Int. J. Engng Ed. Vol. 9, No. 1, pp. 56–59, 1993
Printed in Great Britain.

0742–0269/91 $3.00+0.00

New Directions in Engineering Education at New Jersey Institute of Technology

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New Jersey Institute of Technology has a number of new instruction and research programs currently implemented or planned, that are interdisciplinary, integrative, applications-oriented, and strongly design-focused. These programs are designed to prepare students for rapidly changing technologies and workplace demands, and to address concerns about international competitiveness. Changes include an emphasis on collaborative approaches to problem formulation and resolution, and the development of communications and critical thinking skills. This paper describes these curriculum innovations at the pre-college, baccalaureate, and Master's levels, and also discusses the role of NJIT's major research centers in student education. Planned next steps include incorporation of pollution prevention studies across the curriculum as part of a major National Science Foundation grant.

THE IMPERATIVE FOR CHANGE

A NUMBER of common themes influence the perception of a need for major changes in engineering education. Among these themes are the challenge of rapidly changing technologies; the need for the US to be competitive on an international scale; the importance of competnt product design; the need to strengthen students' communication skills; increasing significance of international and multicultural aspects of engineering; the importance of easing transitions between high school and college, and from undergraduate to graduate studies; diversity issues involving women and minorities; and general concerns about the overall quality of education in the US.

A significant change involves the paradigm shift from focusing on attrition of students as a measure of high institutional standards, to focusing on retention.

Another critical shift is the movement away from placing scientific aspects of engineering at the top of the education pyramid. Practical and integrative aspects of engineering are viewed as increasingly important.

An important driving factor of these concerns is wealth creation. A properly educated engineer is able to contribute productively to the economic well-being of individuals, organizations, and society. They produce value through their work, and also create new industries that create jobs for others.

CHANGES AND INNOVATIONS AT NEW JERSEY INSTITUTE OF TECHNOLOGY

In line with its mission as a comprehensive technological research university, New Jersey Institute of Technology (NJIT) has attempted to address these concerns through an innovative emphasis on interdisciplinary, integrative, and applications-oriented aspects of the engineering education process. Aiding the university in this endeavor are its traditional strong ties with industry, and its traditional emphasis on the interaction of educational, economic, scientific, and social environments. Over the last two decades, the university has evolved from an engineering school to a technological university through the expansion of its graduate and research programs and the addition of three colleges. These changes have facilitated the ability to conduct valuable cross-disciplinary activities.

NJIT's attempts to improve the education process have resulted in organizational changes, curricular innovations, major research initiatives, and collaborative arrangements with industry and with other institutions.

CURRICULUM INNOVATIONS AND CHANGES

NJIT's programs of instruction are increasingly interdisciplinary, integrative, and design-focused. Collaborative approaches to problem formulation and resolution, and the development of critical thinking and communication skills are employed in various courses and programs at the pre-college, undergraduate, and graduate levels as detailed below.

Pre-college level

NJIT pre-college courses are rather extensive; they serve 3,000 students and their teachers annually. The Urban Engineering Program, a six week summer course for 10th and 11th grade students,

places them in teams to formulate and resolve specific urban design problems such as wastewater disposal, transportation systems, and city planning. The instructional modules are designed to be integrated into existing high school curricula.

Outside of the university, starting at the pre-college and pre-high school levels, as early as the 4th grade, NJIT tries to make engineering attractive to students by introducing them to problems that point to the need for good mathematical skills. These skills are seen in a context of tools necessary to solve a problem.

Undergraduate level

A new program has been developed for Chemical Engineering students through the collaborative efforts of faculties in Chemical Engineering, Humanities and Science, Technology, and Society (STS). It is based upon a critical thinking model which identifies four important engineering skills: translation, metacognition (self-appraisal), integration, and argumentation. These skills can be used to foster independent thought, intellectual breadth, cultural breadth, and ethical awareness.

The departments collectively plan the curriculum, and teach the courses as a team. The goals of the program are to stimulate critical thinking, creativity, and communications skills; foster independent thought, a sense of cultural and intellectual breadth, and an awareness of ethical issues; and promote increasing levels of academic performance. Students are encouraged to monitor their own learning progress, integrate knowledge, communicate to various audiences, increase their awareness of the complexity of issues in the engineering profession, and reflect on the connections between personal experiences and professional choices.

Key aspects of the curriculum include courses which focus on critical thinking about ethics, the range of careers encompassed by the specific field, and the engineering profession in general. In the senior year, courses emphasize the importance of applying scientific principles to identifying and solving problems such as conservation and environmental control. Students work in teams of three to complete an open-ended process design problem, including such details as economic and environmental impact analysis and equipment specification.

Evaluation consists of informal assessment of the student's problem-solving abilities throughout the semester with a summative assessment at the end of each course. Teams of teachers formally evaluate papers based on specific criteria. These evaluations indicate a statistical correlation between a student's ability to write about chemical engineering and their successful performance in the chemical engineering curriculum.

In senior year capstone courses, students make twenty minute videotaped team presentations, including problem background, validity of the chosen solution, and a conclusion. In addition to faculty presentations, students also communicate technical aspects of their material to an interdisciplinary audience. Presentations are scored by various faculties according to the level of critical thinking ability exhibited by the students.

These curriculum revisions represent an effort to make the study of chemical engineering more meaningful, and to develop skills more relevant to the work environment. They integrate elements of the curriculum which students might perceive as being dissimilar and unrelated. Further revisions will involve development of additional outcome-related assessment measures, and a broadening of the program to other departments. Obstacles to implementation include the absence of an infrastructure for this type of program in the traditional engineering curriculum, and the challenge of introducing new critical thinking concepts without reducing traditional course content, or increasing credit requirements, in an already overcrowded course of study.

In addition to the chemical engineering program, NJIT has participated as a member of the Gateway Engineering Education Coalition. This coalition, funded by the National Science Foundation (NSF) in 1992, focuses on the connection and integration of individual curriculum elements to the broader educational experience. The goal is to make the study of engineering more engaging and fulfilling. Current projects include a freshmen design laboratory, telecourses among the coalition institutions, business and education partnerships, and a high school to university transition project.

Graduate level

At the graduate level, the interdisciplinary Master's program in Environmental Engineering and Science features capstone courses that focus on design and problem-solving in real situations. Students are required to respond to a Request for Proposals (RFP) from various sources. One example involved responding to an RFP from the Port Authority of NY/NJ for mitigation of hazardous waste at a planned industrial park site. In addition to traditional engineering problems, the response required students to consider health effects, legal liability, regulations and legislation, job creation, tax aspects, and other concerns. Students are organized into 'consulting companies' that compete in providing written and oral RFP responses. The course includes expert panel presentations, site visits, and meetings with the client's technical representatives. Winning proposals have been presented to Port Authority administrators.

INTERDISCIPLINARY RESEARCH CENTERS

To foster interdisciplinary learning, NJIT has developed a group of interdisciplinary research centers. These centers bring together faculty members, students, and industrial partners to perform

research in areas that are carefully selected to match state priorities and nationally cited critical technologies. Examples include environmental engineering and science, manufacturing, transportation, and microelectronics. Although each center studies one of these specific problems, there is a growing amount of interaction among the centers.

In addition to lowering the barriers between teaching and research activities, the research centers have had the beneficial effects listed below.

1. Research at the centers keeps faculty members current in their fields. The research opportunities and corporate involvement also improve the university's ability to recruit new faculty members.
2. The centers provide a means to co-ordinate interdisciplinary research and stimulate cross-disciplinary thinking.
3. Undergraduate and graduate students can take advantage of state-of-the-art applied research opportunities provided by the centers. In addition, corporate ties to the centers increase co-operative education and internship opportunities for undergraduates. These experiences can help focus career objectives, and even provide job opportunities upon graduation.
4. Industrial participation in the centers provides a 'reality check' for the university for the relevance of the research and the resulting knowledge that is transferred to the classroom and industry. Industry involvement also can help identify timely curriculum changes.
5. Research and corporate funding received through the centers often results in improved laboratory, computing, and library facilities.

Two examples of NJIT interdisciplinary research centers are the Center for Environmental Engineering and Science (CEES) and the Center for Manufacturing Systems (CMS).

CEES is dedicated to expanding knowledge and application of hazardous substance remediation, and pollution prevention technologies that are both environmentally acceptable and economically feasible. The programs cross disciplinary and institutional boundaries and, increasingly, international boundaries. Funding is approximately US $12 million annually, with funding from the National Science Foundation (NSF), US Environmental Protection Agency (EPA), the State of New Jersey, and thirty-five corporate members. NSF funding encourages women, minority, and disabled undergraduate student participation.

The most recent CEES program is the Integrated Pollution Prevention Initiative (IPPI), a two-year federally funded effort to identify and remove barriers to pollution prevention and waste reduction. The goal of IPPI is to investigate four principal areas: technology limitations; management strategies; small business needs; and education and training philosophies. In addition to conducting research, the program will attempt to implement innovative pollution prevention strategies in industry, develop public service campaigns, and promote educational change. One important educational change incorporates pollution prevention concerns as an integral part of student design and managemnent projects across NJIT's curriculum.

CMS was established in 1988 to increase competitiveness of New Jersey's manufacturing industries and to improve manufacturing engineering education. The center collaborates with industry, state and federal agencies, and other institutions of higher education to conduct applied research and technology transfer. The focus is on improving basic manufacturing processes, integrating factory operations, and implementing advanced manufacturing technologies. In addition, the center operates a statewide technology extension program to assist small and medium-sized manufacturing firms in solving manufacturing problems.

CMS is linked with NJIT's Manufacturing Engineering programs at the Bachelor's and Master's degree levels. Both undergraduate and graduate research assistants are supported, and undergraduate and graduate students are hired as assistants on the factory floor and in the laboratories. Students are also hired to work with faculty and staff on technology extension projects. The center also provides both individual senior design projects and industry technical assistance projects for the entire senior design class. Also, in co-operation with two regional consortia, students in two-year Manufacturing Technology associate degree programs can gain hands-on experience at CMS. A prototype integrated factory floor laboratory supports classes and faculty development for community colleges that are members of the consortia.

Implementation of research center programs has been hampered by resistance to change, inadequacy of available resources, and a reluctance to cross traditional boundaries between disciplines. Financial incentives, made possible by external support funding, are crucial in overcoming these obstacles.

NEXT STEPS

In contrast to post-World War II educational changes brought about by the engineering science revolution, the goal of present revisions is to make the educational experience more relevant to the broad professional practice of engineering. Current programs at NJIT attempt to educate students in important dimensions beyond technical competence. While the current focus on manufacturing and the environment, and existing industrial ties help broaden the engineering education experience, there is a need for further revision.

To this end, NJIT is revising its curriculum to increase emphasis on design, and on environmen-

tal issues. The current goal is to introduce environmental initiatives into the curriculum through the General University Requirements (GUR) based on the critical thinking and communications models used in the previously-discussed Chemical Engineering Department example. Courses are being redesigned at all levels, English and social science electives will focus on environmental issues, and a junior level course will address creative and collaborative aspects of design. This course will require the students to conduct formal research, and will develop their written communication abilities. The senior capstone courses will include a design project which requires a public presentation. This course will attempt to relate the undergraduate experience to history and ethics. Curriculum revisions will begin on a pilot basis in September 1993. Another important addition to the university is a new library that incorporates computerized search systems to facilitate research in the literature.

A long-term goal is to develop design as a theme for the entire university. As this is accomplished, curriculum changes will occur first in the Honours Program, and then be incorporated into the mainstream curriculum.

Although this paper has detailed specific changes at NJIT, we believe these developments reflect a current nationwide trend to revise current engineering curricula with the goal of increasing and broadening the competencies of graduating engineers.

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