DESIGNING ENGINEERING AND SCIENCE EDUCATION FOR THE 21st CENTURY

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How should engineering and science education evolve in the 21st century? There can be no doubt that today's students are different than those that entered college in the 1970s or 1980s. And the needs of the information age are driving the use of technology and thus the education needs of the students. Engineering and science education will need to change to incorporate technology and accommodate distance learning, and also more quickly evolve as the pace of our world gets faster and faster. It must be relevant to the lives of students and the needs of society in order to attract new entrants.

However, the percentages of women and underrepresented minorities are still low in the engineering and science professions. Much as engineering and science education will need to change due to technology and employer expectations, so will the reach of that education need to change. Other professions – law, business, medicine – are seeing increasing numbers of women and underrepresented minorities enrolling in their curriculum and having success in these fields. We must configure the new look for engineering and science education to be inclusive of everyone in order to meet the needs of the world tomorrow.

Steps are already being taken at many universities around the country to adapt and adopt engineering and science curricula, including making course material more inclusive in the manner in which it is presented, and making other changes that address the concerns of the information age. Leading edge concepts from the colleges of engineering at Kansas State University (KSU), Purdue University, and the University of Colorado at Boulder (UC-B) are presented in this paper.

KANSAS STATE UNIVERSITY

KSU's College of Engineering planning document for the design of engineering education in the 21st century is based on three requirements, discussed below. Core values embedded in the planning document include a focus on the learner in teaching and a recognition of interactions of students with faculty as a major element of the learning process.

(1) Engineering education must be practice-oriented while rooted in fundamentals. Practical training enables the engineer to "doctor" to the needs of society. Just as doctors in training "do rounds", a practice-oriented focus must provide engineers in training opportunities to look over the shoulder of experienced engineers/professors while they instruct and do real engineering. Practice-oriented does not necessarily mean that the student must have a formal co-op/internship or professional employment experience. Short-term projects and student competition projects can provide very beneficial experiences. Of course, there is no substitute for a solid foundation in the physical sciences, the engineering sciences, and the honing of communication skills.

(2) It is critically important, as well, to design an engineering education that is centered on the learner. In today's world, we can no longer expect to "cover all the required information." Instead, we must give students the ability to independently learn what is needed, in college and throughout their professional lives. Traditional teacher-based pedagogy, centered on the instructor (sage on the stage) with passive students, is inefficient and at worst, leads to a process that acts as a filter of students rather than as an educator of students. New accreditation criteria outlined by ABET EC2000 requires engineering education to center on what students actually learn and can do, rather than what we teach. As the KSU College of Engineering embraces this new learning paradigm, with all of its strategies for classroom/laboratory interactions, the student is becoming an active participant in the instructional environment. It is becoming very evident that this approach brings enthusiasm to the classroom (on the part of both professor and students) and greater participation in out-of-class focus groups and interdisciplinary projects. These students will be prepared to "hit the road" upon graduation and will be immediately productive in their engineering careers.

(3) Finally, we must emphasize the integrating or synthesizing nature of engineering, and recognize the holistic nature of the synthesis. This requires us to make connections between the knowledge we offer our students and a purpose for that knowledge. Our students must be cognizant of the important relationships among educational materials and assignments presented in their classes. Students need to understand the interactions that exist for implementation of a successful engineering design, e.g., one that perhaps involves special materials, dynamics, electronics, controls, software, and user compatibility. Research and outreach must be inextricably linked with the formal aspects of education in the service of this requirement and in the implementation of life-long learning opportunities.

In summary, the design of engineering education in the 21st century will affect the content of our curricula, the method of its delivery, and where we deliver our programs. We must offer our students a program in which knowledge is both a usable substance and an ongoing process. And we must help our students see that their formal engineering training is but the start of a life-long process of learning and doing.

To meet the demands of this design for engineering education, the KSU College of Engineering will be expanding some of its programs into a new facility, Fiedler Hall, that will house a state-of-the-art distance-learning center, a truly electronic library, a high-tech auditorium, and student team-learning rooms wired for the information age. Computer-aided instruction and visualization techniques; high-speed Internet connectivity and web access; and cable, satellite, video, and computer-based communications will be integrated into the teaching classrooms, lecture halls, auditorium, and library. The team-study rooms are a unique feature of this learning environment, designed in response to requests from students for an environment to facilitate team-based learning. KSU is poised to build a foundation for engineering education in the 21st century that will keep pace with the tremendous changes occurring in business, industry, and society. The KSU College of Engineering expects that the redesign and delivery modes of these educational strategies will also make engineering an increasingly attractive and welcoming profession for students from underrepresented groups.

PURDUE UNIVERSITY

Purdue's work to design an engineering and science education for the 21st century has had both grass roots and administrative initiatives. The activities described here focus on several efforts that have had a positive effect on populations considered "non-traditional" in the 20th century—particularly women. Collectively, these and related activities have contributed to shifting attitudes across the Schools of Engineering at Purdue.

A series of interactive theater workshops, developed by the Women in Engineering Program in collaboration with Purdue's Schools of Science and Liberal Arts, intended to create institutional change in the classroom (2). The first workshop focused on helping teaching assistants become aware of their own behaviors, and the actions of students in their laboratories and recitations, that could negatively affect the academic experience. Two additional workshops depicted engineering faculty in the classroom and demonstrated how a small change in teaching style could dramatically improve the educational climate for a variety of students. The students most positively affected were usually ones who were not in engineering classrooms 30 years ago. However, the improved learning environment was a benefit for all students. Videotapes of these three interactive theater workshops with facilitator guides (1, 3, 4) allow universities throughout the United States to make similar changes in their classrooms. At Purdue these workshops are now offered for TAs or faculty throughout the university at the beginning of each semester.

Another thrust, this one initiated by the Office of the Dean of Engineering, resulted in the creation of Purdue's Engineering Diversity Forums. These forums are intensive semi-structured workshops in an off-campus retreat type setting that run for two and a half days each. The first session focuses on issues of race and ethnicity with the overall goal of heightened appreciation for the importance of embracing and leveraging diverse perspectives throughout all aspects of our program. The second session focuses on issues of gender, and also includes faculty, staff, students, and alumni. Both workshops are professionally facilitated, and offer ample time for open dialogue and introspection. Participation is entirely voluntary, and since their inception in 1997, more than 100 engineering faculty—nearly 40% of our total faculty population—30 engineering staff, and 60 students and alumni have participated in one or more sessions. Because of the initiative of workshop participants, additional 1-day on campus workshops have been conducted to continue the momentum of the workshops, while focusing on more practical classroom skills. Outcomes to date have ranged from increased self-awareness in individual participants to a faculty-initiated development of a comprehensive diversity plan for the Schools of Engineering.

Innovation in science and engineering education at Purdue is having an impact on our curriculum in many ways. Engineering and science education for the 21st century took a major step forward with the introduction of a dramatic new course offering called **EPICS**; for **E**ngineering **P**rojects **I**n **C**ommunity **S**ervice. This nationally acclaimed program helped earn Purdue a listing in "The Templeton Guide: Colleges That Encourage Character Development" as one of 60 colleges and universities in the nation with an exemplary volunteer service program. Engineering students' traditional design courses are enhanced by this technical elective, which involves teams of engineering and non-engineering students, consultation with non-technical "clients", and community service. Each team assumes total responsibility for all aspects of the planning, design, development, implementation, and maintenance of real engineering projects that are serving the needs of a wide variety of community service organizations which could otherwise not afford to achieve the caliber of engineering services that are provided. The EPICS concept is spreading to a number of sister institutions, and is garnering attention from a variety of educational professional organizations (complete information about EPICS is available at: http://epics.ecn.purdue.edu/main/). At present more than 250 students comprise the more than 20 EPICS teams conducting a variety of engineering projects.

UNIVERSITY OF COLORADO AT BOULDER

CU-B's College of Engineering and Applied Science has been at the forefront in "reengineering" engineering education. The award-winning Integrated Teaching and Learning Laboratory (ITLL), completed in 1997, was one of the first steps in the "reengineering." The Discovery Learning Center, scheduled to break ground in May 2000, is another major step.

The ITLL provides a unique and dynamic experiential learning environment for undergraduate students. It is based on the vision of ". . . to pioneer a multidisciplinary learning environment that integrates engineering theory with practice and promotes creative, team-oriented problem-solving skills." The facility and programs conducted within it use a hands-on, interdisciplinary, team-based approach that mirrors the way engineers investigate and solve problems in industry. ITLL courses in every discipline allow students to experience the entire creative process from analyzing a problem to designing, simulating, building, and testing a solution. First-year design courses allow students to design, build, and test real world products with real customers – such as an assistive glove that a quadriplegic student uses to grasp a soda can. Four capstone design studios provide space for seniors to apply their knowledge with viewing windows for others to observe. Concepts demonstrated in the first-year curriculum due to the availability of the ITLL are now being integrated into upper level courses as well.

The ITLL building itself is also a learning tool with windows into building systems and structures, and sensors planted throughout the facility to collect data on everything from heating and air conditioning to stress loads. All summer, the ITLL is open to K-12 students and teachers for a variety of outreach programs that bring the exciting world of engineering to the community at large. (see *http://itll.colorado.edu*)

Discovery Learning, the College's platform for continuing innovation in engineering education, is intended to provide a student centered, inquiry-based, educational process where the learner develops critical thinking skills, experiences the passion and excitement of original research and engages in problem solving with other learners in a collaborative, technology-enhanced educational setting. It is a different type of learning that builds on interactivity and creates long-range impacts through personal involvement. The Discovery Learning Center (DLC), scheduled for completion in 2001, will provide undergraduate students opportunities to join graduate students, post doctoral fellows, faculty and industry partners in the adventure of discovery. (see *http://discoverylearning.colorado.edu/dli/discovery-learning*)

The ITLL is viewed as horizontal integration – breaking down barriers between departments and learners. DLC focuses on knowledge creation through vertically integrated teams. Mentoring is expected to be an integral part of the DLC model, and crossing disciplines necessary to successfully achieve real-world solutions to real-world problems.

CU-B believes that both of these new paradigms reflect advances in engineering education that make the field more attractive to everyone and engineering education more relevant. They also provide a more inclusive curriculum to attract those groups who are currently underrepresented in engineering.

CONCLUSIONS

Research on gender-equitable and inclusive pedagogy for science, math, and engineering classrooms over the recent past has suggested a number of changes and interventions that could improve retention rates of students from underrepresented groups, as well as increase the attractiveness of science and engineering curricula for these groups. These suggestions include use of pedagogical techniques that focus on the learner; involve students in learning through doing or application; emphasize teamwork over competitiveness; and emphasize the relevance of science and engineering to real-life issues. (See, for example, "Teaching the Majority: Breaking the Gender Barrier in Science, Mathematics, and Engineering", ed. Sue V. Rosser, Teachers College Press, 1995.)

The designs for the future of engineering and science education at KSU, Purdue, and UC-B outlined in this paper incorporate many or all of the proposals for gender-equitable and inclusive pedagogy shown to impact positively on retention rates. Engineering and science deans can leverage their educational planning through interaction with women in engineering/science (WIE/S) programs. WIE/S programs are an important resource for practical examples of pedagogical innovation in action, and can help engineering and science departments realize their educational visions.

And WIE/S programs can leverage educational planning at their institutions to help achieve many of the goals of their programs. The "re-engineering" of science and engineering education underway at many institutions provides a potent opportunity to incorporate much of what WIE/S programs do directly into the mainstream of the college educational environment. It has often been said that gender-equitable and inclusive pedagogy is simply good pedagogy. The convergence of new designs for engineering and science education and WIE/S program efforts demonstrates that this is emphatically the case.

References:

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