Broadening the Engineering Curriculum and Infrastructure

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Abstract *— This paper reports the inception and progress of a comprehensive program to alter an engineering curriculum and provide supporting infrastructure for a paradigm shift from teaching technical topics in depth to an emphasis on learning with breadth. The College of Engineering at the University of Notre Dame in the USA has successfully implemented curriculum enhancements that broaden the learning experience. These include new project-based courses for first-year students, relaxation of course requirements to allow greater diversity, expansion of foreign study programs, new electives in business and entrepreneurship, and modernization of the science and technology courses. Supporting infrastructure includes a new learning center/laboratory, and supporting faculty and staff. Programs with other colleges in the university allow students to earn an engineering degree together with a degree in arts & letters, business or law. Programs with industry and other universities provide internship and research opportunities. Motivation, details, and efficacy of this ongoing effort, together with supporting evidence, are described in this report.*

Index Terms *— Curriculum enhancement, design teams, foreign study, learning center.*

INTRODUCTION

It is often said that change is a good thing. This is true of the educational system as well. But making changes in any curriculum of the university is indeed difficult, as it seems that no system has more inertia. Today, with the increasing changes in technology, it is difficult for the university not to respond in kind. While it is easy enough to avoid radical changes in the content or approach of disciplines such as language or history, engineering does not have the same luxury. Students must stay current in their fields if they are to be practicing professionals. Another aspect, that increasingly affects all curriculums has two parts: the students who now arrive imbued with new modes of learning, and the increasingly technological way in which education is delivered. A change in paradigm has occurred in education in general that is forcing universities to change many things. The new paradigm is learning versus the old way, i.e. teaching. How is this impacting engineering education? How do we meet the expectations of both students and parents that are rising at the same time? The latter is not too surprising given the step rise in the cost of higher education in the United States.

Over the last fifteen years at least, reports emanated from a variety of sources calling for changes in both content and pedagogy [1]-[6]. Due to inertia, changes were minimal. However, ABET, the accrediting agency for engineering programs has over the last 15 years studied how the process took place and found the need for significant change. At the same time, governments were asking for more accountability from the educational establishment. Thus ABET changed the process of accreditation to an assessment-based approach and phased it in over a six year period, calling the new criteria EC 2000 [7]. Most universities have now accepted this change and are moving forward under necessity if nothing else. At the same time, this change provided an opportunity for each program to go beyond simply setting up an assessment process, but also to revisit the curriculum and how it is delivered. Notre Dame has been no exception.

In 1998, with the encouragement and guidance of a new dean, it was time to revisit the six engineering programs in the college. Aside from a number of smaller recommendations, two themes emerged: a change of paradigm from teaching to learning, and significant changes in the first year curriculum for those headed to an engineering program [8]. Many of the suggested recommendations have been implemented in an evolutionary fashion. This paper presents an overview of our pedagogical accomplishments and innovations in engineering education for the new century.

CURRICULUM ENHANCEMENTS

To prepare graduates for the 21st-century engineering workplace, the College of Engineering revised the four-year undergraduate curriculum of each department. A sequence of two courses in the first year provides exposure to basic concepts in all of the engineering disciplines, with hands-on laboratory design activity in a new learning center. These courses give motivation for continuation in engineering, and background for selection of a degree program for the ensuing

three years. A relaxation in the requirement to take certain courses allows selection from a broader range of new technical and business electives.

The First-Year Engineering Curriculum

Undergraduate students at Notre Dame initially enroll in the First Year of Studies, after which they enroll in a specific department in one of the colleges, or in the School of Architecture. The undergraduate colleges are Arts & Letters, Business, Engineering, and Science. The College of Engineering contains departments of Aerospace & Mechanical Engineering, Chemical Engineering, Civil Engineering & Geological Science, Computer Science & Engineering, and Electrical Engineering. First-year students who intend to pursue engineering take a fixed curriculum that prepares them to enter any one of the five engineering departments in their second academic year.

The first-year curriculum for engineering intents enrolled on or before the fall semester of 1999 is shown in Table I. The current curriculum for enrollees in 2000 and later is shown in Table II. Common to both curricula are two semesters of calculus with lecture and recitation, two semesters of chemistry (one with a laboratory), English Composition, University Seminar, and an Arts & Letters elective. The required physics sequence was changed from three 3.5 credit hour courses to two 4-credit courses. In both instances, one required physics course is taken after the first year. The new curriculum replaces the physics course in the first semester with an Arts & Letters elective to allow students to develop their mathematical skills in preparation for the revised physics course in the second semester. The new engineering physics sequence contains a third course that is required for upper class students in specific degree programs.

The major change in the first year curriculum is the introduction of a new two-semester Introduction to Engineering course designed to build the foundation for the departmental degree programs and to generate interest and excitement in engineering. Based in the Engineering Learning Center, this is an interactive sequence where students are assigned projects that focus on multidisciplinary systems. They work in teams using engineering models to analyze, build test, and demonstrate their designs, while documenting their rationale and design decisions. The basic objectives of the sequence are:

- **Basic Engineering**: Problem formulation, analysis and modeling. Use of graphical data, data collection, and design of experiments. Fabrication of practical engineering systems.
- **Basic Computer Skills**: Computer operation and application programs. Engineering analysis with MATLAB, Maple, Excel. Generation of graphs and technical reports.
- **Leadership and Professional Skills**: Improve skills in teamwork, writing, visual and oral communications. Provide time management, study and research skills.
- **Engineering as a Profession**: Introduce the history of engineering and its role in society. Provide guest speakers from varied fields including business. Familiarize students with engineering disciplines and degree programs.

Engineering Design Modules and Courses

The hands-on design team approach of the first year now permeates the engineering curriculum through the senior year. Capstone design courses, multi-discipline design experiences, and GE Learning Modules allow students to hone their technical, interpersonal and communication skills. The General Electric Corporation supported engineering faculty to develop multi-disciplinary learning modules that have been integrated into the course activities of several departments at the sophomore, junior and senior level. The Engineering Learning Center currently supports the following modules:

- Autonomous robots
- Embedded microcontrollers and microcontroller interfacing
- Remote sensing and data acquisition in microprocessor-based systems
- Degradation of organic contaminants in groundwater
- Microelectromechanical systems (MEMS)
- Satellite communications

The college requires all seniors to participate in a design experience. Each department offers one or more design courses. Teams of students from several engineering disciplines execute many of the design projects. Design courses include:

- **Computer System Design**: Teams use commercial CAD tools to design and construct a board-level digital system.
- **VLSI Design**: Teams use commercial CAD tools to design a complex application-specific integrated circuit. Designs are submitted to a commercial foundry for fabrication. The IC chips are returned to the campus for test and verification.
- **Aerospace System Design**: Each team is responsible for the conception, proposal, design and fabrication of a flying aircraft prototype.
- **EE Senior Design**: A two-semester sequence in which teams interface with professional engineers on projects proposed by off-campus engineering firms. Activity proceeds from concept through fabrication, testing and reporting.
- **Mechanical System Design**: Each team develops, fabricates and demonstrates its own solution to a specified problem.

The Integrated Engineering & Business Practices Program

An engineer with 30 years of worldwide management experience at the IBM Corporation teaches this two-semester sequence. It allows students to understand the fundamental functional areas of a corporation, establish an ethical perspective of the role of engineering in business, and build the interpersonal, team, and management skills required for significant contributions to a business enterprise.

The first course, ***Integrated Engineering & Business Fundamentals***, covers the following topic areas:

- The Corporation and Its Financial Processes
- Human Resources and Management Processes
- Innovation Processes, Including Project Management
- Supply Chain Processes and Quality

The second course, ***Advanced Integrated Engineering & Business***, builds on the fundamentals with practice:

- **Business trends:** eBusiness, globalization, outsourcing, entrepreneurship, presentations, business plans, and logistics.
- **Simulation:** A capstone project in which teams execute a computer-aided business simulation.
- **Case Studies:** Examples of business successes and failures, and special presentation projects.

RESEARCH SUPPORT

The College of Engineering involves its students in both theoretical and applied research, as much as possible. Ideally, it would be desirable for all students to have some research experience, but practically this is unrealistic. The intent is to better prepare those with an interest in pursuing graduate studies and to encourage those who may not have thought about such a possibility. It also provides a different approach to learning for those who want to broaden their education. Several opportunities exist, in many ways not unlike those that other institutions, but some are unique.

- **Pure Research:** Many faculty take one or two undergraduates as real working partners in their research programs, having them work much like graduate students, but in a less intense and time-consuming way because of the course loads they carry. During the academic year, students receive research credit toward their degree requirements. If students are available during the summer, they may be hired for a stipend and work full time on the project. Some of these arrangements can last for a semester and others for several years. It is an excellent way to provide a real experience in preparation for graduate studies. The students often become co-authors to papers for conferences or journals. Both theoretical research and applied research operate in this mode. This experience is an excellent way of preparing students to apply for such awards as a NSF fellowship, a Rhodes or Marshall Scholar, or a Goldwater or Udall Scholarship.
- **Research Experience for Undergraduates (REU):** This program is run as a supplementary part of an active NSF research grant, with separate application and funding. It allows a principal investigator to hire with up to ten students from the home university or other universities in the US for up to ten weeks to do research. Students can usually find at least one project nationwide that covers an area of interest, and the interaction with a mentor and several graduate students in a top laboratory can be a life-changing experience. Many of our faculty members offer these in the college each summer with students coming from here and many other places. Again, these experiences are important for applications to the most prestigious graduate schools and for the top awards.
- **Engineering Projects In Community Service (EPICS):** Started by Purdue University's Schools of Engineering in 1996, the EPICS program was brought to Notre Dame and several other universities in a consortium format. Students sign up to work on various projects sponsored by local not-for-profit agencies in the community. Together with a faculty mentor, they write a proposal and then work in teams with the agency to see that the project is completed. Projects can last more than one semester when some students leave the team and others join the team, thus providing some continuity for as long as necessary to complete the assignment. Ideally, the student members of an EPICS team are drawn from several engineering disciplines, with others possibly coming from the liberal arts and business. The faculty members of an EPICS group do not act as group leaders. Their primary role is to serve as consultants to the student group members. At the end of a semester, each student's course grade is based upon evaluations by the customer, the faculty, and each of the group co-workers. This is intended to mirror the evaluation mechanisms that students will face in industry:

STUDY-ABROAD PROGRAMS

The University of Notre Dame established foreign study programs over 30 years ago [9]. These programs started very modestly, with a small number of students. The original locations available for a year of study were in Angers, France and in Innsbruck, Austria. This concept has proven successful for the University of Notre Dame over the years, and has now expanded to over eleven sites throughout the world, each of which has unique and special characteristics. Table III shows data on some these sites. Special arrangements are facilitated in five other locations. Many of the regular programs have grown to the extent that they are always oversubscribed, and Notre Dame currently has the largest percentage of

undergraduate students studying abroad among all the research universities in the country [10]. It should be noted that the Notre Dame overseas undergraduate programs are not open to students of other universities.

Engineering undergraduate students in the standard four-year programs can participate in the Summer Engineering Program in London, and/or spend the first semester of their junior year in the London program or in the Perth, Australia program. The College of Engineering determined that the first semester of the junior year is the appropriate time for its students to study abroad. This allows students two years to prepare properly for the experience, and one year afterwards to integrate it into the final year before graduation. Notre Dame professors and local adjunct professors teach the required engineering courses at these sites. This allows students to maintain continuity in their academic programs upon returning to the home campus in the spring semester. As indicated in Table III, the most popular undergraduate study-abroad program is located in London. The current facility at the northwest corner of Trafalgar Square provides 27,000 square feet on six levels, to accommodate the undergraduate programs as well as graduate programs in Law and Business Administration [11].

Students can obtain a dual degree in Engineering and their choice of major with in the College of Arts and Letters in a five-year program. The engineering executive in modern industry should have a broad background in cultural, social and technical subjects. Some allowance is made for this in the prescribed four-year curricula but, in view of the extent of the technical field that must be presented, coverage of the cultural field is necessarily limited. To provide the broader opportunity, the College of Engineering, in co-operation with the College of Arts and Letters, instituted in 1952 five-year programs combining the basic stem of the liberal arts program with the technical requirements of the various engineering programs. The student completing one of these combination programs will be awarded two degrees: the degree of Bachelor of Arts, and the degree of Bachelor of Science in the professional course pursued. This program allows a student to study a foreign language in the first year, and spend the second year abroad in a country such as France or Austria, where courses are taught in the local language.

SPECIAL PROGRAMS

Within the context of the changes being discussed, one new program has been established and another given more visibility. The former is the formation of a program to specifically address the issues related to our women engineers and the latter is the engineering program for minority students.

- **Program for Women Engineers:** This is the newest element in the mosaic that makes up the College of Engineering. Because of the ongoing need for engineers and the fact that women constitute only about 22 percent of the engineering student population both at Notre Dame and nationwide, the college established a program to deal with issues that impact our female engineers. The number of engineers on campus is relatively small (740 out of 6850), excluding first year students. We also observed that the retention rate for female engineering students was less than that of their male counterparts. An engineer herself, with significant engineering experience, the director of this program focuses on these and other issues that affect our female enrollment in significant ways, including outreach to females in middle schools and high schools. Using the university chapter of the Society of Women Engineers (SWE) as a resource, the program is clearly making an impact after only one year of operation. It is anticipated that measurable improvement will manifest itself in the next several years.
- **The Minority Engineering Program (MEP):** Over a decade ago, a need was seen to increase the population of minority students in the engineering college at Notre Dame, and to insure a high retention rate overall. While the university has an office of diversity and minority affairs, the College of Engineering is unique among the colleges at the university in having its own minorities program director. Various programs have been put into place to insure a high retention rate and to insure overall success of our students. These include Academic Excellence Workshops and a special course designed to expose the students to techniques for mastering excellence in engineering classes. In addition, various outreach programs have been established to reach K-12 students. While the numbers are not huge, the retention rate from second through fourth year is over 95%. This is in keeping with both the university and college graduation rate of 95% in all of the four-year programs.

INFRASTRUCTURE

Support for the new curriculum with hands-on multidisciplinary engineering team projects in the first year requires infrastructure to provide training for the faculty and teaching assistants as well as appropriate laboratory space. The Notre Dame Kaneb Center for Teaching and Learning provides training; the Engineering Learning Center currently provides the space. A proposed Multidisciplinary Engineering Education and Research Building will expand and enhance that space. The Kaneb Center and the Learning Center both have directors and professional staffs that are dedicated to assisting the faculty and students in optimizing the learning experience at Notre Dame.

University Kaneb Center for Teaching and Learning

The mission of the University Kaneb Center is to enhance student learning by serving faculty and teaching assistants in their teaching roles. The center collaborates with colleges and the administration to shape policies, structures, and cultures that support teaching and learning, and to help Notre Dame participate strongly in the national conversation about teaching and learning. The Kaneb Center has worked closely with the engineering faculty and teaching assistants to optimize student learning through the most effective pedagogical techniques.

College of Engineering Multidisciplinary Learning Center

The current 4,000-sq.-ft. center was completed in September 2000 by replacing the auditorium in the Cushing Hall of Engineering. It is a combination of computer clusters, design studio, laboratory, reference center, multimedia/presentation area, and study space [12]. Although created with first-year students in mind, students at all levels in all engineering departments use it. Several upper-level capstone design courses conduct projects in the center. Some courses hold oral presentations in the center, or use it for software tutorials.

Proposed Multidisciplinary Engineering Education and Research Building

Based on the success of the current learning center, construction of a new 15,000-sq.-ft. center is planned. It will be housed in a new facility, the Multidisciplinary Engineering and Research Building. It will provide cutting-edge design, fabrication, and presentation facilities, additional interactive learning modules, and more hands-on engineering experiences.

SUMMARY

Clearly, we have reported a work in progress. After starting in 1999, the college continues to assess the progress being made toward providing, as stated in [8], a *preeminent engineering education*. The student response is enthusiastically positive. Many, faculty, staff and administrators have worked diligently in this effort. More details of their efforts and outcomes have been reported [13]-[16]. The dean of engineering provides the support and determination to carry on this effort as rapidly as resources allow. He obtained support of the university administration in the development of the current engineering learning center. He also obtained university endorsement of the proposed engineering education and research building, with the highest priority of the development office to procure the funds.

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FIGURES AND TABLES

TABLE I
FORMER FIRST YEAR ENGINEERING CURRICULUM

Fall Semester	Hrs	Spring Semester	Hrs
Calculus I	4	Calculus II	4
General Chemistry I	3	General Chemistry II	4
Engineering Concepts	3	Arts & Letters Elective	3
General Physics I	3.5	General Physics II	3.5
English Composition	3	University Seminar	3
Physical Education	0	Physical Education	0
Total Credit Hours	16.5	Total Credit Hours	17.5

TABLE II
CURRENT FIRST YEAR ENGINEERING CURRICULUM

Fall Semester	Hrs	Spring Semester	Hrs
Calculus I	4	Calculus II	4
General Chemistry I	3	General Chemistry II	4
Intro to Engineering I	3	Intro to Engineering II	3
Arts & Letters Elective	3	General Physics I	4
English Composition	3	University Seminar	3
Total Credit Hours	16	Total Credit Hours	18

TABLE III
NOTRE DAME OVERSEAS STUDY PROGRAM SITES

Location	Term	Began	Eg	Total	Programs
London, England	sem	1981	42	169	All
London, England	sum	1988	29	108	All
Angers, France	yr	1966	0	36	Bus, Hum
Dublin, Ireland	yr	1998	2	46	All
Perth, Australia	sem	2001	8	28	All
Fremantle, Australia	yr	1998	0	31	Bus, Hum, Sci
Monterrey, Mexico	sem		2	4	Bus, Hum
Nagoya, Japan	sem	1974	0	0	Bus, Hum
Innsbruck, Austria	yr	1964	0	19	Bus, Hum
Toledo, Spain	yr		2	40	Bus, Hum
Jerusalem, Israel	yr		0	0	Hum
Rome, Italy	yr	1969	0	61	Arch

All = Engineering, Business, Humanities, and Science.
Eg and Total = Number of students enrolled for Summer and Fall, 2002