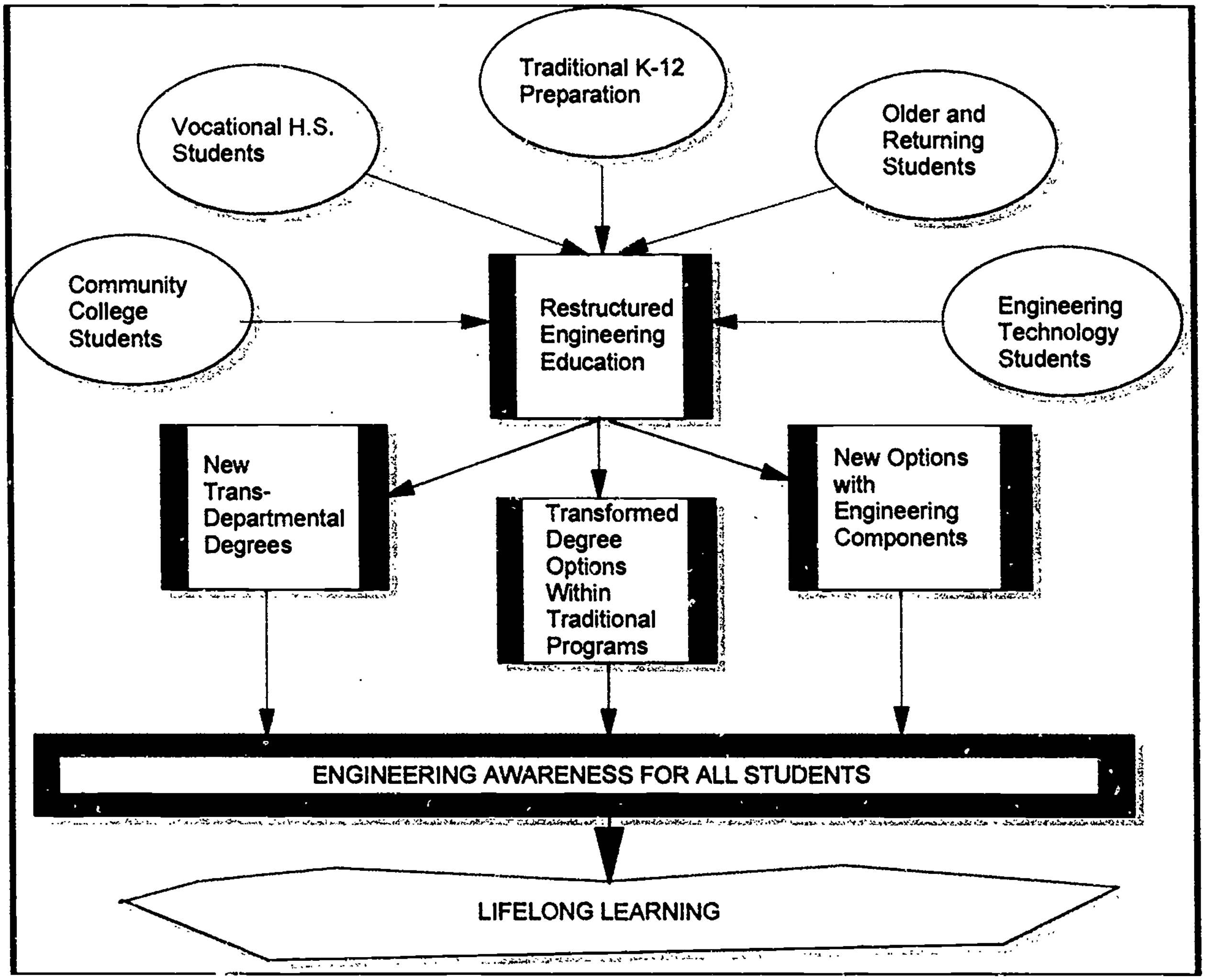

Figure 1. Flowstream of Restructured Engineering Education

This requires new links and new approaches to rewards and incentives, assessment and evaluation for faculty and students.

Faculty Rewards and Incentives

The quality of engineering education is the responsibility of everyone: students, faculty, and the campus administration. However, the faculty play the leading role -- the front line in the delivery of quality engineering education. Critical to the quality of engineering education is a faculty that is diverse in cultural and professional experiences, that is committed to lifelong learning and scholarship, and that places primary emphasis on the education of engineering professionals. In particular, we must develop rewards and incentives that promote the contributions of all faculty and that signal clearly that they are valued colleagues within their units, their institution, and society.

The new system of rewards and incentives should:

- recognize the contributions of teaching, advising, research, and service; and
- provide an appropriate response to contributions that may have received less recognition and remuneration in the past.

Since the reward system is the driving force which encourages or discourages faculty investment in the effort necessary to reform engineering education, changing the faculty reward system is critical.

At most institutions faculty are major players in the faculty reward system. Thus, much of the push for change in the reward system must focus on the faculty. Even though this may be difficult since many senior faculty were rewarded under the old reward system, overwhelming evidence tells us the engineering education reward system must change. Faculties that fail to change will find their engineering programs lagging behind others. These schools will become followers and not leaders and their graduates will find they are at a disadvantage in the engineering market place.

Although faculty are critical agents for change in the undergraduate engineering enterprise, faculty cannot accomplish this change alone. It requires the commitment of the broad academic community (students, faculty, and administration) in cooperation with industry, and government. The goals and objectives require changes in rewards and incentives that include broad and sweeping initial steps. We must avoid creating new barriers during this transformation process. Diverse faculty with diverse interests bring diverse solutions. Some faculty will take strong leadership roles in initiating this cultural change, but the system of rewards and recognition must be structured to encourage the participation of a broad representation of the faculty community and recognize all as valued colleagues. Rewards and recognition must encourage programmatic risk taking without exposing individual faculty to undue career risk.

Implementation and institutionalization of a new reward system will require long term commitment by the community.

Assessment/Evaluation

A new system of rewards and incentives requires the use of existing assessment techniques and the development of new assessment techniques for student learning as well as faculty teaching, advising, research, and service. Such techniques should:

- provide feedback to students on what they are learning including problem formulation, problem solution, critical thinking, innovative design, and creative synthesis;
- motivate further student learning; and
- provide better metrics for assessment of teaching, advising, research, and service.

Assessment drives student learning. The dominant assessment method that focuses on exams and midterms drives students to rote learning, memorization, cramming, and manipulation within narrowly defined problems. An appropriate reward and incentive system promotes meaningful learning, actively involving students in making choices and defining their learning experience. We need new evaluation and assessment methodologies focused on student learning in new educational environments. These methodologies must support the faculty in assessing student learning, the subsequent success of graduates, and the health of engineering educational programs.

Evaluation and assessment have central roles in the curriculum reform process. We need new processes for assessing both student learning and the effectiveness of our programs. The educational community as a whole should undertake this work, with collaboration between faculty, undergraduates, graduate students and industry. NSF has shown it's commitment to this task by awarding prestigious National Young Investigator awards to PI's taking rigorous approaches to understanding the teaching and learning process in engineering.

Diversity

Diversity is fundamental to successful engineering education. Diversity in faculty, the student body, and program emphasis must become part of the future of engineering education. Institutions need rewards and incentives that promote exemplary programs that demonstrate successful recruitment, mentoring, and retention of women and minorities through the senior academic and administrative ranks.

Institutions also need rewards and incentives for exemplary programs that demonstrate the development of a professionally diverse faculty. This includes industrial, international, or government experience as well as education beyond engineering.

The new engineering curriculum must encourage multiple thrusts for diversity. It must serve the needs of students entering the undergraduate educational process on a variety of paths and with a variety of skills and backgrounds. Similarly, the curricular structure should assure flexibility to support the diverse career pathways and goals of students as well as the needs of a student body whose diversity incorporates ethnic, racial, age, and gender diversity, and a very wide diversity in learning styles and aesthetics.

Further, undergraduate engineering education must support two classes of career aspirations:

- all students who have a motivation to practice engineering; and
- those who desire a curricular pathway with significant technical content, but focused on various non-engineering career objectives, including careers in K-12 education, public policy, management, financial services, and health care.

Engineering education must be accessible to a wide spectrum of students coming to us from diverse pathways. Colleges of engineering need to work to make our communities more accessible and responsive to students entering the educational process from many gateways including: community colleges, engineering technology programs, traditional K-12 gateways, the displaced industrial and military workforce, and other returning older students.

Guidance to possible approaches is given by the Foundation engineering education coalition's strong link to community colleges and the Greenfield engineering education coalition's link to community-based technical education programs.

Development of Students

Multiple paths for entry and re-entry to engineering study, as well as the diverse needs of students within our programs, require effective advising and mentoring processes. Engineering faculty, in collaboration with colleagues across the campus, must coordinate the education of our students beyond engineering topics. We must help students integrate rather than compartmentalize their education.

Lifelong learning has become an important concept recognizing the rapid advances in technology over the past 40 years and anticipating that technological changes will be no less for the foreseeable future. Most engineers experience several major job changes during their career. Undergraduate engineering programs can no longer ignore the fact that they cannot provide all the necessary knowledge for graduates to remain competitive in their careers; they must educate the student for life, not just for the initial job. Students must know how to learn, and must be able to assess their skills and educational needs. This requires they have confidence in their ability to satisfy the need for lifelong learning; this confidence must be accompanied and fortified with a passion for the practice of engineering and a zeal for excellence in that practice.

Curricula should be designed to cultivate a sense of professionalism. The student follows the lead of the faculty, adapts to change and, in fact, comes to enjoy the challenge of change. The experience gained from their passage through the education process has prepared graduates to be confident, to move forward and to accept the challenge of change.

Design clinics represent one means of achieving such inculcation of values among students. Harvey Mudd College, the originator of design clinics and an excellent model of the implementation, recently hosted a DUE-sponsored workshop to help others learn how to effectively use this pedagogic device.

Development of Faculty

Faculty are role models for students and no role is more important than that of the faculty member as student, learner, and scholar.

Although individual faculty members have the ultimate responsibility for their professional development, guidance and assistance are important, perhaps critical. Faculty development opportunities can take many forms:

- involving consultants, seminars or workshops which focus on administration, advising, research, or teaching;
- providing a variety of opportunities for engineering professors to maintain engineering literacy in scientific and engineering knowledge, engineering applications, use of sophisticated software tools, and proficiency with design methodologies;
- developing opportunities for faculty to have or maintain industrial literacy involving consulting, industrial sabbaticals, industrial employment, and collaboration with engineers in industry; and
- promoting significant multi-disciplinary interactions among the faculty through: reduced institutional barriers, team teaching, new university structures, and recognition of multi-disciplinary activities in promotion and tenure decisions.

Engineering faculty must take a more proactive role in making industry aware that it is a vital part of the educational process, including seeking active participation in the design, implementation, and evaluation of new curricula. This must include an effort by engineering faculty to work with industry to help them expand their practices for recruiting students, as well as enhance faculty/industry relationships, an area in which far more numerous and sustained programs of real interaction are needed. Further, if the emerging needs of our students are to be met, the faculty as a whole must incorporate significant industrial experience. For example, a DUE-sponsored project at Wytheville Community College is sending engineering technology faculty on industrial internships to gain insights and skills which will enrich their classroom teaching.

The Curriculum: What We Teach and How We Teach

Students learn in different fashions, some more comfortable with traditional lectures, but most more receptive to active learning approaches that engage their problem solving skills and nonverbal cognition abilities. "Learning-by-doing" is the norm in many professional fields and it should be an important component of engineering education. However, current engineering instruction typically relies upon large lectures, highly structured problem assignments, and structured examinations for assessment. The process of engineering education should change to use more effective pedagogical approaches and to engage students more effectively in the educational enterprise. Emerging technologies, including multi-media, computer-based simulation and computer-aided engineering, can be important components in the educational process along with collaborative learning, team projects, and other student centered modes. We seek changes that provide improved learning environments including:

- active learning; collaborative learning; modular learning;
- research, development and practice experience for undergraduates;
- new physical environments;
- distance learning;
- hands-on learning; and
- integrative learning.

Curricula are usually defined in terms of required and elective courses. The typical course definition focuses on the knowledge to be mastered and prerequisite requirements. Most engineering courses are inaccessible to non-engineering students. Curricula for the 21st century should represent holistic education, involving mastery of a limited set of engineering fundamentals, preparation for lifelong learning, and flexibility to allow pursuit of individual student goals and aspirations.

It is impossible to define an engineering curriculum applicable everywhere in the nation. Each school serves its own constituents, and we should expect and applaud diversity in curricula and programs.

Assessment and evaluation of the educational process are critical for exposing problems and enabling continual improvement. Traditional assessment methods such as student surveys of course quality, accreditation processes, and the market demand for graduates should be augmented with new approaches. The current examination, co-sponsored by industry and NSF's DUE and EEC divisions, of Accreditation Board for Engineering and Technology (ABET) criteria, processes and procedures signals a new role for ABET in the assessment and evaluation of engineering education.

Engineering colleges must assume new responsibility for promoting technological literacy throughout the university. For engineers and non-engineers alike, technological literacy means more than acquisition of technical skills and knowledge, more than "nuts and bolts." It also means understanding and appreciating technology's evolution over time, and technology's cultural, social, historical, economic, political, legal and environmental concepts. The future of our avowedly technological society depends on greater technological literacy.

Engineering courses within the engineering discipline benefit non-technical majors, analogous to the benefits engineering students receive from their experiences within the culture of the liberal arts community. Engineering faculty should assume leadership roles in integrating curricular elements across disciplines, including math, the physical and social sciences, and the humanities, to better serve the needs of our students.

Drexel University's Enhanced Engineering Educational Experience program, initiated with DUE support, provides an example of an integrated holistic curricular approach to lower division instruction. The program has proven so popular that its methods have been expanded to encompass the entire freshman class and serve as the basis of the Gateway engineering education coalition.

A DUE sponsored laboratory improvement project at Western Kentucky University provides a model contextual learning experience. As part of a biomedical engineering curriculum, students are measuring occupational exposure to chemical and physical stressors not only in student wood working and chemistry labs, but in local manufacturing plants. Through such methods students can immediately grasp the importance of their studies to real world applications.

Implementation

Anticipating the challenges of the 21st century, undergraduate education, in partnership with industry, must prepare leaders, not only of professional communities, but of all segments in an increasingly technological society. Graduates are, and will be increasingly, called upon to utilize not only technical knowledge, but communication skills, managerial and financial capabilities, awareness of social implications, and ethical judgment. This breadth of skills is needed by graduates who will become effective leaders in areas such as advanced manufacturing, materials and processing, biotechnology, infrastructure enhancement, health care delivery, and environmental preservation.

The engineering education community is well positioned to foster the breadth expected of graduates. Broadly defined, the community includes not only engineering and engineering technology faculty members, but also industrial professionals who supervise interns and cooperative education students, as well as the students themselves as active participants, each responsible for his or her own education. In addition, this community interacts with instructional designers familiar with integrating advanced technologies into effective pedagogic systems, academic support personnel who provide enrichment and enhancement opportunities to students, and academic counselors and advisors who provide students with information on career options and required coursework. **Thus, in order to prepare graduates for the challenges of the 21st century, the engineering education community must**:

- Develop a rigorous educational research base on the teaching and learning of undergraduate engineering topics;
- Restructure curricula to include integration of contextual experience, appreciation for the complexities of physical devices and structures, broad attention to learning environments, and recognition of the differing backgrounds and career goals of students; and
- Develop faculty and organizational structures better prepared to implement revised curricula and laboratories and to address the broad range of factors which influence student learning.

Redesigned engineering educational systems should better meet the needs not only of engineers, but also:

- the large number of students who will use their backgrounds in engineering and technology to serve them in their roles as literate citizens;
- future leaders in industry, academe and government;
- future teachers of mathematics, science and technology, including those at the elementary level; and
- future scientists and mathematicians.

We believe these objectives can be successfully achieved through an integrated systems approach to the design, implementation, and evaluation of undergraduate engineering curricula. The objectives of this approach are to: eliminate barriers caused by departmental boundaries; achieve vertical and horizontal integration within curricula; foster integration between engineering and other technical and non-technical fields; and promote integration of diverse sets of students. Consequently, this requires cooperation among faculty within a given engineering department and faculty in: other engineering departments; science and mathematics; management science; humanities; arts; and social science. Expected results of these collaborations are determinants of successful teaching and learning at the undergraduate level, innovative curricular frameworks, comprehensive faculty development activities to facilitate implementation of the new curricula, and enhanced integrative and contextual laboratory activities.

The interdisciplinary nature of such an integrated systems approach would be central and particularly challenging and would require development by a multidisciplinary project team and strong support across academic units. Examples that illustrate some approaches might include development, implementation, and evaluation of:

- a complete curriculum that integrates topics from science, mathematics, management, English, social sciences and humanities, and from the various disciplines of engineering, created and taught by multidisciplinary teams;
- a new delivery system which integrates the effective use of technology in the curriculum to maximize access to students from underrepresented groups, and to accommodate a variety of backgrounds, learning styles and rates;
- engineering-based curricula intended for students planning to pursue career options such as medicine, law, business, and K-14 level teaching, as well as "engineering and technology appreciation" course sequences for non-engineering students, including science and mathematics majors; and
- a unified engineering core and an integrated capstone design experience with active participation by all departments within a college of engineering.

To be credible all projects would have to include the following features:

- the faculty and institutional support necessary for systemic and lasting impact;

- close cooperation of faculty in engineering with faculty in other disciplines, including, for example, mathematics, science, management and the humanities as a multidisciplinary project team with multidisciplinary representation among the co-principal investigators;
- mechanisms to increase the diversity of students who are attracted to and successful in engineering;
- development of interpersonal skills such as teamwork, leadership, and sensitivity to multicultural considerations;
- emphasis on developing students' capability to learn on their own;
- development and implementation of new, effective instructional methods;
- development of instructional materials, such as textbooks, course modules, lab manuals, software and multimedia presentations;
- an evaluation component with both formative and summative elements to determine how effectively the project is meeting its goals and the cost effectiveness of the curriculum;
- dissemination that facilitates widespread adaptability and increases adoption of the approaches and products developed in the project;

Additionally, projects would be expected to have several of the following elements:

- an emphasis on oral and written communications skills integrated throughout the curriculum;
- a focus on projects, experiential learning, and discovery-oriented learning environments to develop student capability to solve ill-posed and open-ended problems;
- cooperative relationships with industry involving students, faculty and industrial practitioners as a community of learners;
- development of faculty and training of graduate students (for those institutions with graduate programs) to improve adaptation and implementation of effective approaches to teaching and learning;
- initiation of new instructional and staffing paradigms that optimize efficient and effective use of instructional staff and technology;
- flexibility to enable students to prepare for careers in a variety of fields, including medicine, law, business, and teaching, as well as engineering;
- interaction among faculty from education, science, mathematics and engineering in a cooperative activity to enhance K-14 teacher preparation;
- a strong component of international education;
- comprehensive elements to introduce engineering and technology to students from non-technical majors, as well as to students majoring in science and mathematics.

The Reality of Change

For changes in any of our institutions to endure, the community must participate broadly. Engineering education is no exception. Each part of the community has a role and for each we can identify tasks, often to be shared with other parts of the community.

NSF and others provide stimulus for change and the leadership to begin. Academic institutions not only implement the changes but also, in partnership with the employers of engineering graduates, seek to understand better the educational needs of the student. Enabling the graduate to succeed in the current and future global multi-disciplinary world depends on this understanding.

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APPENDIX A: WORKSHOP AGENDA

RESTRUCTURING ENGINEERING EDUCATION:
A SYSTEMS APPROACH
JUNE 6-9, 1994
Wyndham Bristol Hotel
Washington, DC

AGENDA

Monday, June 6th
7:00 - 8:30 PM

Welcome
Dr. Norman L. Fortenberry
Program Director
NSF/EHR/DUE

Overview of Goals and Objectives by Workshop Chair
Dr. Carolyn Meyers
Associate Dean of Engineering
Georgia Institute of Technology

Remarks
Dr. Robert F. Watson
Division Director
NSF/EHR/DUE

Keynote: Interdisciplinary Challenges in Environmental Education
Dr. Mark Wrighton
Provost
Massachusetts Institute of Technology

Q&A and General Discussion

Introduction of Working Group Chairs and Members

Summary and Synthesis of Background Information Previously Distributed by Workshop Rapporteur:
Dr. Edward Ernst
Allied Signal Professor of Engineering
University of South Carolina

Tuesday, June 7th
8:00 - 10:30 AM

Keynote: Lessons from Interdisciplinary Approaches to Manufacturing Education
Dr. Shiv Kapoor
Director, Manufacturing Engineering Program
University of Illinois - Urbana

Q&A and General Discussion on Implications for Other Interdisciplinary Challenges

Keynote: Interdisciplinary Challenges in the National Information Infrastructure
Dr. Robert Janowiak
Executive Director
International Engineering Consortium

Q&A and General Discussion

Focus: Engineers and Teacher Preparation
Dr. Robert F. Watson
Division Director
NSF/EHR/DUE

Q&A and General Discussion

10:30 - 11:00 AM BREAK

11:00 AM - 12:30 PM

Keynote: Interdisciplinary Challenges in the National Infrastructure
Mr. Samuel Florman
Vice President
Kreisler Borg Florman Construction

Q&A and General Discussion

Focus: Engineering Education
Dr. Marshall Lih
Division Director
NSF/ENG/EEC

Q&A and General Discussion

12:30 - 1:30 PM LUNCH

2:00 - 5:30 PM

Afternoon Sessions - Discussions of Key Issues
{Various Breakout Rooms}

Working Group:	**Breakout Rooms:**
Students	Cabot
Faculty	Clifton
Curriculum	Potomac I
Contextual Learning	Potomac II

Breakout Groups (meet in primary groups, write key points)

5:30 - 6:00 PM BREAK

6:00 - 6:45 PM Presentations

Focus: CET Challenges
Dr. Luther S. Williams
Assistant Director, NSF/EHR

Q&A and General Discussion

Wednesday, June 8th

Working Group:	**Breakout Room:**
Students	Cabot
Faculty	Clifton
Curriculum	Potomac I
Contextual Learning	Potomac II

8:00 - 10:00 AM Discussions on Key Issues (Cont.)

Breakout Groups (meet in secondary groups for cross-correlation, write)

10:00 - 10:30 AM BREAK

10:30 AM - 12:00 Noon

Breakout Groups (meet in primary groups, incorporate suggestions)

Noon LUNCH {Potomac I & II}

1:00 - 2:30 PM Preliminary Reports from Primary Groups

2:30 - 5:30 PM Breakout Groups (meet in primary groups; write)

5:30 0 6:00 PM BREAK

6:00 - 6:45 PM

Focus: Fractionators and Integrators
Dr. Joseph Bordogna
Assistant Director, NSF/ENG

Q&A and General Discussion

Thursday, June 9th

Working Group:	**Breakout Room:**
Students	Cabot
Faculty	Clifton
Curriculum	Capitol (Lobby Level)
Contextual Learning	Potomac II

8:00 - 10:00 AM Finalization of Action Plan

Breakout Groups (meet in secondary groups for cross-correlation and write)

10:00 - 10:30 AM BREAK

10:30 AM - 12:00 Noon

Breakout groups (meet in primary groups, incorporate suggestions, and write)

Noon LUNCH

1:00 - 2:30 PM

Final Reports from Primary Groups, Wrap-up, Summary, Adjournment

APPENDIX B: INTERPRETIVE SUMMARY OF KEYNOTE ADDRESSES

Keynote addresses were invited on four topical areas which provide examples of the challenges which will face the engineering education community into the twenty-first century: the environment, manufacturing, the national information infrastructure, and the national civil infrastructure. These challenges provide the context and motivation for current efforts to restructure engineering education in order to produce better prepared engineering graduates. The challenges are broad and require interdisciplinary solution approaches which consider social and political as well as technical parameters. Supplementary remarks by two NSF Assistant Directors provided the policy contexts for the workshop's activities.

Dr. Mark Wrighton, Provost, Massachusetts Institute of Technology

Speaking within the context of numerous activities underway at the Massachusetts Institute of Technology (MIT), Dr. Wrighton's address centered on three major themes:

1. The growing importance of interdisciplinary and interdepartmental collaboration
2. The vitality and synergy which result from student-faculty interaction and the linkage of education with research, and
3. The increasing role of technology in addressing societal needs, particularly in environmental areas.

Dr. Shiv Kapoor, Director, Manufacturing Engineering Program, University of Illinois at Urbana-Champaign

Dr. Kapoor described the Manufacturing Education Program (MEP) at the University of Illinois at Urbana-Champaign (UIUC) which links education, research and technology transfer. The program has three objectives which are relevant to the effort to restructuring engineering education:

1. Promote broad-based educational experiences to large groups of undergraduate and graduate students in various aspects of manufacturing education;
2. Promote strong interdisciplinary relationships among faculty for both teaching and research in computer integrated manufacturing; and
3. Provide meaningful laboratory exercises by employing the latest equipment and blending current research with undergraduate education.

The impact of the MEP program has been the creation of senior design projects which bring together students from various engineering departments, team teaching of two manufacturing courses, joint research project development through two sponsored research centers, and the development of two college-wide undergraduate laboratories.

Dr. Robert Janowiak, Executive Director, International Engineering Consortium

Dr. Janowiak focused on the similarities and differences in the development of the national highway system and the on-going development of the national information infrastructure (NII) by looking at such issues as policy, network structure, standards, supporting industries, funding, customer equipment, customer interfaces, user pricing, and regulation. He noted several critical differences in the two efforts. Principal among these is that the path for successful development of the NII is not certain, and as technologies evolve changes in direction will be critical to success. The three determinants of success will be ease of use, ubiquity, and value-- descriptors with social, economic, and political dimensions.

Mr. Samuel Florman, Vice President, Kreisler Borg Florman Construction

Mr. Florman addressed his remarks to the nation's civil infrastructure. He drew a contrast between infrastructure development methods of the 1940's and 1950's and those of today. Those which could be imposed by executive fiat and those which require building cooperative coalitions of regulators, residents, interest groups, politicians, and technical professionals. Modern engineers must necessarily be adept at interdisciplinary challenges. He specifically noted that engineering professionals must develop skills which were not previously required including excellent communication skills and knowledge of the humanities. However, he cautioned that the technical core of engineering cannot be slighted. He also observed that there can be no single "best" approach; that the strength of the American educational system lies in its diversity.

Dr. Luther Williams, Assistant Director, Directorate for Education and Human Resources, National Science Foundation

Dr. Williams observed that the the past pattern of the National Science Foundation (NSF) of supporting many, small dispersed educational projects may have been successful at producing isolated instances of quality and impact; however, the educational system has not changed much. He noted that it is for this reason that NSF has for the past three years been re-orienting the majority of its elementary and secondary educational activities toward systemic approaches which address problems, imbalances and shortcomings which permeate most school systems. This reorientation is reflected in three programs: the Statewide Systemic Initiatives, the Urban Systemic Initiatives, and the Rural Systemic Initiatives.

Dr. Williams asserted that at the undergraduate level, there is a similar need to address fundamental problems which inhibit the adequate preparation of individuals for the complexities of modern life and work. He cited a lack of recognition of the diverse backgrounds and career aspirations of undergraduate students, as well as an inability to continue to promote the new ways of learning being instituted at the pre-college level as shortcomings of the current system of undergraduate education. He stated that we can no longer alter students to fit the abilities of educational institutions; we must alter the institutions to fit the needs of students.

Dr. Williams advocated the use of comprehensive efforts, at a variety of institutions, to address impediments to providing the academic environments needed for tomorrow's skilled worker and responsible citizen. He recommended that such efforts address the nature of the student-teacher interaction, the complete learning environment, and the relevance of the curriculum to the multi- and interdisciplinary challenges of modern society.

Dr. Joseph Bordogna, Assistant Director, Directorate for Engineering, National Science Foundation

Dr. Bordogna sketched the variety of internal and external pressures which are re-shaping the engineering enterprise. These pressures exist in national and international contexts. He provided an overview of drivers for organizational change in federal science, engineering and technology education and research entities. The effects of these drivers were illustrated by discussion of the National Science and Technology Council (NSTC) Committee on Civilian Industrial Technology and its programs on the Manufacturing Infrastructure and the NSF Civil Infrastructure Systems framework.

Dr. Bordogna outlined the inputs to innovation and wealth creation including science, public policy, technology, economics, and engineering. He then outlined strategic themes for academe in the twenty-first century. These include intellectual integration, organizational integration, investment in people, organizational agility, and accountability. Given these contexts and themes he observed that a holistic baccalaureate engineering education must balance engineering science and engineering practice. He postulated a new paradigm for engineering education which is not cast in terms of "either or", but in terms of balancing complexity and simplicity, uncertainty and precision, problem formulation and problem solving, integration and analysis, teaching and research, as well as independence and teamwork. Dr. Bordogna concluded by observing that academe's broad mission remains the creation of enhanced social welfare through the transformation of resources invested in education and research to produce knowledge.

APPENDIX C: WORKSHOP PARTICIPANTS

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APPENDIX D: KEY ISSUES FOR WORKING GROUPS

Charge:
Our focus during this workshop is to redefine the curricular content (including laboratories) of an engineering education in order to better prepare our students to respond to new challenges in an increasingly interdependent global society. Specifically, the intent is to address vertical and horizontal integration within engineering, between engineering and other technical and non-technical fields, and with respect to integration of diverse sets of students. Explicitly desired outcomes are model curricular frameworks, model faculty development activities to facilitate instruction in the new curricula, and model integrative and contextual laboratory activities .

Goals:
1. Articulate the technical, economic, political, and social challenges inherent in interdisciplinary issues of immediate relevance to the engineering profession. This will be done by way of example with two critical interfacial issues:
The Physical Environment (product and process design, remediation, etc.)
The National Infrastructure (roads and bridges, buildings, communications, etc.)
2. Define the desired characteristics of engineering professionals who can address these interfacial issues (what they can do, what skills they possess, etc.),
3. Define needed linkages among engineering disciplines and between engineering and other fields in order to achieve the desired characteristics,
4. Define the educational structures necessary to achieve the desired personal characteristics and disciplinary linkages,
5. Identify impediments to achieving desired disciplinary linkages and educational structures, and
6. Define appropriate roles and required actions for NSF, professional societies, academic institutions, and other stakeholders to overcome the identified impediments to achieve necessary disciplinary linkages and educational structures.

Cross-cutting Issues:
1. How do we promote life-long learning?
2. How can we improve the public awareness of engineering (i.e., outreach to general public, media, K-12 children, parents, etc.)?
3. How can we change the institutional reward system (for both faculty and students)?
4. How can we provide evaluation and dissemination paths?
5. What is the role of educational technologies and methodologies?

Students

1. Which students is engineering education meant to serve?

How do we create curricula which can address the needs of students with many different career paths, e.g., practicing engineers, scientists, future teachers, social scientists and planners, general citizens?

How can we keep the issues of equity and access to the fore? Can we build into the program safeguards against the women and minority issues receiving only lip service?

How do we keep doors open between technical education and engineering streams, including showing leadership in the K-12 communities from which our students emerge?

2. How do we ensure that the new curricula best meet the evolving needs of the students we are serving?

What engineering skills and attributes will students (majors and non-majors) who are influenced by our programs need to take on disparate roles such practicing engineers, scientists, teachers, social scientists and planners, citizens, leaders of industry and government, setters of technology policy, etc.?

Can we clarify the roles we expect our majors to play in society? What about students who emerge from any new joint programs we might create? Based on these clarifications, what changes must occur within "departmental" offerings and what linkages are sought in broader undergraduate curricula?

Will our new curricula prepare our students to integrate technical, scientific, political, ethical, economic and social and environmental dimensions?

Do degree programs within traditional departmental boundaries adequately meet the professional needs of our students, or should we be thinking of new, trans-departmental degree options?

What mechanisms can we devise to ensure that the new curriculum is consonant with the professional realities that our students will be facing in a rapidly changing economy?

How do we address the needs of older, returning and part-time students, and what is our role in life-long learning?

How will our new curricula be structured to accommodate diversity in learning styles, experience and aspirations?

Many of our students face the probability of employment in a contracting economy. Can we not, as long as we are forging a dramatically new educational process, make sure that we also address finding new mechanisms for making engineering education affordable to a broader spectrum of society?

What kind of mechanisms for evaluating how well we are doing on all of the above can we put in place as part of the program's intrinsic structure.

3. Students are potentially powerful players in the process of educational transformation, rather than merely its beneficiaries. How do we structure the process so as to most effectively collaborate with them, our most natural allies?

Can we design the transformation process to more effectively tie in to the motivation for service that so many of our students exhibit, i.e. an educational service component integrated into the curriculum?

What will be the roles of students in curriculum development and teaching in the new programs?

How do we reward students for involvement in educational change?

What roles ought student societies, e.g. SWE, NSBE etc., play in the change process?

Can we ensure that students will play a central role in evaluation and assessment?

Faculty

1. Who are/should be our faculty?

What are the characteristics of an ideal faculty (as a whole), how does this differ from the current situation? What is the appropriate balance within the faculty (e.g., part-time, adjunct, retired, para-faculty)?

What characteristics should individual faculty members have?

2. How do we develop our faculty?

How do we best prepare faculty?

What kinds of experience should individuals or the faculty as a whole have?

How do we increase recruitment and retention of minorities, women, and persons with disabilities?

How should the hiring process change?

What would be an ideal faculty reward structure? Does it include tenure? How does it differ from the current structure? How do we measure/evaluation faculty work (teaching, research, scholarship, service; quality, productivity, effectiveness)? How does one compare/reward faculty working in different domains? [Dual ladders in industry do not work.] How do we get faculty to change and "buy into" a new reward structure. What is the influence/role of textbook and courseware development?

How do we best educate/train/prepare future faculty? And how do we retrain existing faculty? [Consideration must be given to research, practical engineering, teaching/learning, mentoring/advising.] What is the role of sabbaticals?

How do we help faculty balance conflicting time demands? [Consideration must be given to personal and familial pressures in addition to increased demands from teaching/research/service.] How do we help to integrate their various roles.

3. How do we assist our faculty in their development of curricula?

Faculty are often seen as the major impediment to change. Is this true and, if so, what should be done?

How do we best maintain and improve the quality of instruction, incorporating delivery methods other than lecture and learning systems which work?

How do we disseminate best practices in credible fora (which count toward promotion) while protecting intellectual property?

How do we increase faculty sensitivity and adaptation to increased student diversity?

How do we get institutions to change?

Curricula

1. How do we accommodate differences in the students we serve?

How do we develop curricula that accommodate diversity of learning styles, backgrounds, and outcomes (including non-engineers and non-traditional students)?

How do we adequately address admission of transfer students (including technology graduates, technicians, liberal arts students, returning students, etc.)?

What new delivery methods, and educational technologies should be introduced and/or expanded.

2. How do we accommodate differences in our students professional and personal interests, aspirations, and future achievements?

How do we develop curricula that accommodate actual and potential career paths of our graduates (including professional engineers, managers, entrepreneurs, civic leaders, etc.)

How can we ensure humanistic breadth?

How can we ensure appropriate consideration of the effects of engineered systems on environmental, economic, social, and political systems?

How can we ensure good communications, interaction and teamwork skills?

How can we ensure interdisciplinary, life-long learning skills?

How can we reduce the required, existing content to a realistic level accommodating flexibility, appropriate work load and a 4-year professional degree?

How can we evaluate the effectiveness of the entire curriculum?

How can we best transfer curricula experiences?

What are appropriate structures to achieve our goals (including structures to promote emerging, interdisciplinary areas)?

Experiential/Contextual Learning

1. How do we provide students with the broader (multidisciplinary, international, etc.) contexts within which to view trade-offs (economic, socio-humanistic, energy, materials, etc.) in the design, development, and implementation of engineering systems?

Can we adapt K-12 innovations (collaborative learning, hands-on, etc.)?

How do we inculcate life cycle concerns (including waste and disposal)?

What is the proper level of university-industry interaction (including student work experiences, distance education, etc.)?

What are the desired inter-relationships among faculty, students, and curricula?

What level of technological appreciation is appropriate for non-majors?

2. How do we encourage "world class" design, development, and implementation processes for engineering systems?

What level of linkage is appropriate between technical and managerial studies?

How do we promote closer linkage of engineering design and realization processes?

How do we develop flexible and agile programs?

How do we incorporate "real-world" scenarios and learning?

How to we train our students to operate in entrepreneurial environments?

How do we best develop hands-on, project-oriented classes

What is the role of undergraduate research?

APPENDIX E: BACKGROUND DOCUMENTS

Twenty-six documents relevant to engineering education, manufacturing, and the environment were previewed by Dr. Edward W. Ernst, workshop rapporteur, in order to provide an overview of topical areas for workshop participants. What follows is a chronological bibliography, an analysis and synthesis of the various documents, and annotated summaries of the documents in the bibliography.

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6. *The National Action Agenda for Engineering Education,* Report of an ASEE Task Force American Society for Engineering Education, Washington, DC, November, 1987.

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8. *Report on the National Science Foundation Disciplinary Workshops on Undergraduate Education,* Workshop on Engineering pages 51-55, National Science Foundation, Washington, DC April, 1989.

9. *Scholarship Reconsidered: Priorities of the Professoriate,* Ernest L. Boyer, The Carnegie Foundation for the Advancement of Teaching, Princeton University Press, 1990.

10. *New Challenges in Educating Engineers,* Report of a Conference presented by Illinois Institute of Technology in cooperation with the Association of Independent Technological Universities and the National Science Foundation, June 10-11, 1991, Chicago, IL 1991.

11. *Creating our Common Future,* Frank G. Splitt, International Engineering Consortium, Chicago, Illinois, September 29, 1991.

12. *Amer ·'s Academic Future, A Report of the Presidential Young Investigator Colloquium on U. S. Engineering, M..hematics and Science Education for the Year 2010 and Beyond,* National Science Foundation, Washington, DC January, 1992.

13. *Civil Infrastructure System Research,* Report of a Workshop held by National Science Foundation, Washington, Γ ; April 15, 1992.

14. "Engineering Education: Innovation Through Integration", Joseph Bordogna, Eli Fromm, Edward Ernst, *Journal of Engineering Education,* January 1993, pages 3-8.

15. *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.

16. *The Long View,* National Science Foundation, Directorate for Engineering, September 1993.

17. *Report On The 1993 Industry Summit World Economic Forum,* In Partnership with the Massachusetts Institute of Technology, Cambridge, MA September 9-12, 1993.

18. *Socioengineering,* Norman R. Augustine, Remarks at the University of Colorado Engineering Centennial Convocation, October 1, 1993.

19. *What is at the End of the Technological Rainbow?,* Robert M. White, Remarks to the National Academy of Engineering, October 6, 1993.

20. *Engineers: The Navigators for a Sustainable Future,* George E. Brown, Jr., Representative to Congress from California, Remarks at National Academy of Engineering Symposium on New Directions in Science and Technology, Washington, DC, October 7, 1993.

21. *Engineering a Sustainable Future,* An AAES Policy Statement, American Association of Engineering Societies, Washington, DC.

22. "Studying for the Future: Life-Long Learning in Europe, the U.S. and Japan", Leenamaija Otala, *ASEE Prism*, October 1993, Page 23-29.

23. "Re-engineering Engineering Education", W. M. Spurgeon in *Proceedings of the 23 Annual Frontiers In Education Conference held November 6-9 in Washington, DC*, Lawrence P. Grayson, Ed., Institute of Electrical and Electronic Engineers, IEEE Catalog Number 93CH3373-8, Piscataway, NJ.

24. "Taking the Lead", Winfred M. Phillips, *ASEE Prism*, December 1993, Page 52.

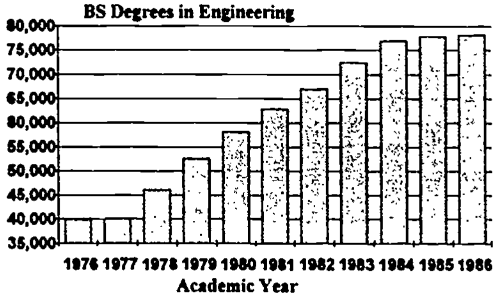
25. *Major Issues in Engineering Education*, A working paper of the National Research Council's Board on Engineering Education, Washington, DC. 1993.

26. *Engineering Education in a Changing World,* a workshop held by the American Society for Engineering Education, February 24-25, 1994. [Formal report released October 1994]

Analysis and Synthesis of Background Documents

[Edward Ernst, workshop rapporteur, provided an overview of relevant documents to the workshop participants. An abridged version of this overview, the viewgraphs presented and the associated commentary, is reproduced below. The numbers in brackets are references in the preceding bibliography.]

Degrees Granted



There was a rapid increase in undergraduate engineering programs over the ten year period 1976 to 1986. During this decade, the number of baccalaureate degrees doubled. The increase in faculty that accompanied this rapid increase was about 10%. Academic year 1985-86 was the peak year and the number of baccalaureate engineering degrees decreased for the years following until about 1993. 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 workshop. However, the issues raised were broader and continue to echo in more recent examinations.

Crisis

- **Faculty Shortage**
- **Action for Change**
- **Quality vs. Quantity**

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) [2] and the American Society for Engineering Education (ASEE) [5]. Indeed for the NRC [2] the perceived crisis in engineering education was a strong factor in the motivation for undertaking the study. And while the NRC [2] 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 [5] perceived that the crisis emphasized the need for new directions in engineering education.

In two additional studies by the NRC [3,4], 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.

Broad Education

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

Several studies, reports, and commentaries [2, 3, 5, 8, 10, 14, 18, 20, 26] advocated a curriculum that offered significant breadth beyond the technical discipline. Even within the technical part of the curriculum, an NRC study [3] as well as a recent NRC working paper [26] urge flexibility and more attention to the use of the computer in engineering courses in addition to the call for better, more relevant labs.

Content and Context

- **Engineering: An integrative process**
- **Technical and**
  - ✓ Economic
  - ✓ Political
  - ✓ Social
  - ✓ Environmental

Following the Grinter Report, engineering curricula included an increasing amount of engineering science that emphasized analysis and specialization of the technical content. Two sources [14] and [16] note this and make the recommendation 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 [16] urges engineering to take the lead in integrating science and engineering. Representative George Brown supports this view when he makes an eloquent plea [20] 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 [1] but with less emphasis than in the later papers. Bordogna, Fromm and Ernst [14] note that engineering's core lies in integrating all knowledge to some purpose.

Manufacturing

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

An early NRC study [1] 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..."

Education: A Continuum

- **Career-long learning**
  - ✓ Rationale
  - ✓ In curriculum
  - ✓ Knowledge base and capability
  - ✓ Motivation and capability
- **Four or five years**
  - ✓ Baccalaureate
  - ✓ Masters

By 1985 many of the leaders in engineering education 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 [5] supported this objective, with a slightly difference 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 [10] and the engineering deans [25] added to the need for a knowledge base and capability the need for the graduates to have a motivation and commitment for career-long learning.

For many years the question of whether the baccalaureate should be four or five years in length was debated. These reports [6, 18, 25, 26] 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.

Faculty

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

There are several issues associated with engineering faculty. The NSF and the NRC [12, 16, 26] express concern that the present recognition and reward systems do not encourage faculty to participate nor strive for excellence in undergraduate teaching. Boyer [9] 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 [5] notes that faculty development must be a structured process and states [6] that faculty development is the responsibility of the faculty member.

Structure

- **Number of schools, programs**
- **Assessment tools**
- **Foreign graduate students**
- **Professional schools**

An ASEE study [6] 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 [5] urged that new PhD programs in engineering not be started but existing programs be expanded to meet the needs.

Discussion at a recent ASEE workshop [25] 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.

This same ASEE workshop [25] noted the increasing fraction of graduate students who are foreign nationals as well as the increased fraction of the PhD degrees awarded to foreign nationals. A working paper of the NRC's Board on

Engineering Education [26] suggests that more US citizens should be encouraged to enter graduate school and continue to the PhD.

One of the task groups reporting in [25] 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.

Interfaces

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

An NSF workshop [8] presented engineering education as a key for retaining US technological preeminence and, hence, US competitiveness. Although Representative George Brown [20] notes that engineers as leaders are needed by the US, conferees drawn from technological institutes noted [10] the perception that engineers, upon graduation, do not aspire to nor attain major leadership positions.

The need for partnership among businesses, governments, and academia emerged as a common thread at the World Economic Forum [17]. Winfred Phillips, Dean of Engineering at the University of Florida, [24] notes the need for partnerships between industry and engineering schools. As a related matter, the concerns for manufacturing engineering education, as reported by the NRC [1], must be seen in the relationship of engineering and business schools, and industry.

Students

- **Focus on learning**
- **Broad career opportunities**
- **Emerging professionals**
- **Engineering and engineering technology**

At the recent ASEE workshop [25] the group on Reinventing Teaching/Learning reported an emphasis on learning uncharacteristic of the early reports. Both ASEE [25] and the NRC [26] 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. These are 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 [14] that engineering educators, "...place primary emphasis on the development of students as emerging professionals..."

Technological Literacy

- **Public**
- **Leaders**
- **US educational system**
- **Higher education faculty**

At the 1993 Industry Summit sponsored by the World Economic Forum [17], Thurow notes that, "It is just as important to have a numerate public as a literate public." The working paper [26] of 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 Martin Lockheed, notes 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 [12] 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..."

Global Future

- Sustainable future
- Environment

The world's environment was offered by the 1993 Industry Summit [17] 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 [16] includes protecting the environment among the nation's most pressing problems. The AAES Policy Statement on Engineering a Sustainable Future [21] 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 Splitt of the National Engineering Consortium when he notes that a sustainable future is threatened by the closely coupled *Four E's*: Environment, Education, Energy, and Economics.

Infrastructure

- Civil infrastructure
- Human infrastructure

An NSF workshop [13] noted that, "...the deterioration of the nation's (civil) infrastructure is a serious problem with profound consequences..." Another NSF workshop [15] 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 [15] to be no less important than the civil infrastructure. Although it is not readily expressed in dollar terms, the annual expenditures are significant. For example, annual expenditures for education exceed $350 billion with $290 billion expended by public institutions.

Economics

- Structural transformation
- Human capital
- Job creation

The report of the 1993 Industry Summit [17] 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 [22] 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 [19], 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 to technological change.

Annotated Summaries of Background Documents

This background information document includes summaries from the 26 reports, papers, presentations, or other items listed in the table of contents. The summaries are an attempt to capture some of the statements from the various items that seem to pertain to the theme and topics for the workshop. Liberal use has been made of the abstracts and the executive summaries where these are available.

To the extent possible, the various items are in chronological sequence with the earliest dates first. Although these items are all from the not-so-distant past (1985-1994) they do show a shift in the concerns about engineering education that seem to reflect shifts in national priorities over this period.

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 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 knowledge, and hence curriculum for both sides....

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 Washington, DC 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. Many of these pertain to topics for the workshop.

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 institutions 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 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 future 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 incorporation 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.

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 bachelors 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 upon 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 that 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 principal 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.Ds....

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 Faculty

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.

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.

1. 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.

Quality of Academic Engineering Programs

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 may result if resources, both human and financial, are not adequate.

Focus on the Future: A National Action Plan for Career-Long Education for Engineers
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 the 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 principal 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 features 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 begin 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 principal 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 the broad sense -- and in the way engineering education is done, and to nurture young people within an educational environment that is alive with exciting change to pursue both challenging industrial and dynamic academic careers. ...The actions recommended focus on human resources, creation of materials for educational use, and the transportability of those resources throughout the nation's engineering education system. In addition to nurturing young people in engineering, these recommendations also stress the need to spread an understanding of technology throughout society as a whole by including engineering concepts in the liberal arts and business educational experiences.

Report of the NSF Workshop on Undergraduate Engineering Education, J. C. Hancock, Chairman, May, 1986.

Scholarship Reconsidered: Priorities of the Professoriate
Ernest L. Boyer
The Carnegie Foundation for the Advancement of Teaching
Princeton University Press, 1990

Boyer's introductory remarks could lead the reader to believe that this book will be an apologia for undergraduate teaching as opposed to research. While the end result is a recommendation that the status of teaching be elevated, the role of research in the university is by no means diminished. Indeed, Boyer succeeds in wrapping the several faces of university life into the single activity of scholarship and exploring the various ways in which that scholarship may be made manifest. Specifically, he describes: the scholarship of discovery; the scholarship of integration; the scholarship of application; and the scholarship of teaching.

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 charge to make *connections across the disciplines* and place *the specialties in larger context.* He even suggests that we have a responsibility *for educating non-specialists, 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 institutional 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 as such 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 allocated 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 life-long 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 over burdened 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 life-long 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
International 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 Workshop held by National Science Foundation 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 subsurface 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
Journal of Engineering Education, January 1993, pages 3-8

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-à-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 expenditures by public institutions accounting for roughly $290 billion of that total -- and education is only one component of human infrastructure investment. Productive human resource investments and well functioning social institutions are critical to economic growth and well-being. We need to know more about the effects of physical infrastructure on work patterns, employment, and incomes.

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 paradigms 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 as 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 Thursday-Sunday, September 9-12

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 OECD 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 Rudenstein at the summit's second plenary. It is an important problem which travels, "We can't just hope for a marvelously scientific solution."

A. A. Loudon, Chairman and Chief Executive Officer of Akzo, was unequivocal about the population problem, "Why is there this population problem and why is it not on the front page of today's politics? The population explosion is the most pressing of all global problems and it should be shifted from its sectarian taboo to the reality of today's politics."

Massachusetts Governor William Weld offered a summary of a number of opinions about the on-going impact of technology: "One point of view holds that jobs will flow steadily out of the developed countries of the world. Another perspective tells us that only the developed countries, with their high levels of education, will be able to participate in the knowledge-based industries of the future." The most hopeful outcome would be a positive-sum game for both the developed and developing world.

Robert Palmer, President of Digital Equipment Corporation noted, "A world wide information infrastructure is being set up that will have a pervasive impact on the global economy. Developing and developed nations alike will be able to participate in its creation, use and -- most importantly -- its benefits." He described microprocessors, storage, and communications as the most visible and dominant of these technologies.

Boris Saltykov, Minister for Science, Higher Education and Technology Policy of Russia, addressed the technology theme. There is a real need, he said, for social and education infrastructure as well as a skilled labor source.

Lester Thurow, Professor of Management and Economics at the Sloan School of Management referred to the large number of Asian students studying in the U.S. China, like other Asian countries, is getting a "human Marshall plan" in the form of students who carry the benefits of their American educations back home. "To some extent, we pump information to the rest of the world, but we are also a siphon to bring information back."

The need to focus on education was acknowledged by panelists to be of critical importance and not just in the Third World. Thurow noted, "There is a great divide between those who have educational skills and those who don't." In Eastern Asia the average peasant is willing to make great sacrifices to make sure he will have literate children. Currently in the U.S., Thurow added, 29 percent of young Americans drop out of high school. In addition, the world is moving in a more mathematical direction, Thurow noted. "It is just as important to have a numerate public as a literate public."

Global interaction was recognized as not simply desirable in today's world, but absolutely necessary.

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 elements:

1. Emphasize the basics.
2. Develop team skills.
3. Teach the political process.
4. Develop communications skills.
5. Place greater emphasis on "systems engineering."
6. Understand the internationalization of human activity.
7. Open the doors wider to women and minorities.
8. Commit to continuing education.
9. Assure that an engineering education is affordable.
10. Require a five to six year course of study for an engineering degree.

Today it takes *seven* years to train a lawyer, *eight* years to produce a medical doctor; but only *four* years to anoint an engineer. ...We should continue the current so-called "four-year" bachelor's program. ...The basic engineering degree should become the masters degree, and the entire curriculum should be revamped to center around that longer and more extensive program.

What is at the End of the Technological Rainbow?

Robert M. White
National Academy of Engineering
October 6, 1993

History has proven that technological change is the pathway to economic growth and higher standards of living for our citizens. But persistent high levels of unemployment are in part frequently laid at our technological doorstep. ...Our studies at the academies have shown that technological advance has been the most powerful job creation mechanism society has devised.. At the same time, the introduction of new technology has changed and eliminated many jobs.

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. ...It is strongly influenced by economic, trade, and political forces. ...Technological change affects domestic employment both positively and negatively in direct and indirect ways. Indirectly, technological forces underlie the integration of the global economy. It is modern communications and air transportation that enable the world-wide operations of modern industrial corporations. Technological forces underlie the intense global competitive situation, which in turn generates the need to have access to foreign markets, to lower costs or production, and to capitalize on capabilities in engineering and technology throughout the world....

It is often only in the long-term that the technological effects become apparent in our national statistics. Many technological advances do not diffuse into the economy rapidly. ...It takes years for new industries to become major employers.... The effects of the job displacement are frequently regional or industry specific and make little imprint on overall national employment in the short-term. But integrated over the long-term the effects add up as other causes of unemployment fluctuate over time....

Morgan Stanley economist, Steven Roach has noted that white collar unemployment has now reached parity with blue collar unemployment for the first time. This phenomena raises questions of whether the services industries will remain the engine of job growth as they have been in the past. Indeed, the same forces that have slowed the growth of manufacturing employment while raising manufacturing output appear to be affecting many service industries...

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.

Engineers: The Navigators for a Sustainable Future
George E. Brown, Jr., Representative to Congress from California
Remarks at National Academy of Engineering
Symposium on New Directions in Science and Technology
Washington, DC
October 7, 1993

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 usually 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 retrain 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
Leenamaija Otala
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 issue 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, the 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 summary is produced from personal notes. The formal proceedings of this workshop are available from the American Society for Engineering Education] The workshop involved over 60 individuals, most of whom were deans of engineering, reflecting the sponsorship of the Engineering Deans Council. Except for a keynote address by Charles Vest, President of MIT, and luncheon addresses by Joe Bordogna, Assistant Director for Engineering of NSF, and Norman Augustine, CEO of Martin-Marietta Corporation, the workshop focused on the discussions of five task groups.

1. Reinventing Teaching/Learning
2. Value Added of Undergraduate Education
3. Life-long Learning
4. Graduate Education and Research
5. The New Vision of the University

The five task groups met in parallel for three periods, twice on the first day and once on the second day. At the end of the first day the entire group gathered to hear reports from each of the five task groups. This was repeated the afternoon of the second day, with more time allowed for discussion.

The discussions in each task group appeared to be wide ranging and efforts were made to focus on action oriented recommendations. Some of the highlights of the task group reports are given in the following paragraphs.

Reinventing Teaching/Learning

This group considered several elements that impact the teaching/learning environment.

- Technology
- Classroom arrangement
- Roles: students, faculty, administrators
- Student outcomes: a) what students DO, what students BECOME.

The various sectors involved/served need to be considered as well.

- Engineering education community
- Government
- Industry and business
- Foundations
- Pre-college community (this includes both the students and their families)
- Taxpayers

The recommendations of the group focused on areas for change.

1. Productively apply modern learning theory
2. Re-focus the faculty value and reward system
3. Include broad based non-classroom experience: a) workplace experience, b) laboratory/research experience, c) co-curricular activity, d) extra curricular activity
4. Foster an environment supportive of students

Value Added by Undergraduate Education

Underlining the discussion of this task force are several broadly accepted characteristics:

1. A sound technical education is a given.
2. A functional graduating engineer (flexible and adaptive) is expected.
3. Accommodates a diverse student body.
4. Emphasizes experiential as well as doctrinal material.

Recommendations:

1. Endorse the paradigm of a context based set of programs as the foundation for ABET accreditation.
2. Form a task force to define the core attributes of an engineer.
3. Develop a library of assessment tools, including surveys for employers and graduates.
4. Ensure: a) practical experience in the undergraduate curriculum, b) integration across disciplines, c) sensitivity to public opinion.
5. Acknowledge multiple career paths, both within and between employers: a) finance, b) entertainment, c) medicine, d) "servicing" the service industry, e) opportunistic.
6. Be mindful of new educational modalities.

Research and Graduate Education

This group offers three strategic themes for change:

1. The post baccalaureate degree of the 21st century.
2. An economic model for funding research and graduate education.
3. Faculty professional activity models.

Recommendations:

1. Develop a practice oriented master of engineering program.
2. Create co-op, internships, and teamwork experiences for graduate programs, including the Ph.D.
3. Provide new educational programs for leadership.

4. Enrollments in doctoral programs should realistically reflect U.S. career opportunities and national demographics.
5. Achieve excellence by having a strategic focus on a limited number of research programs; obtain breadth through inter-institutional collaboration.
6. Develop professional education programs as revenue centers.
7. All federal funding for science and technology programs should use peer review and open competition.
8. Enhance technology transfer and industry/university partnership through flexible intellectual property policies.
9. The public policy committee of ASEE should improve both its communication and influence with congress.
10. Recognize and reward diverse faculty contributions.
11. Explore new organizational structures to foster inter-disciplinary research and inter-disciplinary educational programs.
12. Develop mutually beneficial programs to enhance personnel exchange between industry, academe, government.

Life-long Learning

Life-long learning involves several sectors of our society: a) government (NSF), b) universities (education), c) industry (training), d) practicing engineers (they have a need for life-long learning).

Conclusions

1. Students must learn how to learn on their own.
2. The modalities available for life-long learning may not match the needs and capabilities of the student (the life-long learner).

Recommendations:

1. Inculcate in the graduate the desire for life-long learning.
2. Convince the undergraduate student that life-long learning is important.
3. Offer life-long learning seminars on a regional basis to help identify and understand life-long learning needs.
4. Make these life-long learning needs known broadly.

Questions:

1. How does the engineering college recover the costs of offering life-long learning opportunities?
2. How can appropriate awards for participants be provided to both life-long learning students and to participating faculty?

New Vision of the University

A new vision for the university focuses on serving the multiple customers for the multiple services offered: education, research, service. These customers include: students, employers, industry, and government. In addition, we need to recognize our competitors: foreign universities, national laboratories, not-for-profit research institutes.

Recommendations:

- **Life-long learning**: The baccalaureate program should be designed by engineering faculty to provide not only the knowledge base, but of even greater importance, the motivation and capability for life-long learning.
- **Success oriented strategy**: Engineering faculty should redesign the engineering education experience to provide a success oriented environment. The diversity of students in terms of demographics, academic preparation, and experience with technology should be recognized. The variety of ways in which students learn should be better understood to help develop and select appropriate teaching methods. Information/communication/education technology should enhance student learning. New metrics for assessing student learning are needed that helps students and faculty determine progress toward goals. The Engineering Deans Council should take action to collect meaningful data on undergraduate engineering retention. Such data should be published in suitable form.
- **Assessment**: The present Task Force on Engineering Competency Assessment should shift its focus to an exploration of processes and methods for assessment of the quality of engineering education programs. The Task Force should reconstitute itself and ABET should be asked to assume the role of secretariat for the Task Force.
- **Professional School**: The Law, Medical, and Business schools serve to demonstrate elements of the model for an engineering school as opposed to science departments which are the model for most engineering colleges today. Some elements that may be different in the professional school as envisioned are:
  - Departmental structure;
  - An engineering clinic that serves industry and government to provide teaching opportunities as well as income from the fees charged;
  - A continuing education function to meet the needs for life-long learning;
  - A master of engineering program that is more than a stepping stone to a Ph.D.;

- A research/graduate study program with MS and Ph.D. degrees modeled on the present research/graduate study programs;
- A four-year baccalaureate preceding the master of engineering degree. This is a degree program with greater breadth that precedes the technical depths of the master of engineering and provides the basis for other professional education and other non-engineering professional careers.

Board on Engineering Education
A Working Paper
Major Issues in Engineering Education

[This summary is produced from working documents and personal notes. The formal report is expected to be available from the National Research Council after April 1995.]

Introduction

The symposium on February 28, 1994 at the San Francisco Airport Hilton was the third of four such meetings organized by the Board on Engineering Education to discuss the topic, *Major Issues in Engineering Education*. Discussion at each meeting is focused by a Working Paper prepared by the Board and distributed in advance to those participating . The agenda is organized in a sequence of sessions each with a brief presentation about a topic by a member of the Board of Engineering Education, followed by general discussion. The time allotted for each of the sessions ranges from 30 minutes to about an hour.

Engineering education has been the subject of periodic evaluations for much of this century. A number of these from 1930 to 1985 have contributed to a strong sense of "where we are now" and "where we ought to go" in engineering education. These reports appear to have been heeded by major decision makers in both academe and government. The reports were not revolutionary. Rather, they described and reinforced principles that are basic to engineering education.

- The need for strong grounding in the fundamentals of mathematics and the physical and engineering sciences;
- The importance of design and laboratory experimentation;
- The development of communication and social skills in young engineers;
- The need for integration of social and economic studies and liberal arts into the curriculum;
- The importance of good teaching and attention to curriculum development; and
- The need to prepare students for career-long learning.

Today, the central themes for engineering education are the same but the emphasis and the approaches are different.

A Vision for Engineering Education

The Working Paper presents a vision for engineering education that is broad and forward looking. It paints a picture of engineering and engineering education that is much different than today. In this picture engineering education:

- Offers a broad liberal education that provides the diversity and breadth needed for engineering;
- Prepares for entry into careers and further study in both the engineering and non-engineering marketplace;
- Develops the motivation, capability, and knowledge base for life-long learning;
- Provides an academic environment that encourages and rewards faculty for excellence in both teaching and research;
- Teaches the public to appreciate the value of engineering and an engineering education.

Major Issues in Engineering Education - Some Options for Action

Each of the major issues (A through G) identified by the Board on Engineering Education is addressed in the Working Paper and during the discussions.

A. The Student Pipeline: Access Issues

In addition to the often repeated statements about the need to increase the number of women and under-represented minorities in the profession, among the graduates, and in the engineering student body, the Working Paper highlights several intervention strategies that seem to have had a positive impact. The paper also notes a need in both the pre-college and college years to allow for individual variation in abilities and backgrounds. The concern about adequate preparation in mathematics and science suggests that efforts are needed to gain broad acceptance of the view that a *good education* must include math, science, and technology.

B. The Undergraduate Engineering Experience

This issue covers: 1) the curriculum, 2) teaching methods, 3) retention, 4) the four-year baccalaureate model. A more integrated curriculum is suggested in which the segmentation of mathematics, basic science, engineering science, design, experimentation, and humanities and social sciences are de-emphasized. The discussions suggest a need to recognize that design and experimentation are as fundamental for engineering study as mathematics, basic science, and engineering science. For today's engineering workplace it is important that the graduate understand the context of engineering as well as the technical content.

Curricular structures may be a barrier to needed innovation. Efforts are needed to develop new curricular models including those with significant flexibility. Perhaps a new paradigm is needed.

In changing the engineering education experience, it is important to provide funding for adopting, adapting, and implementing innovation developed elsewhere as well as the development of innovative curricula, methods, and approaches.

Several questions are raised about whether the teaching methods used today are appropriate, and several infrequently used methods are offered for consideration. Much is known about teaching and learning that seems to be ignored in engineering education. Perhaps a new model for learning and for student-faculty interaction is needed in engineering education.

The retention of engineering students from matriculation to graduation seems unnecessarily low. In the past this was considered a strength -- a necessary "weeding out" of students inadequately prepared or insufficiently motivated. Today's environment questions whether this is either necessary or desirable. Changes in curricula and teaching methods should be those that positively impact retention. An emphasis on student-faculty interaction deserves attention here.

The question of whether engineering should be a four-year baccalaureate program is visited once again. The answer is clearly yes, but even more education is needed. The diversity of the workplace for engineering graduates requires that an engineering education be flexible, diverse, broad and personalized. The four-year baccalaureate degree (of about 120 semester hours) is a basic building block for engineering education. For some students this leads directly to careers. For many others additional formal, full-time education is required. For the design, development, and research careers on which most of today's engineering curricula are focused, post-baccalaureate study is an imperative. For some, it should be the research oriented masters and doctorate programs that are so successful. For others, a masters degree for the engineering professional, different than most current engineering masters degrees, is needed. The baccalaureate in engineering should be a liberal education with emphasis on engineering and science and the context in which engineering is practiced. The baccalaureate graduate in engineering would be prepared for graduate and professional study in engineering and other fields and for careers in marketing, management, and other areas. The knowledge base, motivation, and capability for life-long learning should be a hallmark of the baccalaureate in engineering.

C. Graduate Engineering Education

Concerns for this issue include: 1) preserving our pre-eminence in graduate education, 2) practice-oriented graduate study, 3) participation by foreign nationals in US engineering graduate programs. Although arbitrary limitation on foreign graduate students in US graduate engineering programs seems unwise, steps are needed to increase the participation of US citizens in graduate engineering programs at both the masters and doctorate levels. Some problems that appear to surface with foreign graduate students suggest that the schools should implement standards of excellence for communication in English and in cultural sensitivity for all graduate students.

D. State of the Engineering Professoriate

Any changes in engineering education such as those considered in this paper depend very much on the engineering professoriate. The question is whether the environment for the faculty is appropriate for stimulating and nurturing the changes needed.

The engineering faculty reward system is the first and may well be the most critical item addressed. The present system seems to create a bias that favors research over undergraduate teaching. An obvious remedy is to strike a more appropriate balance between teaching and research in the faculty reward system. Here, the comments of Ernest Boyer in his monograph, "Scholarship Rediscovered: Priorities of the Professoriate," offer guidance. However, it seems necessary that, in addition to a broader view of research (Boyer would use the term scholarship), faculty include a balance of teaching and research (scholarship) in what they do and that both shall be evaluated and both must be of acceptable quality.

A second concern is the present lack of diversity among the faculty in several aspects: gender, race, ethnic background, industry and government involvement, management perspectives, and others.

The professional development of the faculty must become a concern of the faculty, both individually and collectively. The university must support these efforts.

E. Continuing Education of Engineers and Other Technical Personnel

The "system" needed for the continuing education of engineers and other technical personnel is yet to be designed/developed. A primary goal for the baccalaureate engineering program must be to provide the knowledge base, the capability, and the motivation for life-long learning. We do poorly on providing the capability as we know too little about what this involves, along with what the "system" involves. Responsibility for life-long learning rests with the engineer, supported as needed by the employer. The "system" involves engineering schools, professional societies, private vendors, and others.

A study is needed to understand the nature of this "system," what is needed, and what should be put in place to meet these needs. We should recognize that engineering education is a continuum, extending from kindergarten to retirement. Life-long learning begins early.

F. The Cost of an Engineering Education

The escalation of the cost of higher education concerns many individuals. Engineering education is, if anything, more expensive than higher education in general. Among the items discussed, two should be noted: 1) find ways to increase or maintain teaching productivity while retaining or enhancing quality, 2) identify new funding sources.

G. Technological Literacy

In our intensely technological era, 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. This concept has been termed "technological literacy."

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. This must be followed by the acceptance of this commitment on the part of engineering faculty by non-engineering faculty who must recognize and accept engineering as part of the broad liberal education needed by all students.

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