NSF Centers' Approach to the Integration of Research and Education

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***Abstract* - The rapid integration of cutting-edge, multidisciplinary research into the engineering curriculum is a challenge for educators. The National Science Foundation Engineering Research Centers have pioneered this type of integration since 1985. The goal for the Engineering Research Centers program is to educate engineers capable of integrating fundamental knowledge across disciplines to advance systems-level technology. Forty-three Engineering Research Centers have educated thousands of graduates who have proven to be effective in industry. The next generation of Engineering Research Centers currently under development have the mandate to provide opportunities for research and learning collaboration that will prepare graduates for leadership in innovation in a global economy. To accomplish this integration of research and education, Engineering Research Centers develop comprehensive education programs that provide learning opportunities across the learning continuum, from precollegiate levels through lifelong learning. Outreach activities, undergraduate curriculum and research opportunities, graduate programs, and continuing education for professionals are offered. Advances fostered through Center research activities are incorporated into learning materials appropriate for each level. To disseminate the most effective mechanisms to accomplish these goals, Engineering Research Center educators have developed a best practices manual.**

Index Terms – Integration of research and education, Engineering Research Centers

INTRODUCTION

National Science Foundation (NSF) Engineering Research Centers (ERCs) developed from a meeting led by the Office of Science and Technology Policy of the White House in 1985. It was noted that while engineers were taught within the constraints of traditional disciplines, new advances were occurring at the boundaries between the disciplines. It also was noted that engineering education did not adequately prepare students for the team-based, interdisciplinary engineering actually practiced in industry. The Office of Science and Technology Policy report therefore called for the integration of research into engineering curricula. These recommendations were subsequently incorporated into the NSF Engineering Research Center Program's mission. Under the assumption that cutting-edge, systems-level engineering problems require new problem-solving skills, NSF gives each Engineering Research Center a mandate to address entwined research and education problems. NSF envisions a complete integration between research and education in Centers, where the nature of the research demands new and swiftly implemented pedagogy, course content, and curriculum changes, and where the need to train students by making them partners in discovery requires research to be managed as an educational tool for students of all ages. In addition, NSF requires that Centers take proactive steps to insure that a diverse group of students and faculty participate in these programs. This is done through the development of a comprehensive program that offers educational opportunities across the learning continuum from postgraduate education down to the precollegiate level. This paper will discuss those education efforts at the collegiate level.

GRADUATE RESEARCH

Engineering Research Centers train graduate students through the conduct of interdisciplinary research in a team-based environment, and through courses that inculcate an interdisciplinary, systems approach to engineering problems. Students not only acquire the depth of a traditional disciplinary degree, but also benefit from increased breadth through exposure to the interdisciplinary environment characteristic of Centers. Centers recognize that this type of interdisciplinary training differs substantially from traditional disciplinary degrees, and they intentionally develop research projects that require problem-solving that crosses disciplinary lines. The thesis committees for ERC graduate students may include academics from different disciplines as well as industry researchers.

GRADUATE COURSES

In addition to the research experience, Engineering Research Centers typically develop new courses that reflect their research fields, and modify existing courses to reflect Center research. Much Center-generated knowledge is transmitted initially via "special topics" courses before finding a vehicle in more structured course sequences. Often these courses enroll both graduate and undergraduate students, are team-taught, and are developed by faculty at multiple institutions. Courses are generally institutionalized into the engineering curriculum and therefore are available to the wider student population and extend beyond the NSF funding cycle. It is also common for Centers to develop new degree programs (masters and/or doctoral), minors, or certificates. Between 1985 and 2003, 1,494 course modules for new and ongoing courses, and 119 new degree programs or certificates were developed by Engineering Research Centers [1].

UNDERGRADUATE COURSES

In many cases, Center research areas have not been traditionally taught at the undergraduate level because they cross disciplinary boundaries. For example, particle science had been virtually missing in the undergraduate curriculum until the Particle Engineering Research Center at the University of Florida in Gainesville established an introductory-level course for senior undergraduate students. In addition, the Particle Engineering Research Center leveraged additional resources to develop a particle product and process design course and computer-based modules in aerosols engineering. Aerosols were previously only taught at the graduate level and these modules are specifically designed for an undergraduate audience. It was determined that primarily senior students were being impacted by these courses that brought state-of-the-art Center research into the curriculum. Particle Engineering Research Center faculty looked for a mechanism to reach younger students to increase their interest in the field, and collaborated with the college to integrate a particle science module into an existing freshman-level introductory engineering course. This module introduces particle engineering to over 700 freshmen annually.

At the Center for Advanced Engineering Fibers and Films (Clemson University, Massachusetts Institute of Technology, and Clark Atlanta University) undergraduates can take “Introduction to Fiber and Film Systems,” an undergraduate technical elective that develops students’ systems-level understanding of fibers and films. The course teaches students to identify the steps in fiber and film production processes, explain the effects of process variables in a system on the structure and properties of fibers or films, and collaboratively create computer code to visualize the results of mathematical modeling. Because of the diverse educational backgrounds of the students, the course comprises both traditional lectures as well as modules. For example, students majoring in computer science take a module on polymer chemistry, while students majoring in chemical engineering take a module on visual programming language. The governing models for polymer extrusion, fiber spinning, film formation and structure property relationships are then presented in traditional lectures. Student teams undertake interdisciplinary projects that require an integrated approach to problem-solving. The course thus provides a capstone design experience much earlier in the students' careers than would be possible in the traditional curriculum. Furthermore, the course gives students the opportunity to develop an industrial perspective by arranging site tours of local fiber and film facilities. Industry personnel brief students on the processes and on technical issues.

In other cases, research at Engineering Research Centers has led to entirely new undergraduate curricula. For example, faculty at the Center for Advanced Engineering Fibers and Films (Clemson University, Massachusetts Institute of Technology, and Clark Atlanta University) have spearheaded a movement to restructure international materials education. The objective of the proposed changes is to train an engineer who considers molecular issues before designing the process or product, and then uses molecular information to increase the accuracy of the actual design.

In May 2002, an international workshop called “Touchstones of Polymer Processing” was held at the Polymer Processing Institute at the New Jersey Institute of Technology. The participants concluded that a new five-year undergraduate curriculum in molecular engineering and science was needed to prepare students for careers that combine molecular biology, complex fluids, polymer chemistry, polymer physics, chemical engineering, etc. In November 2003, CAEFF hosted a follow-up workshop at the University of Leeds to outline the new curriculum, develop syllabi for the required courses, and discuss multi-university implementation. The envisioned education reforms emphasize a fundamental understanding of molecular issues, molecular transformations, multiscale analysis, and a systems approach to process/product design.

UNDERGRADUATE RESEARCH

A successful way to bring research into the undergraduate curriculum is through undergraduate research experiences. Engineering Research Centers typically involve undergraduates as research assistants (either for pay or for course credit) during the academic year, and as summer interns. For example, the Particle Engineering Research Center has established the largest multidisciplinary undergraduate research program in the College of Engineering at the University of Florida. Over the past ten years this program has placed over 800 students from fourteen departments and three colleges on Center research projects. As is generally the case with these types of programs, it initially accepted only junior and senior students, but beginning in the third year of the Center, underclassmen were accepted.

In addition to integrating research into the undergraduate curriculum, undergraduate research serves other purposes. There is broad consensus in the engineering education community that undergraduate research is an important component of the engineering curriculum [2, 3, 4, 5]. A hands-on research experience is believed to better prepare students for graduate school, and perhaps equally important, to motivate them to continue beyond the bachelor’s level [6, 7]. A main rationale for these types of programs is that they can serve to increase graduate enrollments by increasing both awareness of and preparedness for graduate research. Faculty see the recruitment of graduate students as an incentive to participate in undergraduate research programs [8]. Programs that encourage students to pursue graduate degrees in engineering are especially important given trends showing a decline in the number of science and engineering graduate students [9, 10].

An additional benefit of undergraduate research may be the role it can play in retaining undergraduate students in the field of engineering through the bachelor's degree. Engineering educators are facing troubling statistics. Enrollments and undergraduate engineering degrees are down across all demographic categories [11]. Enrollments of women and minority are even more problematic [12, 13]. The Commission on the Advancement of Women and Minorities in Science, Engineering and Technology (SET) Development called for a "national imperative" and "drastic steps" to make the American SET workforce more representative of the general workforce and cautioned that the United States could find itself with a shortage of SET workers. Significant numbers of students who indicate an interest in pursuing engineering at the beginning of the freshman year drop out of the field before graduation [14]. It is also well documented that these rates are higher for women and minorities [12], exacerbating the problem that begins with lower enrollments from these groups. Studies indicate that the dropout rate is very high during the freshman year [14, 15].

The Board on Engineering Education of the National Research Council in 1992 sought to identify successful retention strategies and indicated that attitudes were more important than academic factors. A longitudinal study of women in engineering determined that a positive relationship with an advisor and entering a department are critical factors in retention for sophomore women. It has also been theorized that technical experiences outside of the classroom can enhance retention by helping students become integrated into the institution [16]. A notable project was initiated at Dartmouth College and adapted as the Penn State University Women in Science and Engineering Research. This is a program that was designed to use research as a retention program for freshmen women, and rather than only involving academically gifted students, it was designed to include average students. This program placed women in three semesters of research and reported a 50% reduction in dropout rates among these students [17]. A research experience is a vehicle that can provide students with the positive relationships with faculty and integration into a department, thereby enhancing retention in engineering programs. Another retention problem identified is that traditional engineering programs often include the basic math and sciences classes in the first two years, but students do not begin engineering classes until the third year [18]. Many students drop out before they get into the engineering coursework. This realization spurred the development of many lower-level undergraduate engineering classes. Early research experiences can also address this issue.

Boasting approximately 26% minority and 35% women students, the Particle Engineering Research Center undergraduate research program has consistently outperformed national numbers for the participation of women and minority students. The Particle Engineering Research Center conducted a study to identify the factors that contribute to its success in attracting female students. The Particle Engineering Research Center demonstrated that participants in the research program reported a high level of satisfaction. Analysis of the survey results indicated that responses became increasingly positive as time spent in the Center increased. As mentioned earlier, research shows female students report a lower level of self-confidence, and it is probable that self-confidence in the lab increases with time. Therefore, laboratory experiences that last more than one semester could serve as a mechanism to address the lack of confidence reported by female engineering students.

Centers are also challenged to integrate research into the engineering curriculum of students who do not attend the Center institutions. The common mechanism for accomplishing this is through a summer residential Research Experience for Undergraduates (REU) programs. All Centers place visiting students on interdisciplinary research teams for up to ten weeks in the summer to allow them to learn about research that would not be available to them on their home campus. Program goals include providing interdisciplinary laboratory experiences to undergraduates, improving student competence in a laboratory, and increasing the participation of women and minorities in engineering. The PERC has provided 110 students with a 10-week program for the past eleven years through the REU program and has developed a roadmap that can serve as a model to other institutions that would like to offer a similar program [19].

Research projects conducted by undergraduates in the CAEFF REU program are tied to the Center's study of fibers and films. The Center envisions a new paradigm for developing these materials through equations that couple molecular and continuum information and through corresponding three-dimensional images created in the virtual domain. Verification of these mathematical and visual models is achieved experimentally. REU projects, as an integral part of the Center's strategic plan, ideally comprise all three of the intellectual focuses of the Center: mathematical modeling, visualization, and experimentation. An interdisciplinary perspective, a systems approach, and industrial relevance – the hallmarks of ERC research – are inherent in the REU projects. REU alumni develop many of the skills necessary to function effectively on collaborative materials design teams through activities that teach laboratory safety and techniques; the nature of science and the scientific method; the roles of observation, measurement, and experiment in science; ethics in scientific research; presentation skills and scientific communication; and team building.

TEACHING MATERIALS

Another way research can be integrated into the graduate and undergraduate curricula is through the development of teaching materials, and Engineering Research Centers have again led the way. Between 1985 and 2003, 163 textbooks were published, as well as multimedia software on immunology, electronic materials processing, cluster tool design and semiconductor manufacturing processes [1].

DIVERSITY

NSF further mandates that the integration of research and education should be accomplished by a diverse group of students and faculty, and that the Engineering Research Center integrative approach be disseminated to a diverse audience. As a result of proactive recruiting, Engineering Research Centers exceed national averages in engineering schools in the participation of women and minorities at both the student and faculty levels. This success resulted in the Deputy Director of NSF asking in 2003 that Engineering Research Centers ensure that students traditionally underrepresented in science and engineering have the opportunity to become trained in and contribute to Center research fields. Centers therefore forge partnerships with NSF human resource development programs such as the NSF Louis Stokes Alliance for Minority Participation program, which produces over 18,000 minority bachelors degrees every year, and the NSF Alliance for Graduate Education and the Professoriate, which helps prepare hundreds of minority graduate students in science, mathematics, and engineering for academic careers (http://nsfagep.org/). A more diverse, expanded workforce is thus being trained in the systems approach that NSF hopes will mold the future of engineering.

CONCLUSIONS

NSF Engineering Research Centers are uniquely positioned to provide both undergraduate and graduate education in cutting edge research by supplementing traditional disciplines with multidisciplinary experiences. This includes courses, new degree options, and research experiences. The mandate of the Engineering Research Center program and the length of the awards (ten years) allow strategic planning on how to bring Center research into all levels.

The legacy of the first ten years of the Engineering Research Center program is 1,080 bachelors degrees, 1,677 masters degrees, and 1587 doctoral degrees awarded to students trained in this environment [1]. A measure of the success of the integration of research and education was determined by surveys of Engineering Research Center graduate employers conducted in 2003 and 2005 that found that over 80 percent of supervisors rated Engineering Research Center graduates superior to non-Engineering Research Center students in their overall ability to perform their jobs, in their ability to work in interdisciplinary teams, and in both the depth and breadth of their technical understanding [20]. Additionally, a study was conducted to determine the degree to which the Engineering Research Center culture fostered institutional change on their campuses. It was determined that the most significant long-term impacts on these campuses were those related to engineering education [21].

The Centers have produced a best practices manual to assist others who are interested in using the Engineering Research Center model in their own institutions (http://www.erc-assoc.org/manual/bp_index.htm).

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REFERENCES

[1] Triennial Report for the Period FY 2001-2003 , Committee of Visitors for the Engineering Education and Centers Division, NSF.

[2] Ataai, M. M., Holder, G. D., and Toplak, R. F., "Research Experience for Undergraduates at the University of Pittsburgh Department of Chemical and Petroleum Engineering," *Proceedings of the 1997 Frontiers in Education Conference*, Pittsburgh, PA, November 5-8, 1997.

[3] Gates, A. Q., Teller, P. J., Bernat, A., Delgado, N., "Meeting the Challenge of Expanding Participation in the Undergraduate Research Experience," *Proceedings of the 1998 Frontiers in Education Conference,* Tempe, AZ, November 4-7, 1998.

[4] Passos, N. L., Carpenter, S. B., "True Undergraduate Research: Foundation for Graduate Studies and Critical Thinking," *Proceedings of the 1999 Frontiers in Education Conference*, San Juan, PR, November 10-13, 1999.

[5] Veléz-Reyes, M., Pérez-Quiñones, M., and Cruz-Rivera, J., "The Industrial Affiliates Program at the University of Puerto Rico Mayagüez," *Proceedings of the 1999 Frontiers in Education Conference*, San Juan, PR, November 10-13, 1999.

[6] May, G. S., "An Evaluation of the Research Experiences for Undergraduates Program at the Georgia Institute of Technology," *Proceedings of the 1997 Frontiers in Education Conference*, Pittsburgh, PA, November 5-8, 1997.

[7] Saacks-Giguette, M. and Lang, R. R., "Implementation of a Research Program at an Undergraduate Institution," *Proceedings of the 1997 Frontiers in Education Conference*, San Juan, PR, November 10-13, 1999.

[8] Narayanan, Ram M., "Use of Objective-Based Undergraduate Research Project Experience as a Graduate Student Recruitment Tool," *Journal of Engineering Education*, July 1999, pp. 361-365.

[9] "Graduate S&E Students and Degrees in the United States," Higher Education Science and Engineering, Science and Engineering Indicators, published on-line at http://www.nsf.gov/sbe/srs/nsf96334/foreign. html. National Science Foundation, Arlington, VA, 1998.

[10] Olsen, K., "Total Science and Engineering Graduate Enrollments Falls for Fourth Consecutive Year,"Division of Science Resources Studies, National Science Foundation, Arlington, VA, pub. NSF 99-316, December 17, 1998.

[11] Brainard, Suzanne G., and L. Carlin, "A Six-Year Longitudinal Study of Undergraduate Women in Engineering and Science," *Journal of Engineering Education*, October 1998, pp. 369-375.

[12] Anderson-Rowland, Mary R., "Understanding Freshman Engineering Student Retention through a Survey," *Proceedings of the 2001 American Society of Engineering Education Annual Conference*, Session 3553.

[13] Brainard, Suzanne G., S. Staffin Metz, and G. M. Gilmore, "WEPAN Pilot Climate Survey: Exploring the Environment for Undergraduate Engineering Students," available at www.WEPAN.org.

[14] Besterfield-Sacre, Mary, C. J. Atman, and L. J. Shuman, "Characteristics of Freshman Engineering Students: Models for Determining Students Attrition in Engineering," *Journal of Engineering Education*, April 1997, 139-149.

[15] Reichert, Monty and M. Absher, "Taking Another Look at Educating African American Engineers: The Importance of Undergraduate Retention," *Journal of Engineering Education,* July 1997, pp. 241-253.

[16] Nava, Patricia, "The Formal Research Group Model as an Undergraduate Retention Tool," *Proceedings of the 2001 American Society of Engineering Education Annual Conference*, Session 1332.

[17] Wakhungu, Judi Wangalwa, M. Covington, and L. Brown, "First-Year Women in Science and Engineering Research:

Attuning Programs To Benefit Average Students," *Proceedings of the 2001 Joint NAMEPA/WEPAN National Conference*, April 21-24.
Alexandria, Virginia, pp. 39-41.

[18] Shuman, Larry J., C. Delany, H. Wolfe, and A. Scalise, "Engineering Attrition: Student Characteristics and Educational Initiatives," *Proceedings of the 2001 American Society of Engineering Education Annual Conference*, Session 1430.

[19} Donnelly, A.E., K. Carlin-Morgan, and S. Aldrich, "Developing and Implementing a Successful Research Experience for Undergraduates Program: A Roadmap Designed by the Engineering Research Center for Particle Science and Technology," Frontiers In Education 2000 Annual Conference, Kansas City, Missouri, Oct. 18-21, 2000.

[20] The Engineering Research Centers (ERC) Program: An Assessment of Benefits and Outcomes, December 1997, Linda Parker, Project Director, Engineering Education and Centers Division, Directorate for Engineering, National Science Foundation, Arlington, Virginia. www.nsf.gov/pubs/1998/nsf9840/nsf9840.pdf

[21] Program Evaluations and Studies Conducted by EEC: 1990 to March 2007, http://www.nsf.gov/attachments/108276/public/EEC-ENG-NSF_evaluations_1990-2007_COV_version.pdf