Integration of Research and Education in a Multi-Institutional Center

Elizabeth A. Tranter
Virginia Polytechnic Institute and State University, Blacksburg, VA 24061
etranter@vt.edu

Abstract - **As a National Science Foundation Engineering Research Center, the Center for Power Electronics Systems (CPES) has developed programs serving Virginia Tech and its four core partner institutions, as well as outreach institutions and more than 70 industry partner firms. Multi-institutional research centers require key supporting structures for emerging areas of research exploration within each institution, including the necessary curricular articulation to enable cross-university collaboration. Shortly after its inception in 1998, CPES executed inter-university cooperative agreements which established a common set of practices for sharing academic and laboratory resources across institutional boundaries. These agreements, strengthened by tight linkages between research and education strategic planning within the Center, resulted in a significant broadening of access to technical expertise within established institutions. This approach also nurtured extensive program development at partner institutions with emerging programs in power electronics. Through collaboration of research area leaders with educational personnel, the Center developed a programmatic framework for program administration, communicating a shared vision, implementing shared goals, and extending the impact of the Center programs. This paper describes specific mechanisms for intercampus, with a particular emphasis on the integration of academic and research program development within minority-serving institutions in the CPES consortium.**

Index Terms – education, ERC, NSF, multi-institution

INTRODUCTION

A key element of program development within multi-institutional research centers is the establishment of Education and Outreach programs which support emerging areas of research exploration within each institution, while providing the necessary curricular and infrastructure articulation to enable cross-university collaboration. As a National Science Foundation (NSF) Engineering Research Center (ERC), the Center for Power Electronics Systems (CPES) has developed Education and Outreach programs serving Virginia Tech and its four core partner institutions, University of Wisconsin-Madison (UW), Rensselaer Polytechnic Institute (RPI), University of Puerto Rico-Mayaguez (UPRM) and North Carolina A&T State University (NC A&T). The CPES consortium also involved the University of Florida, California Lutheran University and the University of Maryland as well as outreach institutions and more than seventy (70) industry partner firms.

CPES partner universities share a common goal to develop education and outreach programs that provide multi-disciplinary, team-driven, and systems-oriented educational opportunities to pre-college and university students, as well as practicing engineers. In support of these goals, the Center identified the following objectives for education and outreach program development:

- Designing a multi-disciplinary curriculum focusing on power electronics system design and problem-solving skills;
- Developing connectivity with industry, partner institutions, and the larger power electronics community;
- Introducing pre-college and undergraduate students to the possibility of pursuing careers in power electronics;
- Extending education and outreach program development to each CPES partner campus;
- Establishing programs that increase participation of women and underrepresented minorities in Center programs.

Among the first generation of multi-institutional ERCs, another important goal of CPES was the creation of a research and education environment in which lead and core partner campuses collaborated as equal contributors to the Center. A foundation for this collaboration was provided by the two existing power electronics consortia at VT and UW, each involving approximately (40) partner firms. Tight integration among institutions was a strong priority in the development of the research strategic plan and roadmap, which included joint campus responsibility for research thrust-level and project-level deliverables at key stages in the research program.

This paper will describe specific mechanisms for intercampus collaboration and intercampus program management, with a particular emphasis on the integration of academic and research program development on minority-serving institutions which are members of the CPES consortium.

ADMINISTRATIVE ORGANIZATION

In order to ensure continuity between research and education program objectives, research area leaders and campus directors served also served as Education Program

Committee members. The Education Committee reviews program components and objectives, strategizes the implementation of cooperative education efforts, and reviews progress toward goals. In 2004, the team was augmented with an Education Technology Specialist in VT's Department of Teaching and Learning, who developed and implemented an in-school assessment study for the Center's pre-college outreach program.

Cooperative Agreements

Shortly after its inception in 1998, CPES executed inter-university cooperative agreements which established a common set of practices for sharing academic and laboratory resources across institutional boundaries. Initially, a memorandum of understanding was drafted to establish a core listing of courses in the areas of power electronics, packaging, and system design and integration. Sharing of CPES Educational Resources among partner campuses is governed by Cooperative Agreements for Distance Access of Courses and Student Exchange. These agreements establish a set of common policies and procedures for cross-registration, including billing of tuition and fees, grade assignment, and the terms for the distance delivery of courses. At present, eighty-six (86) power electronics and related courses are offered at CPES partner campuses. Twenty-seven (27) of these courses are offered in distance format. These agreements and resources, strengthened by tight linkages between research and education strategic planning within the Center, resulted in a significant broadening of access to technical expertise within established institutions.

This approach also nurtured extensive program development at partner institutions with emerging programs in power electronics. Through collaboration of research area leaders with educational personnel, the Center developed a programmatic framework for communicating a shared vision, extending the impact of the research program, integrating new courses and course revisions with the research program, implementing shared goals, and sharing expertise across campuses.

COMMUNICATING VISION

A primary concern within a multi-institutional center is the diffusion of a common vision across geographic, departmental, and degree program boundaries. The early identification of core and related courses which will be shared through distance learning and exchange programs also provides a point of departure for a course revision plan. Through annual revision of key existing courses, elements of ongoing Center research can be integrated into the existing curriculum. Since 1998, sixty-one (61) course revisions have occurred within the Center's eighty-six (86) cross-listed courses.

Early comparative study of the partner institution curricula facilitates the discovery of articulation concerns within the consortium. Such articulation concerns constitute potential points of disruption for collaborative research, distance learning, and exchange programs. The outcome of this study may lead to the development of new courses and/or modules to address these concerns.

Curriculum Articulation

Within the CPES consortium, one such articulation concern was identified in the curriculum of a partner institution which lacked a fundamental, systems-oriented course in power electronics that was present in the curricula of other partner institutions. Through the work of the Education Committee, key elements of an existing course at the lead institution were targeted as the basis for course development at the partner institution. In Fall 2000, the lead institution offered this course in a distance learning mode exclusively to the partner institution, while simultaneously offering weekly discussion sessions by distance delivery for both faculty and student attendees. In 2001, the partner institution offered a new course which was preparatory to the target course. The course content was supplemented by lecture tapes from the lead institution, and study sessions and office hours were provided by the partner institution. In 2002, both the preparatory course and the target course were fully in place at the partner institution. As a result of this initiative, enrollment in basic power electronics classes at the partner institution rose from two (2) to twenty-two (22) students in one year. The implementation of the new course sequence was enhanced by the sharing of all target course materials, including homework problems, design projects, website, lesson plans, course proposal, ABET forms, and capstone design course proposal with partner institutions. The customization of these materials into a course track, ultimately culminating in a capstone course in power electronics, was a collaborative effort among faculty at the partner institution, who were able to properly contextualize the Center-related course within the curriculum of their own program. Further articulation efforts related to this initiative will be discussed in the fifth section of this paper.

New Course Development

To date, a total of fifteen (15) new power electronics and related courses have been developed as part of the consortium. While some of the new courses address curriculum articulation issues, others fill critical needs which reflecting the Center's expansion into new research and technology development areas. For example, the lead institution, initially accessed power electronics packaging courses from a partner institution. In later years, the lead institution enhanced its collaboration in this research area through the hiring new faculty, and the development of undergraduate and graduate-level courses within the discipline. Throughout the life of the Center, new courses were developed in each of the thrust areas and sub-disciplines that defined the research program. Many of the new and revised courses also serve as the basis for new degree and certificate programs, as well as short courses for industry.

Although new course development and the modification of existing courses form a strong supporting structure for communication of vision, the Center identified a need for a course for which the Center vision itself was the focus. This course, Power Electronics System Integration, is team-taught

each Spring semester by all research thrust leaders and is distance-delivered to all institutions within the Center. This class is recommended for undergraduate students in their senior year of study, as well as graduate students beginning their study at the Center, and is a required course for all students in the consortium. Updated on an annual basis based on student and faculty input, this course provides students with a systems-oriented perspective on power electronics research conducted within the Center. The course includes a broad overview of advanced power electronics technologies with an emphasis on multi-disciplinary aspects of integrated design. It also investigates relationships between system application requirements and technological challenges in circuit topologies, power semiconductor devices, sensing and control, integrated packaging, and thermal management, and their impact on the system reliability and cost. The final portion of the course serves as an introduction to the concept of integrated power electronics modules and their application in distributed power systems and motor drives. As part of the work for this course, students are required to relate the topic of each lecture to their own research within the Center as part of teleconferenced discussion sessions held throughout the semester.

IMPLEMENTING SHARED GOALS

Coordinated course development efforts at each of the core partner campuses have also enabled the implementation of shared program goals within the consortium institutions. To date, four (4) of the five (5) campuses have developed specialized tracks for power electronics within the electrical engineering undergraduate program. These tracks have been implemented as degree tracks, degree concentrations, or certificate programs, depending on the structure and existing infrastructure within each Department. Power electronics options or concentrations to the undergraduate degree were formally begun initiated within the Bradley Department of Electrical and Computer Engineering at VT, the Department of Electric Power Engineering (now part of the Department of Electrical, Computer, and Systems Engineering) at RPI, and the Department of Electrical Engineering at UPRM. Options at each campus involve completion of both required and elective course work within a designated set of power electronics and related courses. In 2003, the power electronics option at VT was made more flexible by the addition of a technical elective and by the designation of the basic power electronics course as a capstone design course. At the University of Wisconsin-Madison, this goal was achieved through development of a certificate program.

In 2002, CPES established a power electronics option for undergraduates majoring in Electrical Engineering at Virginia Tech. The option works within the ECE 15-credit-hour technical elective requirement so that the option can be completed with no additional course work beyond the B.S.E.E. degree. Required and elective courses for the option range from controls and microelectronics to power electronics and alternate energy systems. The power electronics option has been available to undergraduates completing degrees beginning in spring 2002. As new courses are developed, they are evaluated for possible inclusion as technical electives within the option. An illustration of VT's option is included in Figure 1 below.

RPI's concentration in Power Electronics Systems was designed for any student in the Department of Electric Power Engineering who wished to pursue more in-depth knowledge in the discipline. Required and optional courses for the power electronics concentration at RPI are illustrated in Figure 2.

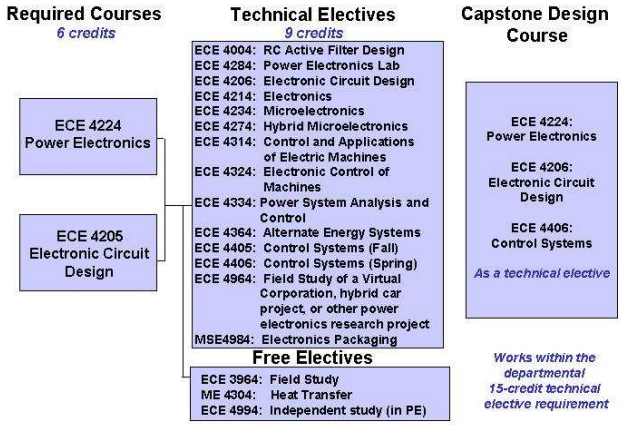

FIGURE 1
POWER ELECTRONICS OPTION AT VIRGINIA TECH.

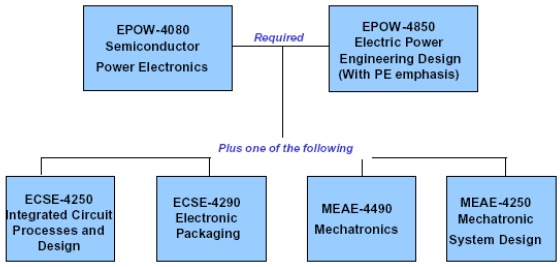

FIGURE 2
POWER ELECTRONICS OPTION AT RENSSELAER POLYTECHNIC INSTITUTE.

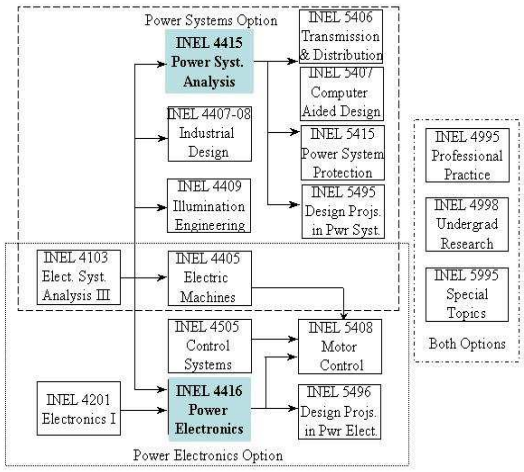

FIGURE 3
POWER ELECTRONICS OPTION AT UNIVERSITY OF PUERTO RICO-MAYAGÜEZ.

The power electronics option developed at UPRM complements an existing option in power systems in the sharing of coursework elements [1] [2]. The option also includes new courses developed as part of the Center. Figure 3 illustrates required courses for the options in both power electronics and power systems.

The power electronics certificate program at UW is based on an existing course requirement for Grainger Fellows, but provides the benefit of expanding the program structure and components to those who do not receive fellowship support. Successful applicants to the program must have completed at least two years in the university's College of Engineering, and must successfully fulfill B.S. degree requirements in any engineering program within the College of Engineering with a field of specialization in electric power engineering, have completed (by date of graduation) at least 9 credits (including at least 6 credits in ECE) from a prescribed list of power electronics courses.

Although a formal degree option in the discipline has not been created at NC A&T, the goal of an undergraduate degree option has been fulfilled be the creation of the basal-level course sequence in power electronics systems, which can provide a platform for a capstone design experience in power electronics.

EXTENDING THE IMPACT OF CENTER PROGRAMS

A key element of successful program development within the Center was the customizing and redirecting of program implementation strategies to best fit the needs of students. For example. Upon the inception of the Center, the graduate student exchange program was conceived as the primary means of intercampus collaboration within the Center. When conducting an annual Strength, Weaknesses, Opportunities, and Threats (SWOT) analysis with the students of the five campuses, it was determined that this program alone would not be sufficient to achieve strong and pervasive intercampus linkages within the Center. While the existing consortium agreements were effective in making resources available across institutional boundaries, students noted a number of key barriers to participation in full-semester exchange programs. Primary concerns included disruptions in project work at the students' home campus as well as the personal upheaval caused by relocating their residence for an extended period of time. The latter concern was particularly prevalent among students who were married or in long-term relationships, or who had children.

Short-term Exchange Program

Since intercampus collaboration was a primary goal of the Center, the Education Director and intercampus student council were charged with developing a new system of collaboration which would achieve that goal while addressing the barriers to participation identified by the students. In order to stimulate student interest and involvement in intercampus research and educational opportunities, the CPES Student Leadership Council proposed a short-term exchange initiative. This initiative was designed to provide Center students with travel scholarships to visit partner campuses in order to perform collaborative research and to participate in educational programs. The Education Director, who administered the program through the lead campus, also coordinated the logistics and reimbursement of all travel, regardless of the campus origin or destination of the exchangee. Information dissemination among partner campuses is enhanced through the delivery of presentations by participants at both the home and host sites.

Since its inception, the short-term exchange program has been used for the purposes of research collaboration, laboratory use, software training, and participation in education programs such as short courses. Since 2003, more than 100 student exchanges have been completed through CPES.

Research Experiences for Undergraduates

It was also decided that the short-term exchange program could be used to extend the impact of the Research Experiences for Undergraduates (REU) program. Although short-term exchanges occurred on a year-round basis, the majority of short-term exchanges took place during the summer, when schedules are more flexible.

For campuses with emerging programs in power electronics, beginning graduate students with no prior experience in power electronics often benefited from a summer research experience activity which mirrored that of undergraduate students. To this end, the Center devised a short-term exchange program for graduate students. This opportunity was offered in parallel to the REU program, so that undergraduate and graduate students from the same home university would be invited as a team to the host university. Research projects reflecting the respective levels of graduate students and undergraduate students were devised. With the assistance of the students' academic-year advisors, the projects were related in terms of research area. This resulted in strengthening of the team, as well as a dual mentorship structure in which undergraduate students received guidance from graduate students at their home university as well as the host university. Upon completion of the program, graduate students had developed a strong basis for intercampus research collaboration in the coming year. Undergraduate student projects, devised with follow-up academic-year work in mind, often formed the basis of their senior design projects. Their continued involvement in the Center was facilitated by the presence of the graduate students with whom they had worked during the summer. Both graduate and undergraduate student participants applied for short-term exchange scholarships during the following academic year, so that they could continue intercampus collaborations and use of laboratory resources.

In order to further enhance intercampus connectivity, a non-credit introductory course was added to the REU and the parallel graduate short-term research exchange program. This course, required for both undergraduate and graduate programs, was designed as a bridge between the introductory circuits course (required for admission into the program) and the introductory systems-oriented power electronics course now implemented in various formats at the Center's partner campuses. Class was held daily for 60-90 minutes during the first three weeks of the program, then three times per week for the remainder of the program.

The non-credit course focused on fundamental concepts of power electronics common to all projects, progressing to the discussion of basic modeling techniques for power conversion and advanced modeling techniques to improve the efficiency of the design. The course concluded with presentation and study of full design examples and observation of an advanced design experiment in power electronics research. The format of the course was flexible enough to address avenues of inquiry suggested by the students. Student input frequently resulted in the scheduling of tutorials in design and simulation software, use of specialized instrumentation and discussion of questions related to specific projects.

Course participation benefited REU and graduate students in several ways. First, it provided a common frame of reference for all participants, while enhancing the cohort experience for both REU and graduate students. It provided a structured environment for the discussion of project-related questions, separate from project meetings. Since fundamental questions were addressed in the course, time with the mentor was more effectively spent on research and interpretation of results. Third, a follow-up study indicates that REU participants achieved far greater confidence in their ability to perform research and to succeed in graduate-level study in the discipline as a result of their participation in the program. The study also showed that performance levels in subsequent power electronics coursework were significantly higher than their non-REU counterparts. [3]

Louis Stokes Alliance for Minority Participation

During the initial years of the Center's REU, the Education Committee recognized the potential of programs such as the NSF Louis Stokes Alliance for Minority Participation (LSAMP) for recruitment of diverse students into Center programs. The Education and Outreach program included strong linkages with minority-serving institutions, and four of the five partner campuses of the consortium belonged to a regional LSAMP program. Since prior initiatives to include LSAMP scholars in Center research had proved quite successful, the Center submitted a proposal to develop a dedicated research program for LSAMP scholars.

This initiative, funded in 2004, sought to build on the growing collaboration between the ERC program and the LSAMP program in order to develop an REU in power electronics targeted exclusively to LSAMP participants. The purpose of this program is twofold: 1) to provide additional opportunities to ERC students to obtain a rich undergraduate research experience, including consecutive summer experiences for interested students and a service learning component engaging participants themselves in mentorship relationship with younger students; and 2) to encourage the participants' pursuit of engineering research activities and graduate study after completion of the REU program.

During the past three years, the LSAMP REU program has been held in parallel with the existing REU program. Consortium resources have been used to extend the impact of the summer experience into the academic year, through short-term exchanges and undergraduate research assistantships offered at their home campuses. Due in part to these enhanced linkages, as well as active engagement of REU alumni in recruitment activities at their home campuses, the numbers of minority and Hispanic students applying for an accepted into Center programs increased dramatically. From 2002-present, twenty-eight (28) of thirty-five (35) REU and LSAMP REU students have been underrepresented minority or Hispanic students. [4]

Results from the REU and LSAMP REU participants' research, as well as those of graduate research assistants are presented at the Center's Annual Conference. The CPES Annual Conference is designed to provide a forum for the Center to share its research progress with industry partners and the larger power electronics community. The CPES Annual Conference is organized by a student committee, which is responsible for developing the technical program, poster session, and general logistics as well as development of the conference brochure, proceedings, and proceedings CD. This event attracts approximately 250 participants from industry government and academia each year. Through participation in this event, REU and LSAMP REU students as well as short-term exchange graduate students gain experience in preparing, submitting and occasionally reviewing conference papers, as well as delivering technical and poster presentations.

Students are also encouraged to publish their results in referred journals, and to present their work at conferences. In 2006, two REU alumni gave an oral presentation on electronic power distribution systems at an LSAMP Conference held in Baltimore, MD. Their oral presentation won first place in the engineering session, from a field of twenty (20) presenters from HBCUs across the country in this category.

CONCLUSIONS

Administration of a multi-institutional Center in which each campus participates as an equal partner is a significant challenge and requires significant program coordination within both research and education programs. Based on the experience of the CPES ERC, the fundamental framework of this collaboration is defined by the scope of the research program as well as the definition of goals and tasks within and among projects. As shown in this paper, the Education and Outreach program can play a significant role in enhancing this collaboration through creation of supporting structures. The purpose of these structures is communicating vision, implementing shared goals, and extending the impact of Center programs. The lead university plays a critical role in the execution of these programs through establishing and implementing shared policies and practices within the consortium.

In order to develop and implement these supporting programs, structured and regular input from students across the consortium is needed. Development of an intercampus Student Leadership Council, the purpose of which is to advise the Center's leadership regarding such program development, is critical. The Council also conducts regular and independent SWOT surveys in order to evaluate the relative successes of these efforts, and to make recommendations for future implementation strategies.

A critical challenge for all consortia is strategic planning. In the case of consortia developed as the result of a single sponsored project, transitioning the Center to new funding sources is of particular concern. In such cases, the securing of institutional commitments to sustain the partnership, along with the support of industry consortia and research sponsors is essential to sustaining intercampus collaborations. Early planning and consistent evaluation and input from key stakeholders, including students, provide key insights into the value added by multi-institutional collaboration, as well as opportunities for future growth.

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