CHAPTER 4

EDUCATION PROGRAMS

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4.0 EDUCATION PROGRAMS

CONTENTS

4.1 INTRODUCTION/OVERVIEW

The mission of an ERC is to produce globally competitive engineers with the depth and breadth of education needed for success in technological innovation and for effective leadership of interdisciplinary teams throughout their careers

Education is one of the three primary foci of the ERC Program's mission, along with research and technology transfer. The goal of ERC education programs is to develop a team-based, research-inspired, and industrial practice-oriented culture for the education of graduate and undergraduate students that will produce engineering leaders for the future. ERC graduates make up a new generation of engineers who are adept at the cross-disciplinary team approach to problem solving; who understand and share industrial perspectives on research, design, and manufacturing; and who are well-prepared to contribute readily and productively to industry as a result of their experience with engineering systems and testbeds. An important feature of all successful ERCs is active outreach to involve faculty and students from other institutions in ERC research and education programs. This includes outreach to precollege students and teachers aimed at introducing engineering concepts in precollege education, in order to stimulate interest in engineering careers. It is also vital to increase the involvement in engineering of underrepresented populations, including minorities, women, and persons with disabilities. Finally, ERCs are charged with enriching engineering education at all levels by integrating their research findings into new curricula for students and practitioners.

This chapter reviews ERCs' education activities. It is aimed at a diverse audience, centering on those operating or planning to operate ERC education programs, but also extending to faculty and staff of all university-industry research centers and engineering educators generally. It addresses issues of program planning and direction, including management roles, strategic planning for the education program (including "life after NSF"), funding, and the role of NSF in developing and enhancing education programs. It describes the broad spectrum of ERC education programs for graduate, undergraduate, precollege, and community college students, including ways to increase the involvement of underrepresented populations. It discusses curriculum development in all its aspects. It reviews outreach techniques for making contact with sectors outside the university. Since interaction with industry is particularly important for ERCs, it points out ways to increase industrial involvement and interaction. Educational outreach to other institutions is explored, reviewing both domestic and international activities and their benefits to the centers. The chapter describes educational delivery systems, including the internet, with a review of effective applications of hardware and software systems designed to affect the curriculum. Finally, it summarizes some of the lessons learned in developing ERC education programs.

4.1.1 ERCs and Their Role in Education

Since the mid-1980s, when concerns about U.S. industrial competitiveness were widespread, it has been widely believed that baccalaureate programs in the Nation's

engineering schools have tended to produce engineers who, while well prepared in engineering science, need more experience with technological advancement and interdisciplinary teamwork before…who need more training before they can meet the basic needs of industry. Many large corporations find that they must provide significant training beyond on-the-job experience. Traditional engineering students obtain little practical experience in their educations. Furthermore, although industrial employers place high value on teamwork, most graduating engineers traditionally have had limited experience in working in teams.

ERCs are designed to produce graduates who excel in these areas, where traditional graduates fall short. (Attachment 4-1, at the end of this chapter, summarizes the results of a study of the job performance of ERC graduates.) The centers try to bring to engineering education a new culture based on goal-oriented values, complementing the theoretical science-based education long predominant in academic engineering. Those involved in the ERCs have come to recognize that education may actually be the centers' most important means of contributing to the Nation's global competitiveness. ERCs devote much energy and resources to "spreading the culture" through education, and to creating an environment conducive to this new kind of education.

ERC education programs are a primary means of achieving the overall goal of culture change in engineering education, and in academic engineering generally. They encourage that change by articulating the ERC ideals, making opportunities available to implement the ideals, and facilitating the use of those opportunities. Faculty buy-in is essential; only if the faculty believe in the ERC educational/cultural model and act accordingly will ERCs succeed in their mission to change the overall culture of academic engineering.

4.1.2 Unique Features of ERC Education Programs

Certain characteristics are common to nearly all ERC education programs, reflecting NSF's education goals for the ERCs: a strongly cross-disciplinary approach, an emphasis on the involvement of industry, innovative use of educational technology, and a dedication to reaching far beyond the host universities to include a diverse group of students of all ages who might be inspired to become engineers or scientists.

ERCs encourage students to work in teams by focusing them on engineered systems that require input from various disciplines, such as manufacturing, materials processing, biomedical systems, multimedia technologies, or earthquake engineering, with an awareness of technology and product development issues. Direct interaction with industrial researchers, both on campus and at industrial sites, is a vital feature of ERC education. ERCs emphasize engineering design and synthesis, with a strong coupling between research and education programs. In addition, they devise innovative undergraduate and graduate degree programs and courses and update curricula and course materials as new research discoveries occur. Because of this approach to education, employers in industry often note that ERC graduates are more effective and productive than their traditionally trained counterparts. For more than a decade, these graduates also

have provided a new dimension to education as they have joined the faculties of engineering schools across the country.

Each ERC has a Student Leadership Council (SLC), which students involved in ERC research and education are encouraged to join. Not only do SLCs give students a forum for social interaction with other students with similar interests; even more importantly they provide a focus for developing many of the leadership skills for which ERC students are known. SLCs conduct outreach projects to precollege students and other groups. They host research seminars and poster sessions. They even participate in the strategic planning and direction of the centers through a Student SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis they conduct in conjunction with NSF site visits to the centers. (See Chapter 8, Student Leadership Councils.)

Collaborating with other ERCs and other universities and extending the ERC experience to precollege students and teachers as well as businesses are responsibilities that all centers have taken on as part of their education mission. In addition, the ERCs are expanding outreach to involve women, underrepresented minorities, and disabled persons from other institutions in research and education projects relevant to the goals and objectives of the ERCs. While NSF gives ERCs flexibility in the type of educational outreach they employ, the Foundation views such outreach as essential if the Nation is to tap into a broader pool of potential engineering talent that traditionally has been underutilized.

The primary role of the education programs in the centers is the education and training of students, fostering their professional growth in a multidisciplinary environment with team research, industrial interaction, and an integrated engineering systems approach. The education should include practical approaches to engineering as well as theory in order to better serve the needs of industry. As part of the ERC education plan, strategies should include the active involvement of undergraduate and graduate students in all facets of the center programs, particularly the team-related research activities. Participation in university-industry collaborative research teams, mentoring of students by industrial researchers, industrial internships, and participation in research seminars are all mechanisms that deepen students' understanding of real-world engineering practices and requirements.

Each center has a person on the staff or faculty who is responsible for developing and shaping its education programs. The job is referred to by various titles and may occupy various places on the organization chart, depending on the center. In this chapter we use the title "education coordinator /director."

The following traits/characteristics have been observed in students who have been actively involved in the education programs of an ERC, compared to those who received a non-ERC education (see Attachment 4-1). ERC students:

- have a broad cross-disciplinary education and awareness
- have a broader outlook, integrate knowledge more readily
- work better in a collaborative mode

- have a more global perspective
- have more effective communication skills, both oral and written
- benefit from professional conferences and participation in the NSF review process
- have training in systems-level engineering research
- are more flexible in resolving research problems by using other disciplines in to help resolve problems
- have experience in interactions with industry
- pursue active involvement in team activities
- tend to seek more research-oriented jobs than non-ERC graduates
- have a more interdisciplinary perspective on responsibilities
- need less on-the-job training and are able to contribute to real work earlier in their employment than most other graduates
- have hands-on experience and are willing to apply hands-on-skills
- are more sought after by industry, take responsibility and contribute earlier in their careers, and rise to positions of leadership more often.

These are significant differences. The authors hope that the specific suggestions, examples, and experiences related in this chapter will clarify the ways that these educational distinctions are achieved.

4.2 EDUCATION PROGRAM PLANNING AND DIRECTION

4.2.1 Planning Considerations

In planning an education program, a center's leadership team must take into account the following:

- *Center Mission Statement.* An ERC is a unique organization that has three mandates from NSF: (a) cutting-edge research, (b) technology transfer of the results of the research, and (c) preparation of the next generation of engineers and scientists. The mission statement should recognize the education component of the center.
- *Education Program Goals.* Program goals must be specified at the beginning of the planning process. The leadership team, including the center's overall director, must develop them in conjunction with the director of research, the director of technology transfer, and the education coordinator/director. (All of these functions are known by different titles at different centers.) This step will ensure integration of research, technology transfer, and education (a hallmark of the ERC Program) and implementation of the program. These goals should be consistent with the mission statement and must address the scope of the program, the mechanisms for integrating center research and education, and mechanisms for industry-student interactions. The requirements for precollege educational outreach must be taken into account. Because ERCs have a particular mandate to ensure adequate representation of women and minority students, recruiting measures to meet this mandate must be included. The goals will determine the scope and range of the education program.

- *Organizational Considerations.* Initial planning must include the human resources that will be needed. The director of the education program should be a professional at the same level on the organizational chart as the research and technology transfer directors. It is recommended that a full-time professional be engaged at the outset and included in the planning stages of the program. While some centers rely on part-time faculty members to serve in this position, employing an individual with an education programming background will allow the center to implement a complete program.
- *Strategic Planning.* Given the limited lifespan of an ERC, the center's management must give strategic planning a high priority, beginning in the initial stages of a center proposal. Strategic plans are dynamic documents that guide allocation of limited resources. They must be revisited annually to ensure that they are able to react to changes in the research and industrial environment and to allow for the exploitation of opportunities that arise during the year.
- *Budget.* The education program should include resources that match the proposed plan. While supplemental funding (from foundations, NSF, and industry) for particular programs is available, center resources should be earmarked to support the fundamental components that allow the center to meet its core educational goals. A typical ERC directly spends $7 million on education and outreach.
- *NSF/Center Interface.* NSF has an important guidance and support role to play in the development and growth of ERC education programs.

4.2.2 Scope and Range of Education Programs

ERCs are perhaps unique in their mission to provide an array of education programs across the learning continuum, from precollegiate through collegiate to lifelong learning for postgraduates. (Figure 1 represents schematically the scope of a typical ERC education program.) It is therefore useful to develop an education program in phases that are implemented over several years. The initial focus must be determined by the education coordinator/director in collaboration with the center director and other members of the leadership team.

A phased approach works best. The initial program components would generally comprise curriculum development activities and programs for undergraduate and graduate students. Phase 1a would include course modules and activities for the local college level and precollege students. Phase 1b might include outreach activities for undergraduate and graduate students at other institutions, such as a Research Experiences for Undergraduates (REU) program. Phase 2 might be continuing education activities for practitioners. Phase 3 would include precollegiate outreach activities. It is important to set priorities for these activities in the initial planning stage and obtain consensus among the center's leadership on the appropriate order of implementation. A mature program, such as the model in Figure 1 that offers programming at all levels, requires significant resources (both human and financial).

4.2.3 Education Program Direction and Management

4.2.3.1 Qualifications of the Education Coordinator/Director

To implement a comprehensive education program, serving a variety of constituents, it is recommended that a full-time administrator be named. Most ERCs have designated a member of the faculty or senior administrative staff to direct education programs; in several centers an associate director holds this position. The title for this function varies, reflecting the different administrative structures of different ERCs. In some centers with small administrative staffs, one or more existing staff members carry out the functions of education coordinator/director along with their other duties at the center or in the university, but this approach limits the ability of the center to offer a wide range of programs. The position should be considered not a support position, but rather a professional position with appropriate professional status.

The choice of education coordinator/director, and the appropriate positioning of this person as a member of the center's leadership team, will determine the success of the center's education program. In some centers, the management believes that this person should have a PhD, to elicit the full respect and cooperation of faculty. This is especially important for curriculum development. This question should be considered and resolved at the outset by the center director and the executive committee. In any case, the primary

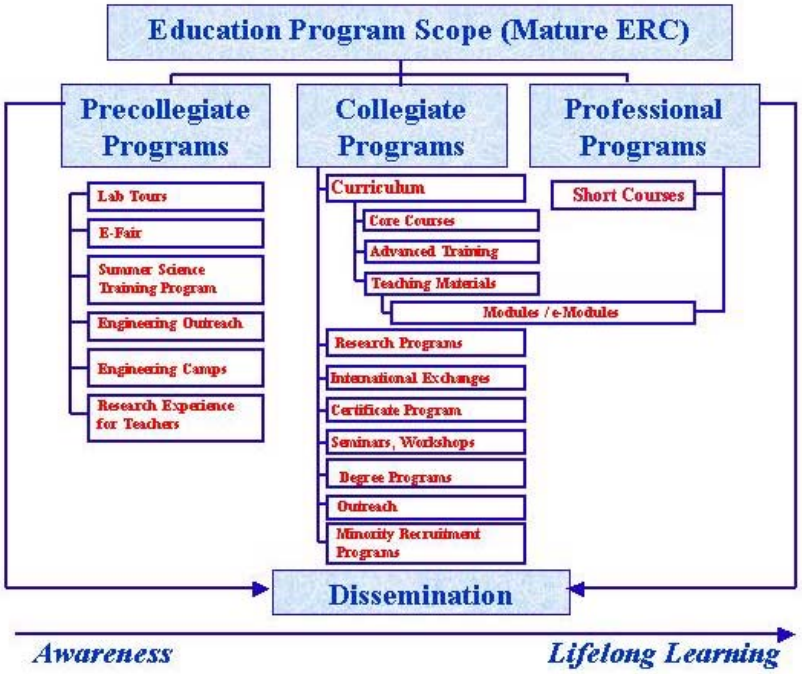

Figure 1. Scope of a typical ERC education and outreach program

focus should be on identifying an individual with an appropriate background to be responsible for the education activities of the center. His or her interest in interacting with students should also be a major selection factor.

Education coordinators/directors are responsible for writing up all aspects of their education programs for the ERC annual report and other documents. They also develop and write grant proposals of many types to expand their education programs. Therefore, strong communications skills and an ability to prepare successful proposals are important.

It is recommended that an education advisory committee be established to give center faculty a mechanism to provide input into center education programs and to provide support for them. The composition of this group can include center faculty, external faculty, and industrial partners as is deemed appropriate.

4.2.3.2 The Education Coordinator/Director's Position in Center Management

An ERC's education program is no less vital than its other two central activities (research and technology transfer). The education coordinator/director should be a full-fledged member of the center's leadership team, along with the research and technology transfer directors. Only with such coordination and cooperation will the center be able to integrate research and industrial participation in its education program.

A variety of organizational structures can lead to successful education programs. In some centers the center director closely monitors the education coordinator/director, to provide continuous oversight, input, and knowledge of the education programs. In other cases, the education coordinator/director has the freedom to manage the education programs with limited oversight. The appropriate management style will vary from center to center.

4.2.4 Strategic Planning

4.2.4.1 Strategic Planning Process

The strategic planning process for education is conducted in different ways at different centers, with a variety of participants, including the education coordinator/director, the center director, an education advisory committee and/or the center administration, and possibly industrial or university involvement. Examples of different strategic plans are on the Engineering Research Centers Association website (at http://www.erc-assoc.org/educate/edstrat.htm).

Some ERCs involve faculty from all departments of engineering or representatives from industry in the strategic planning process. Knowing the state of the art in your ERC research areas provides a base from which to modify and develop courses. Several ERCs use the activities of annual report planning and preparation as the time to review education program strategy and make changes. Some ERCs give the education coordinator/director and staff leeway to make initial plans and decide on strategies, which are then reviewed by the center director and/or appropriate committee. Other ERCs form teams consisting of the education coordinator/director, center director, some faculty members, and sometimes a graduate student representative. Another means of student

input is a student advisory committee. Often the membership of such a committee is drawn from the center's Student Leadership Council (see Chapter 8 of the Best Practices Manual).

ERC education coordinators/directors can consult their counterparts at other ERCs for ideas in constructing the initial plan, and they can meet with their center directors, industrial liaison specialists, and senior center faculty to gather input on ERC education. In addition, the education coordinator/director must become familiar with the curricula at his or her particular school of engineering and other relevant departments within the university. Multi-university ERCs also must accommodate requirements of their affiliated universities' curricula.

In developing the strategic plan, one should begin by defining the issues of relevance to the particular ERC's vision, mission, and goals.

4.2.4.2 Initial Planning Issues

Among the issues to be considered in developing and implementing the education plan for an ERC are:

- development of an education vision and goals (both short-term and long-term) consistent with the center's strategic plan and objectives
- identification of the particular populations and student groups to be impacted
- assessment of resources, both personnel and financial
- development of guidelines for undergraduate and graduate student participation
- development of a recruitment strategy for undergraduate and graduate students, recognizing that different strategies are required
- design of an outreach strategy to include K–12, undergraduate, graduate, industry, community, etc., short-term and long-term, which meets NSF and center goals
- development of a plan to recruit and retain underrepresented populations in engineering (women, underrepresented minorities, persons with disabilities) in the center's education and research areas
- development of a strategy to infuse ERC research findings into the curriculum
- development of mechanisms to integrate students into all aspects of the center
- development of mechanisms for industrial interaction at all student levels, graduate and undergraduate
- development of a schedule of ERC courses, seminars, and other academic requirements so students can commit to them early in their careers.

Once the strategic plan is developed, it can be used to help write the annual report each year and to plan budget requests and revisions; the plan can be easily reviewed and updated to reflect future progress in the center.

Following is one model of the process of developing a strategic plan:

- *Overall Goals/Objectives.* The first step is to develop a statement of the overall goals/objectives of the education program, keeping in mind the center's vision (what

you want it to be) and mission statement (what you do to implement the vision). Such a statement should include what do you want to do; whom you want to affect, and how you intend to accomplish it. For example, an educational goal/objective might be "to develop and deliver innovative educational initiatives to prepare scientists and engineers for the challenges of the emerging biology based industries, in order to produce a generation of engineers and scientists with a cross-disciplinary team perspective." The strategy to accomplish this goal could include "a major outreach to middle and high school students and teachers."

- *Initiatives and Actions.* Next, one must develop specific initiatives (specific, focused activities) and the actions for carrying them out. (Actions should be stated in measurable terms.) Initiatives might be planned in the areas of precollege outreach, undergraduates, graduate students, lifelong learning, and curriculum development. For example, "K–12 initiatives will provide opportunities for elementary, middle, and high school students and teachers to understand the center's research field and goals." This initiative might be supported by actions such as "Maintain a program of yearly demonstrations to X number of schools" and "Develop a web module."

An education strategic plan also should provide for developments over time. A plan appropriate for an ERC in its early years must change as the center matures, and will change even more as the center works towards self-sufficiency.

4.2.5 Graduating Centers: Planning and Preparation

An important issue in strategic planning is the impact of the ERC's 10-year life cycle. Some program components are amenable to institutionalization, but others depend on supplemental funding that is not likely to be continued after funding ends. Courses that have been added to the curriculum by the center and any associated certificates, minors, and/or majors should be integrated in the university curriculum prior to the end of the center, thereby becoming part of the continuing programming of the university.

As a center approaches the end of the cycle, these concerns come into sharper focus. NSF hopes and intends that the culture of ERC education will continue in the center; but without continuing support from the university and industry, it is likely that most of the ERC's education programs will end. The center's education coordinator/director should work with the center leadership to develop a self-sufficiency plan from the outset. This plan can include soliciting education funding from the university, foundations, and the private sector (notably industry).

When a center "graduates," or reaches its full term, NSF supplemental funding for educational activities may continue on a competitive basis, provided the center still operates as an ERC. Depending on the financial strength of the graduated center, some education programs may be cut back or ended. Areas that may be affected include the extensive involvement of undergraduates and underrepresented populations in the education and research activities, as well as outreach programs. The continuation of a

graduated center in some ERC-like form is essential to maintaining support for the associated education programs.

Preliminary data from earlier graduated centers suggest that:

- Research becomes focused on applied, short-term projects that may not be suitable for dissertation level work.
- Undergraduate research and outreach program components (including programming for minorities and women students) decline.
- Student involvement, interdisciplinary focus, and team-based research decline.
- In most universities with graduated centers, the main lasting effect of the NSF ERC funding to date has been the development of multidisciplinary degrees, minors, and certificates that have helped shift engineering education away from the traditional disciplinary compartmentalization towards the interdisciplinary focus that is required to solve today's engineering challenges.

Studies and a recent survey of graduated centers have shown that successful continuation of education programming depends on several factors:

- A full time (hard money) person to coordinate activities, who is prepared to seek funding from grants and other sources
- Strong institutional support, including support for the ERC education culture as well as significant cash or other direct financial assistance; finding champions of the education and preparation of students, both in industry and at the university level, is critical
- Faculty motivated to continue and institutional incentives that further this motivation
- A strong, continuing commitment on the part of center leadership to the goals of an ERC education program
- Successful securing of funding from governmental agencies and foundations
- Creative ways of packaging program elements that fit the type of activities industry is able and willing to support (i.e., lab training internships, design course support, graduate fellowships).
- a strong, evolving research program.

Attention must be paid to all these characteristics from the outset. They must be nurtured and maintained throughout the life of the center, to provide a platform for successful implementation of the strategic plan.

4.2.6 Developing a Budget

The budget of an education program depends on many factors, including the education plans of the center, the expected industrial involvement, the number and type of NSF supplemental funds granted, and the initiative of the education coordinator/director. The size and complexity of the program will depend on the commitment of the center's leadership to the education program and the priorities set during the initial planning stages.

4.2.6.1 Establishing Appropriate Budget Levels

Items that should be in the education budget include:

- administrative costs (such as the education coordinator/director's time, support staff, printing, and data management)
- graduate student support
- funding to support the undergraduate research program
- funding for precollege outreach
- travel (for recruiting, dissemination, and so on).

The initial budget for education should include funding for start-up, advertising and recruiting, and other efforts to ensure a successful beginning for the program in addition to stipends for undergraduate students (for center research fellows, summer research programs, and other activities), research assistantships for graduate students, and appropriate staff support. Because ERC education programs must make extensive reports to NSF, data management capabilities must be planned for at the outset.

The initial budget may include some costs (such as travel) that support the development of relationships with other undergraduate and minority institutions. Once these relationships have been developed, budgets may be partially reallocated to other purposes. Some centers use education budgets only for stipends and student support, with staff and travel budgeted in other center funds.

Dissemination is an important part of an education program. There are many opportunities for engineering educators to learn from each other, such as Frontiers in Education (FIE), the American Society for Engineering Education (ASEE), Women in Engineering Programs and Advocates Network (WEPAN), and the National Association of Minority Engineering Program Administrators (NAMEPA). Travel funds should be provided to allow them to participate in these meetings and organizations.

The education program will include contributions from others, including editors, publications coordinators, and staff engineers. The center's education budget should allocate a portion of the time of these personnel to the education budget.

As the center matures, NSF supplemental funding and leveraged support from other sources, as well as industrial funding, should increase.

As the center approaches graduation, the most likely scenario for continuation of the education programs is through leveraged support via additional funds from the university, foundations, industry, or state programs as well as NSF/ERC education programs.

Education budget decisions allocating overall resources should be made by the center leadership—including the director, education coordinator/director, research director, and industrial program director—serving as an executive committee. In some ERCs, education coordinators/directors submit proposals for funding along with research proposals of the thrust area and project directors, and all proposals are considered by an

ERC funding committee. Some ERCs have a budget for program development, which includes scholarship/fellowship stipends and seminar and travel expenses.

Faculty attitudes toward center education programs differ with respect to funding. A research faculty member who is also coordinating an education program commented, "It is clear that faculty respond to rewards (primarily funding). If money is allocated primarily on the basis of research, then there is little incentive for faculty to devote significant effort to developing new or innovative educational activities." At many ERCs, however, faculty are enthusiastic about the education programs and even offer to support additional students from their research funds.

4.2.6.2 Sources of Education Funds

Funding for educational activities may be derived from a number of sources. Ideally, after the first few years, it should not depend entirely on internal ERC funds. Specifically, there are opportunities for competitive supplemental funding from the ERC Program, education/outreach awards from other divisions and directorates of NSF, special grants from industry members of the center, funds from the university for diversity-promoting activities, education grants from philanthropic organizations, and possibly state sources. Opportunities should be pursued to leverage the funding received, using non-federal ERC funds for matching. Some centers have been quite successful in leveraging their education budgets with university, state, and other federal resources. Foundation funds may be used for matching funds with NSF-supported activities.

ERC Program supplemental funds are provided for special initiatives, such as the Research Experiences for Undergraduates (REU), outreach to historically black colleges and universities (HBCUs), technology schools, and international programs, as well as other special supplemental funds. Such programs significantly strengthen ERC education programs. (See Section 4.3, “Education Programs.”) They provide a focus for center education activities and serve as a fulcrum for leveraging support from other sources, including industry. The programs go considerably beyond the traditional research-focused mandate of university research centers. Indeed, they place a substantial demand on the administrative and financial resources of ERCs. However, they are part and parcel of the broader mandate of these centers to develop a new and more industry-focused, product-focused culture for academic engineering and to spread that culture through education. In that sense, then, "outreach" is simply extended ERC education.

In addition to the ERC Program’s REU funding are NSF-wide REU and Research Experiences for Teachers (RET) programs. It should be noted that many ERCs have found it important to supplement the NSF REU funding by various means, to develop strong REU programs.

Adequate baseline funding must be provided to the program, however. A collection of supplemental grants alone does not make a coherent program, as not all funding opportunities will fit in the education strategic plan and only those that do fit should be pursued.

4.2.6.3 Strategies for Funding Education Programs

ERCs have taken many creative routes in leveraging educational and outreach activities, including the following:

Contacts with industrial partners or other corporate sponsors have been used as a means of providing additional funding for educational programs.

- The ERC for Environmentally Benign Semiconductor Manufacturing sponsors a three-week Teacher Institute for which teams of teachers (a math and a science teacher) from the same school are recruited. The teachers spend time in the center laboratories and local industry and also develop curriculum enhancement activities. The local industries participating in the program pay part of its expenses. RET funding from NSF also supports this effort.

Collaborations with other institutions has also proved a source for leveraging funding.

- The Packaging Research Center has partnered with the International Microelectronics Packaging Society and NSF to provide undergraduate research fellowships to undergraduates at non-PRC institutions in an outreach educational program to promote packaging research at other undergraduate schools.
- The Center for Reconfigurable Manufacturing Systems at the University of Michigan has a Museum Project in collaboration with the Ann Arbor Hands On Museum. The Museum provides in-kind support in the form of expert advice, contacts, and space. The exhibit educates participants about manufacturing and increases awareness of the progress in manufacturing.

State governments and other governmental agencies have also provided a source of support.

- The Center for Subsurface Sensing and Imaging Systems at Northeastern University has over the past several years conducted the CenSSIS Challenge "Hidden Worlds" project for high school students and their teachers at the annual Massachusetts Pre-Engineering Program, Inc., competition. The "challenge" project has been funded through a grant from the Massachusetts Department of Education.
- The Biotechnology Process Engineering Center at MIT has had over the years several training grants from the National Institutes of Health to help fund the training of graduate students.
- The Multidisciplinary Center for Earthquake Engineering Research has made the most of funding from several sources (FEMA headquarters, FEMA Region II, New York State Emergency Management Agency) to coordinate a program to develop an accurate earthquake-loss estimation model for the greater NYC area. With funding from these sources, augmented by MCEER educational funding, several outcomes were achieved: an effective website for outreach (especially important in reaching those in the low- to moderate earthquake hazard areas) was established, undergraduates were involved in the research, and a number of reports and papers were produced. Additional knowledge and information was contributed by those supported by other sources in New York and New Jersey. At the project's conclusion,

an impressive amount of regional data on seismic hazard and building inventory and distribution will be made publicly available.

The NSF Engineering Education and Centers Division also provides special supplemental funding for some programs. REU supplements are used by most centers, and RET supplements are also available. Other supplements become available periodically. For example:

- The Center for Power Electronics Systems at Virginia Tech received NSF supplemental funding through the PER (Partnership for Education and Research) solicitation program for CPES's Lego Robotics Challenge project. This program is concentrated in Southwest Virginia, a region that has historically lacked such a program. Its intention is to introduce elementary and middle school children to science and technology concepts at an early age.

Other NSF engineering divisions and other directorates also have been sources of support. For example:

- The three earthquake engineering research centers (EERCS) served as a catalyst to develop the University Consortium on Instructional Shake Tables (UCIST), currently a consortium of over 40 institutions. The three centers cooperated in the design of a bench-scale shake table to encourage interest in structural dynamics and earthquake hazard mitigation at the undergraduate level. The cooperation among the centers inspired the investigators to go after an NSF grant from the Education and Human Resources Directorate's Division of Undergraduate Education, which provided 1:1 matching of funds for the acquisition of the hardware for the first 25 universities.
- The NSF-wide Integrative Graduate Education and Research Traineeship (IGERT) program funds activities that are organized around an interdisciplinary research theme and involve a diverse group of faculty members and other investigators. An IGERT project is expected to provide students with experience relevant to both academic and nonacademic careers by linking graduate research and education through such activities as internships and mentoring in industrial, national laboratory, academic, or other settings. As such, ERC students and programs could easily qualify for IGERT funding, although at present no ERCs have an IGERT award.

One of the best ways to leverage funding and improve the efficient use of a center's resources is to join with others in setting up and implementing projects. Once the fixed costs have been met, additional participants bring down the cost per participant and provide cross-fertilization of expertise.

- Since their inception, the three EERCs have had many such tri-center projects. While each center has an REU on its diversified campuses, there is a combined REU symposium at which all participants gather. The three centers take turns in putting this on. The centers develop and then share graduate teaching modules on specialized subjects. Also, the centers are undertaking organizing student field missions to visit sites of recent earthquakes; these include 2-6 students from each earthquake center as well as students from other universities. This past year the students were able to visit Taiwan.

Another way to extend the reach of education dollars is to take advantage of programs that are already in place. Thus the centers don't have to reinvent the wheel or fund the final activity events.

- CPES' Lego Robotics Challenge culminates in FIRST Lego League (FLL) competition opportunities. FLL is an established joint endeavor between FIRST (For Inspiration and Recognition of Science and Technology) and LEGO Mindstorms.
- CenSSIS' "Hidden Worlds" challenge is a component of the annual Massachusetts Pre-Engineering Program, Inc., competition.

Some further tips:

Be aware of the financial environment of your industrial partners. Check with them to see if their budgets are based on the "use it or lose it" system. If so, they may be able to donate funds during the last quarter of the company's fiscal year. Continuing education programs for industry can be self-supporting and/or generate funds by pricing short courses properly. Surveying the center's industrial partners will help determine if this is an option for a given center. Written educational materials developed for either practitioners or students can also be sold at cost to cover the production for the materials.

Flexibility in budgeting is extremely important. The ability to fund an opportunity when it arises is essential if the center is to benefit from such opportunities. It is useful if there is a discretionary pool of funds in the center for capitalizing on education as well as research opportunities. It is also important to know what educational expenses the departments and universities can help defray. Tuition remission, possible use of non-overhead accounts for educational programs, university scholarships or fellowships, existing education programs that might provide matching funds, appointments as a TeachingAssistant for a semester—all these can help augment the education budget. Check with the Student Affairs or Minority Affairs Offices for possible Fellowship Programs. Not only will the students gain prestige and invaluable contacts if awarded such fellowships but the center's budget will benefit as well. Centers should work with campus and college foundation offices to identify sources of potential funding and to coordinate their efforts. Also check your other funding sources to see if there is supplemental funding available under their programs. An example is the possibility for funding for minority students on NIH individual investigator grants.

Be sure to market your successful educational programs to your universities, your industrial stakeholders, and others outside. The resulting positive publicity may attract volunteers and other support or help recruit students. Publicity of center programs also promotes the concept of the ERC.

While it is understood that a portion of the center budget should be devoted to educational activities, there appears to be a tendency across the ERCs to make the direct education allocation (i.e., exclusive of graduate student support) relatively small. Such an approach leads to difficulties in developing a strong education program and meeting NSF's goals for ERCs. It is helpful to understand that there are more demands for programs but usually there aren't additional funds allocated. Therefore, attention must be

given to developing strategies to fund these programs and increasing the effectiveness and efficiency of the use of resources for the educational area.

4.2.6.4 Education Staff Funding

Funding and staffing for the education program should be consistent with its high priority among NSF's goals for the ERC Program. Some centers have found that administering a truly comprehensive program requires two professional staff, with an education coordinator in addition to an education director. Support staff must be provided to the education programs as required, depending on the overall size of the center's administrative support staff and the breadth of the education programs. Part-time support for specific activities can usually be arranged using existing staff or student workers. The staff requirements should be a function of the programs being offered and the associated resources.

It is difficult to specify the amount of staff time required and the level of funding, because these are dependent upon the education goals and objectives of the center as well as the level and breadth of programs offered, the age of the center, and other factors; however, an under-funded program will have difficulty meeting the ERC education mandate.

4.2.7 Role of NSF

Personnel of the NSF Engineering Education and Centers Division are very obliging in helping the ERC education coordinators/directors develop and enhance their education programs. They have the experience to provide guidance and identify others who might serve as resources to assist in strengthening the education programs. NSF also provides publicity to industry and works through other NSF programs to support the centers.

As noted earlier, one of the key ways that NSF has helped, and will continue to help, is in the area of supplemental funding based on competitive proposals. The funding provided serves as a nucleus for developing strong education programs. More recognition of the importance of ERC education programs in the ERC annual meetings and during site reviews will help education coordinators/directors to strengthen their respective education programs. NSF support is philosophical as well as financial and is critical for developing strong ERC education programs and ensuring that education is an important aspect of the centers.

Some examples of NSF's aid to ERC education programs are these:

- By continually stressing the importance of education and educational programs in the ERC, NSF program directors and officials emphasize to the leadership and faculty of the ERC the significance of these programs. This greatly helps the education endeavors at the centers.
- NSF provides opportunities for additional sources of funding and publicizes these funding options to the centers.
- NSF provides the supporting framework for coordination between centers.

- NSF realizes the significance of collaboration between centers and encourages these collaborations verbally and through funding sources.
- NSF provides critical insight to our centers through the annual site visits that help improve center programming.
- NSF provides guidelines that define the programs from the inception of the center to the reporting guidelines that document annual progress.
- By mandating an industrial component to the center's architecture, NSF has laid the groundwork for the development of education programs with a strong industrial element, benefiting undergraduate and graduate students.
- By funding the ERC centers, NSF is promoting innovative programs that allow cutting-edge technology to be developed to the point where it can be utilized by industry and benefit the general population. Center education programs are an essential vehicle for disseminating these new technologies into industry, by means of the center graduates and outreach.

A strong relationship with the NSF ERC Program Leadership, and especially the center's NSF Program Director, will enhance the development and implementation of an ERC education program.

4.3 EDUCATION PROGRAMS

ERC education programs have evolved displaying many common features that have been shown over time to work in the ERC culture. At the same time, there is great diversity of program elements, reflecting the centers' differing missions and their organizational relationships with specific universities, industries, and professional fields. These differences occur both in the details and in the attributes designed to address the individuality of each ERC in its particular university, field, and industrial base. This section describes both the shared and distinctive features of those programs. Attachment 4-2 lists the education programs at all levels for each of the centers, with links to their websites for more detailed descriptions.

The ERC Program has several innovative educational features that make it uniquely beneficial for students. Educational programs are essential to each center's mission. The ERC Program was designed to address the issues of turning research discoveries into high-quality, competitive products to satisfy an increasing global demand while preparing engineering graduates with the diversity and quality of education needed by industry. ERC education programs offer the following general benefits for students and their eventual employers:

- *Cross-Disciplinary Systems View.* ERCs view the cross-disciplinary nature of their education programs as an attraction for students. All ERCs have cross-disciplinary missions, and most have students and advisors from many departments. For example, to capitalize on the revolutions in molecular cell biology, genomics, and proteomics, faculty of the Biotechnology Process Engineering Center at MIT developed a new engineering discipline with a molecular-to-systems view of biological processes,

which in 1998 became the nucleus of a new formal academic unit at the interface of biology and engineering. Other centers have been equally creative, developing courses combining engineering and sciences, for example, or engineering and business courses. The Center for Wireless Integrated MicroSystems (WIMS) at the University of Michigan developed Engineering Enterprise, which provides an alternative path through the engineering undergraduate curriculum by substituting management modules focused on microsystems for mainly elective courses.

- *Teamwork.* Teamwork experience is vital to engineering students. ERCs' industrial partners are generally impressed with the maturity and team preparedness of the graduates, who have had more industrial interaction than the average engineering graduate. Several centers, such as Georgia Tech's Packaging Research Center (PRC), have at least one full-time staff engineer for each thrust area, who works with teams of graduate and undergraduate students.

- *Involvement of Industry in Education*. Several ERCs encourage students to have industry advisors on their thesis committees. This supplement to traditional academic mentoring gives graduate students a valuable perspective on industry's concerns and gives them a head start on careers in industry. In addition, most ERCs require or suggest an industrial internship for each student, to acquaint him or her with real industrial problems. During internships, a student spends on average 10 to 12 weeks working under the supervision of an industry researcher or engineer at a company site (generally one of the center's industrial partners). Such an opportunity provides the student with a chance not only to become familiar with industrial work, but also to receive an offer of permanent employment after graduation. Other centers meet this need in their own ways. For example, the Mid-America Earthquake Center provides one- to five-day site visits for graduate students to work with government agencies, contractors, or industry personnel on their existing research projects. The Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC)'s Industrial Educational Partners Program provides internships, panel discussions and meetings between industry and faculty/students. Students at Clemson University's Center for Advanced Engineering Fibers and Films (CAEFF) have the opportunity to gain industrial perspectives by taking part in the Master of Science Industrial Residency Program, during which graduate students conduct industry-defined research on site.

- *Communications Training and Opportunities.* Student researchers make many of the presentations at center reviews, and many have more opportunities to travel to conferences to present papers or posters than the average graduate student. The University of Michigan ERC for Reconfigurable Machining Systems (RMS) provides "Student Presentation Skills" (a series of half-day workshops). Students receive training in professional writing and are encouraged to publish. Many centers also have libraries of publications and videos, readily available to center participants.

- *Mentoring Opportunities.* Many ERCs provide opportunities in which graduate students work on teams with younger students or are chosen to act as mentors on special projects. GTEC offers seminars on various aspects of a mentoring experience.

The ERC for Reconfigurable Machining Systems offers "Team Effectiveness Skills" workshops.. UWEB provides mentoring training for REU faculty and graduate student mentors, as well as for the undergraduate mentees.2

- *Exposure to the Latest Developments.* Students are able to stay on the cutting edge through increased travel opportunities to conferences, visiting scientists programs, seminars, and annual student conferences. For example, the University of Florida's PS&T Visiting Eminent Scholars Program exposes center participants to world-renowned experts brought to the center for extended visits. This gives them a chance to interact with their global peers. PEER's student-run seminars invite industrial representatives from the Business and Industry Partner Program to campus to discuss their current projects and technology needs with students and faculty.

4.3.1 Graduate Programs

Research is the main direct educational mechanism by which graduate students interact with the ERCs. It has been said that the distinction between research and education is not really valid at an ERC; the two activities overlap and interact at many points. Graduate students work under the supervision of one or more faculty member*s* associated with the center in an area related to one of the center's research thrusts. Most of the centers ensure that the research projects are cross-disciplinary in nature and conducted with a spirit of teamwork. The goal is to have ERC graduates be adept at this systems-level, cross-disciplinary team approach to problem-solving. They should understand and share industrial perspectives and be well prepared to contribute immediately and productively to jobs in industry.

4.3.1.1 Recruitment

Because the centers must be ever mindful of the relationship between them and the associated departments and colleges, recruitment must follow the application procedures of the student's potential department/college first. However, once the student has been accepted in an academic program, probably the two most influential means of attracting students to the centers are word of mouth and the center's internet presence. Faculty and staff should involve themselves in department/college programs (such as the admissions committees) to be aware of newly available students. Center personnel should keep a network of contacts in department or college recruiting offices (particularly special offices for women or minorities) who have regular interaction with students. Invite those contacts to presentations about the center. If these individuals are familiar with the center's program, they are more likely to steer promising students that way. Students and faculty traveling to conferences should be provided with brochures or fliers to spread information about the center. The center's website (particularly student opportunities) should be updated regularly and often. Finding an application on the website with a due date that is two years past is most discouraging.

Another venue for recruiting is on-campus chapters of national organizations—and the annual national meetings of these organizations. Again, make information available at such meetings. Advertising of special financial incentives may also be used.

4.3.1.2 Student Financial Support

Most graduate students are supported financially by the center. Others are supported from other funding generated, often, by the ERC or faculty involved. ERCs are creative in covering the costs of graduate education through industry contracts, NSF grants, foundation or corporate scholarships, other federal and state agency sources of support, and industrial partner support for graduate students.

NSF's Graduate Engineering Education (GEE) Program has become a source of funding for fellowships targeted at minorities and women. Fellows may be paid as graduate research assistants (GRAs) or may take courses for credit, often being paid a stipend under a graduate fellowship. Full-time summer research positions, supported through grants-in-aid or other means, provide an intensive research and educational experience for graduate students under this program.

In some cases summer fellowship programs are developed by the ERCs themselves to provide special educational opportunities for their graduate students at other institutions or locations. A good example of such a program is the Mid-America Earthquake Center's (MAEC) Student Field Mission Fellowship. Students who are awarded this fellowship travel to London to join the earthquake engineering class of Imperial College on a field trip to earthquake sites in one part of the globe.

ERCs also encourage graduate students to apply for professional society or industry scholarships, or in some cases prepare proposals and perform contract research for funding to pay for conferences and research. Successful proposals allow graduate students to travel to conferences and companies.

As another funding source, some ERCs, such as MIT's Biotechnology Process Engineering Center, encourage their graduate students to actively participate as teaching assistants in the courses that are related to the center's research thrust. This training provides experience in teaching and at the same time is very helpful to students who are planning a career in academia.

4.3.1.3 Graduate Outreach Programs

One of the goals of ERCs is to provide global leadership not only in the center's research areas, but in education programs as well. To fulfill this goal, most ERCs developed education programs involving other universities, professional organizations, or industry. The focus of such activities is on educating and training faculty and students in other institutions and establishing long-lived collaborations. For example, the Particle Science Summer School in Winter at the University of Florida's Center for Particle Science and Technology sponsors a week-long event that brings together a large group of graduate

students involved in particle science research projects from several U.S. universities along with experts from academia and industry. The experts develop and present two-day intensive course modules in leading research areas; students attend at least two of them. Student participants also attend seminars on six additional specialized topics and a panel session provided by the industry experts. More information about this program can be found at http://www.erc.ufl.edu/Education/GraduatePrograms.htm.

Many ERCs provide opportunities for faculty and doctoral students from other countries to conduct research and gain experience, generally by hosting the visitors for one- to three-month visits. Such programs offer valuable chances for collaboration and enhance the visitors' research. Some of these ERCs have established international internship programs, augmenting financing of students from international institutes. Others have established exchange programs with foreign institutions. As a result of such partnerships, faculty from the participating institutions direct research and teach courses at each other's university. Such programs also permit ERC students to take courses in the international institution and their students to study at the ERC.

4.3.1.4 Multi-Site Centers

All multi-university ERCs and EERCs are required to develop programs to ensure that their students benefit from courses and labs available at the different sites. To integrate graduate students at multi-institutional centers into research and education activities, some centers have developed special activities, such as these:

- *Graduate Student Exchange Program.* Virginia Tech's Center for Power Electronics Systems (CPES) students majoring in electrical engineering may attend classes at all five CPES universities, with credits for classes accepted by each student's home institution. The goal of this program is to provide students with a broader background and allow them to take courses not offered at their home institutions. It is designed to maximize interaction among graduate students, provide opportunities for students to experience different learning environments, and expose masters-level students from one of the campuses to the possibilities of pursuing PhDs at other campus.
- *Annual Research Assistants Symposium.* This annual activity brings together the MAEC's graduate students and provides an opportunity to meet and discuss current research and cross-disciplinary activities. Student researchers and faculty members from all MAEC institutions get an opportunity to interact from both a cross-institutional and cross-disciplinary perspective. Participating graduate research students present posters, participate in training exercises, and give presentations on their research.
- *Networking Multi-Institutional Centers*. Researchers at the Multidisciplinary Center for Earthquake Engineering (MCEER) at the University of Buffalo are leading the initiative to create an electronic network linking its diverse experimental facilities. The object is to overcome geographic limitations and leverage the existing capabilities to share experimental and advanced computational resources and data. The establishment of the network requires developing new procedures and methods,

adapting and integrating existing technologies, and developing new methods of communication, storage, and interpretation.

Multi-institutional centers have found that it is necessary to devise collaborative agreements to set forth the policies and procedures governing cross-university programs and student exchanges. Attachment 4-3 gives, as an example, a student exchange agreement from CPES.

4.3.2 Undergraduate Programs

Integrating undergraduate students in the educational activities of ERCs is mandatory, and perhaps the single most innovative aspect of the ERC education program. While the research focus and educational vision of ERCs may differ, active involvement of the undergraduates has a major impact, not only on their education, but also on those around them. A special feature of the ERC Program is the emphasis on undergraduate participation in research. Each of the ERCs has one or more programs through which undergraduates from the center's home institution(s) engage in research projects. Many also involve undergraduates from other institutions in ERC research activities through the ERC Program's competitive Research Experiences for Undergraduates (REU) program (see section 4.3.2.2.)

4.3.2.1 An Emphasis on Undergraduate Research

Most ERCs have at least 15 to 20 undergraduate participants involved in research programs during the academic year. Across all of the ERCs, the ratio of graduate to undergraduate students is 2:1. Some have exceeded that goal. For example, since 1999, the ERC for Reconfigurable Manufacturing Systems has maintained or exceeded an undergraduate-to-graduate student ratio of 1:1 (in fall 2002, the numbers are 51 undergraduates to 46 graduates). These undergraduate programs share several features. Students come from any of the departments that relate to the center's work and are selected from among the best students. Generally, each student works with a designated faculty member and, under his/her supervision, conducts research with one or more graduate student mentors, receiving academic credit and/or a stipend for the work. In some centers, students may use their ERC-sponsored research as a basis for a senior honors thesis or independent study course.

Undergraduates may be recruited through presentations at student organizations such as the student chapters of professional societies like the Institute of Electrical and Electronic Engineers (IEEE), the American Society of Mechanical Engineers (ASME), the American Society of Civil Engineers (ASCE), the American Institute of Chemical Engineers (AIChE), and through organizations like the Society of Women Engineers (SWE) and the National Society of Black Engineers (NSBE). They may also be recruited through announcements in the student newspaper, the ERC's website, printed flyers, and directly from classes and colleague's recommendations. Also, deans and departmental and other university offices may be helpful.

There are a variety of ERC home institution undergraduate programs. Many of the features are similar to the REU programs and are described in detail on the homepages of the centers. Some examples are:

- The Integrated Media Systems Center (IMSC) at the University of Southern California has a competitive program for undergraduate research projects. The undergraduates submit proposals, and the chosen projects are awarded $4,000 per project (individual or team)
- The University of Washington's Engineered Biomaterials ERC (UWEB) publishes the *Journal of Undergraduate Research in Bio-Engineering (JURIBE)* twice a year, now in partnership with GTEC, to showcase the research results of undergraduates in engineering and applied sciences. UWEB also has an Undergraduate Scholars in Research Program (USIRP), which lasts for four quarters, during which participants take the "Engineer's Tool Chest" courses, which has components such as ethics and communications; participate in a poster session; may become part of an industry research team; and may have a research paper published in *JURIBE*.
- The Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC) has an Undergraduate Research Scholars (URS) Program, which recruits from metro Atlanta colleges and universities. It involves a full year's commitment to research designed by a graduate mentor along with communications training, ethics issues, research seminars, and industrial field trips.
- The Pacific Earthquake Engineering Research Center (PEER), at the University of California at Berkeley, has an undergraduate scholars course that involves selected students in a four-week-long course of performance-based earthquake engineering and exposes students to opportunities at the PEER core institutions.
- Northeastern's Center for Subsurface Sensing and Imaging Systems (CenSSIS) has a High-Tech Tools and Toys Laboratory, to introduce undergraduates to the techniques of interfacing computers with state-of-the-art subsurface sensing and imaging systems and subsystems.
- Vanderbilt's ERC for Bioengineering Educational Technologies' (VaNTH) undergraduates may serve as both research assistants and as testers and advisors on the effectiveness of new learning materials developed at the center.

A general source for information on the education programs of the centers is the ERC-Association's website, where education programs of all the centers are available through http://www.erc-assoc.org/educate/edopps.htm, and where achievements in education are described at http://www.erc-assoc.org/topics/6-c.htm.

4.3.2.2 Research Experiences for Undergraduates

The NSF-sponsored Research Experiences for Undergraduates program was started in 1988 as a vehicle to engage undergraduates in research. For the summer of 2002, almost 50 such programs, besides those at ERCs, are scheduled, and more applications are being processed. These programs are listed and briefly described on the website http://www.nsf.gov/home/crssprgm/reu/reulist.htm.

Customizing the REU Program to Meet the Needs of ERCs. The ERC Program has developed its own, modified version of the REU program to encourage students from other institutions to participate in ERC research during the summer–with an emphasis on women, minorities, and persons with disabilities. Each site accommodates 10 or so undergraduates and is organized around a general theme. Most of the ERCs have this modified REU program, for which they receive supplementary funding. Specific information is available on the website of each center.

The traditional REU programs attracted students who were generally between their junior and senior years, and mostly from universities that might be viewed as likely sources of graduate students for the departments involved in the program. However, under supplemental ERC REU funding there is also a strong emphasis on recruiting REU students from a diverse population, including women, members of underrepresented minorities, those with disabilities, transfer or dual-degree students, and students from post-secondary technical schools. These students may not be from the engineering disciplines most prominently represented in the center, and may not even be engineering students. Undergraduates majoring in physics, chemistry, social science, and business may be valuable and productive REU participants. Because of the burgeoning REU programs, the competition for the easily identifiable top students from the traditional sources is intense. Broadening the applicant pool can help to achieve diversity while retaining high standards, attracting a new pool of students to engineering.

Recently, there has been an interest in including an international experience in REU programs. Doing so obviously presents more complicated logistical issues but provides an exciting attraction to bright undergraduates. Since there are so many REU programs, the students are often beginning sophomores or juniors and may be interested in multiple REU experiences. Such students might be the best candidates for international programs.

Florida's Center for PS&T participated in the first NSF-French REU program in 1997. The program has since expanded to include Holland and Australia. In 2001, in a "reverse REU," four ERC students were sent to conduct research at the Ian Wark Institute, University of South Australia, and the Technische Universiteit Delft, the Netherlands.

REU students enjoy a hands-on research experience that is complementary to the experience of the institution's own undergraduate research programs. A benefit of an undergraduate research program is that graduate students often act as mentors and advisors to the undergraduates, helping to supervise their research on a day-to-day basis. This role provides the graduate students with an opportunity to develop and enhance both teaching and managerial skills while providing the undergraduates with one-on-one interaction with a role model who is close to them in age and experience.

A number of ERCs combine REU programs with other programs or funding sources. The availability of supplementary funding allows field trips and extended travel to be included in the experience. Also, the considerable expense involved in long-distance relocation has been a barrier to some gifted students, and supplementary funding can be helpful. Again the best sources of specific information are the center websites. Providing

an interesting research, cultural, and social program for the group require*s* planning and supervision, but the wide availability of campus facilities in the summer facilitate*s* this process.

Because their REU students were located at multiple institutions, the multi-site Earthquake ERCs—the Mid-America Earthquake Center (MAEC), the Pacific Earthquake Engineering Center (PEER), and the Multidisciplinary Center for Earthquake Engineering Research (MCEER)—initially encountered some challenges in implementing REU programs but have learned to cooperate very successfully in this area. The ready availability of videoconferencing has been very helpful in this regard along with a multi-center REU symposium at the end of the summer. Some of the REU activities of these centers have led to closer collaboration between graduate students and faculties.

The Marine Bioproducts Engineering Center (MarBEC) adapted the REU program to actively involve students placed at far-flung sites (Hawaii, California, and an industrial partner's sites). The initial orientation was held at UC Berkeley, and then students reconvened periodically via the internet and videoconferences.

REU Program Features. Students gain many benefits from their REU experiences that are not normally available to students who are not involved in ERC education programs. REU students:

- conduct individual or team research on ERC-related projects
- develop teamwork skills through interaction with undergraduates, graduate students, and faculty
- are encouraged to continue their education in graduate engineering programs
- develop communication skills through written reports and oral presentations
- participate in ethics and professionalism activities
- interact with students from other universities
- publish articles on research or give research presentations at national conferences
- participate in industrial interactions
- interact with a truly diverse group of students.

REU Program Structure. REU students may work as individuals or in teams, which may include the ERC's own summer undergraduate interns and even graduate students. The projects should include at least some elements of their own design and should be supervised by ERC faculty and graduate students. In many cases this environment provides first-hand knowledge of how industrial research teams operate. The total number of undergraduates involved in these summer projects from all sources at a given ERC can vary from as few as 4 or 5 to as many as 40 or 50. Some multi-site ERCs may have only a single REU program, so that the teaming with local students is vital. The mix of backgrounds, cultures, and approaches brought by students from different educational backgrounds is an important part of the REU experience. In addition to research projects, a well-rounded program of REU activities can include:

- field trips to industrial sites
- workshops on technical writing and public speaking
- seminars in topics such as programming and engineering ethics
- meetings with high school students visiting the campus
- mentoring by graduate students and industrial residents
- assistance with graduate school admissions applications and scholarship materials
- exposure to an array of center publications.

Issues that require special planning include housing (prearranged and on campus in the same area), meal cards or subsidy for meals (to minimize the need for cash), on-campus transportation if needed, and access to institutional facilities. Careful scheduling of out-of-laboratory activities is necessary to minimize research disruptions.

REU Recruitment. Recruitment of REU participants can be challenging, since the main focus is on underrepresented populations, and the number of programs aimed at these populations has expanded. The ERC REU program has provided a critical outreach component to ERCs, giving them the opportunity to extend their work to many other institutions. Recruitment techniques that have proven successful include:

- personal visits to other institutions
- development of long-term relationships with historically black institutions and other targeted institutions
- recruitment efforts by previous REU participants on their home campus
- recruitment through national organizations such as NSBE or SWE
- participation in career fairs
- internet and worldwide web postings
- exchange of potential participants between ERC education coordinators/ directors.

As centers mature, they interact with other ERCs to help them recruit REU fellows for appropriate research areas. This exchange of applicants has been done on an individual basis, from education coordinators/directors to center directors, and (in the past) via an e-mailed ERC Education Digest.

REU Follow-up/Tracking. Follow-up with former participants extends the influence and value of the REU program and contributes to the participant's involvement in engineering and the continuation of their education toward advanced degrees. Former participants can be provided with guidance and assistance with applications for graduate school and for financial aid. Arrangements can be made with center industrial partners to assist participants with potential employment opportunities. Maintaining contact with former REU participants requires considerable effort, but it increases the likelihood that they will continue on to graduate engineering education. Learning of their accomplishments is also rewarding.

4.3.2.3 Involving Students in the Life of the ERC

Most ERCs have student councils (often known as "student leadership councils"). These organizations give students a collective voice while also serving as a pipeline for useful input and information from the students to the center administration, and NSF. Student councils foster development of leadership skills. For example, the Georgia Tech/Emory Center for the Engineering of Living Tissues' Student Council Educational Outreach Committee placed second in the Governor's Georgia Technology Public Service Leadership Award. This was valuable recognition for the student council group from state educators and science professionals for their outreach to middle and high school students and teachers in an effort to educate the public about biotechnology and tissue engineering.

The student groups serve a social function as well. Along with other less formal activities such as weekly breakfasts, pizza parties, or birthday celebrations, they help to promote a sense of center identity by providing opportunities for interaction with each other and with faculty members. Remember that food is one of the greatest incentives to increase attendance at events and activities. However, be aware that the funding source for food and beverages, in most instances, cannot be from research contracts or grants. Discretionary funds must be used for most entertainment expenses.

Chapter 8 of this Manual addresses Best Practices of Student Leadership Councils.

4.3.3 Community Colleges and Technical Institutes

The nation's community colleges and technical institutes are valuable and often underused sources of technical workers. Community colleges serve a vast number and diverse population of students. For example, in Maryland between 40% and 60% of students in post-secondary education are at community colleges. Due to the flexible scheduling, modest cost, and other reasons, community colleges attract large numbers of women and minority students. It is estimated that half of the Hispanic students attending college nationwide are at community colleges.

In addition, many community colleges have historically close ties with industry. Industry-oriented or industry-sponsored certificate courses and technical training programs are often associated with community colleges rather than four-year colleges. For example, Howard Community College (HCC), which is collaborating closely with the Johns Hopkins ERC in Computer-Integrated Surgical Systems and Technology (CISST), is already the basis of a Regional Center in Emerging Technologies and has industry-funded labs and certificate courses oriented toward technology industries. The technicians and skilled workers of the technology industries are likely to be products of the community college systems.

Despite this obvious connection with the ERC technology infrastructure, very few ERC programs have actively focused on creating links with community colleges. We are aware of only four ERCs that have made substantial partnerships with community colleges or technical institutes. It may be that community college efforts, falling in the gap between education on the cutting edge of new technology and outreach effort to the

K–12 pipeline, simply offer less obvious benefit to the ERC universities. It is also possible that, because of an emphasis on continued technological innovation, few ERC's have developed to the stage of a mature technology where training programs are an industrial priority.

The CISST effort is the most active link with a community college among current ERCs. A major CISST effort to join community college faculty was proposed to become an Advanced Technology Education (ATE) regional center. This effort included partnerships with JHU, Howard Community College (in the Baltimore suburbs), and Baltimore Public Schools along with Carnegie Mellon University (CMU), Allegheny Community College, and the Pittsburgh Public Schools, focusing on ERC summer research experiences for community college and high school teachers. Articulation agreements for community college student transfers to the ERC institutions as well as "reverse articulation agreements" for JHU and CMU students to take hands-on and certificate courses at the community colleges were also proposed. Although this proposal was not funded, an ATE planning grant was recommended as a supplement and is being pursued.

Another successful ERC-community college program has been established at the ERC for Environmentally Benign Semiconductor Manufacturing (CEBSM) at the University of Arizona (UA). This program links Pima Community College (PCC) students with ERC undergraduates to work as a team in an internship at an industrial site. Six to eight students, evenly divided between PCC and UA students, have been given the opportunity to work together at industrial sites to explore the engineer-technician teaming aspect of technology. This program has been a successful vehicle for career networking and recruitment, as one PCC student and one UA student have taken jobs with their internship employer. The program is being expanded though a connection with a Research Experiences for Teachers program to team a K–12 teacher with the two students at the industrial site.

The ERC in Reconfigurable Machining Systems (ERC/RMS) at the University of Michigan has entered a partnership with Washtenaw Technical Middle College (WTMC). The ERC/RMS has given a presentation to parents of the WTMC students, provided opportunities for tours of the ERC facility, sponsored a student-to-student panel, and created a mentoring program. Currently 13 ERC students and 16 WTMC students are participating in the mentorship program, and the ERC/RMS has plans to expand this effort.

One side effect of the community college links has emerged from the JHU experience. A large workshop on "Linking Teachers to Research Experience," aimed at high school teachers, drew 300 high school and middle school teachers to HCC on a Saturday where they viewed posters and demonstrations related to ERC themes and learned about more than 40 Research Experiences for Teacher (RET) opportunities at the ERC. The large turnout may be attributed to its location at HCC. Community colleges are designed to be accessible to the community; parking is easy and the intimidation factor is low. People know where the community colleges are and are accustomed to coming there for

community events. The Center for Power Electronics Systems at Virginia Tech is proposing to exploit this effect in using community colleges as regional meeting places to work with elementary and middle school teachers.

4.3.4 Precollege Outreach

It is widely recognized that much of the difficulty of recruiting enough well-prepared students into engineering programs is a "pipeline" problem, the roots of which lie farther back along the educational path than the freshman year, reaching into high school and even earlier academic experience. ERC K–12 outreach programs are focused at helping fill that pipeline with prepared and motivated students. However, no ERC can be all things to all constituencies. Each ERC should determine what precollege offerings make sense in the context of its strategic plan, resources, and community relationships.

Some suggestions for achieving successful outreach can be drawn from experience:

- To make the best use of limited resources for ERCs' precollege outreach, many ERCs work in partnership with other education and outreach programs. For maximum impact, it is best to seek out established programs to which ERCs can add significant value, or to find promising new endeavors with which to partner.
- Another feature of many successful outreach programs is the involvement of graduate and undergraduate students or student leadership councils (SLCs) in school visits, student tours, or as teacher or student research mentors. Secondary school students often relate well to university students, who are closer to their own age.
- To encourage program diversity, it is useful to partner wherever possible with established campus multicultural programs. Engineering colleges normally have offices responsible for multicultural programs and recruiting.
- To have successful outreach programs in multi-university centers, it is best to have a professor, staff member or student responsible for the outreach program at each participating location. Programs can be administered from a central location, but an on-site representative on each campus is desirable. Forming an education committee or thrust with a representative from each campus can be valuable in accomplishing this goal.

The outreach programs described below are for both K–12 students and their teachers. Programs aimed at students include summer camps and courses, research experiences and internships, science and engineering competitions, lab tours and school visits, lectures, and science and education fairs. Teacher programs include conferences and workshops, research experiences and internships for teachers, and development of curricular materials and classroom aids.

4.3.4.1 Outreach to Students

Student Camps and Courses. Many ERCs have sponsored student camps and courses to involve K–12 students in fun, hands-on science experiences and thereby interest them in technology and careers in science, mathematics, and engineering. Summer camps are

particularly popular as programs targeted at minority students. To develop and implement such programs requires a significant commitment of administrative and research staff time and resources. Some existing programs are:

- ERC for Particle Science and Technology (summer camp)
- ERC for Computer-Integrated Surgical Systems and Technology (summer camp)
- Center for Power Electronics Systems (summer camp)
- ERC for Reconfigurable Machining Systems (five-day program aimed at minorities)
- Engineered Biomaterials Engineering Research Center (two programs of summer research experience for high school students)
- Integrated Media Systems Center (Multimedia University Academy to provide job training for at-risk inner city students).

FEATURED EXAMPLE:
The ERC for Particle Science and Technology collaborates closely with the University of Florida College of Engineering Gator Outreach Program, in a series of four middle school and high school summer engineering camps. Participants learn about engineered particle systems by making paint, learn about particle characterization, and experience colloidal chemistry with everyday examples. One camp is designed specifically for middle schools girls and another is designed for minority students, to improve engineering awareness in these underrepresented groups.

FEATURED EXAMPLE:
The ERC on Reconfigurable Manufacturing Systems has been an active participant of DAPCEP (Detroit Area Pre-College Engineering Program). The mission of DAPCEP is to increase the number of historically underrepresented students who are motivated and prepared academically to complete a university curriculum in science and engineering. The ERC program involves bringing area 7^{th} and 8^{th} grade students to campus on Saturdays to study topics on Design and Manufacturing in the ERC/RMS such as "Learn New Ways of Making Things." ERC/RMS students act as the instructors and mentors for the program.

Research Experiences for Students. Most ERCs also offer summer research programs or internships for K–12 students. The purpose is to get students into research labs early in their careers, to excite an interest in research and in science or engineering careers. These programs can require significant effort from administrative and research staff. They generally involve center graduate students, too.

Student Competitions. Several ERCs sponsor student technology competitions or science fairs. Often this is done by involving center researchers and graduate students as well as local partner organizations. The purpose is to involve students early in exciting science projects and research, or in fairs and exhibits displaying interesting and topical research.

The ERC for Computer-Integrated Surgical Systems and Technology, for example, sponsors a "What Is Engineering?" program at the Montgomery County Education Fair. The Center for Subsurface Sensing and Imaging Systems (CenSSIS) at Northeastern University sponsors a design competition for middle school students at risk.

FEATURED EXAMPLE:
The ERC for Computer Integrated Surgical Systems and Technology sponsors a semiannual robotics competition for local high school students. The CISSRS LEGO Robot Competition is a weekend-long competition giving high school students hands-on education and experience in engineering problem solving. The students, working in teams, use LEGO Mindstorms™ kits provided by the ERC to design, build, and program a robot to perform a simulated surgical procedure.

FEATURED EXAMPLE:
The instructional shaking tables being developed by the three Earthquake Engineering Centers under the University Consortium for Instructional Shake Tables (UCIST) are also serving as a means of outreach to pre-college students, non-engineering students, and the general public. For instance, a mini-shake table competition among high school students was being developed as a cooperative project of the Structural Engineers Association of California (SEACOC) and the ten partner universities of the Pacific Earthquake Engineering Center in California, using these shake tables. The winner of each regional competition was hosted by SEAOC to their Annual Meeting where the "finals" of the competition took place. This program builds on the PEER/UC Irvine K-12 LEGO shaking table competition, in which students receive basic building instruction, then build and test their models in a group competition. According to PEER Education Director Gerard Pardoen, "When the shake table gets going, the students get terribly excited!"

Student Tours and Visits. Another way to involve local K–12 students and teachers in ERC research is to offer tours to school groups, or to send ERC students into local schools to demonstrate and discuss their research. These tours and visits may require slightly less organizational time than organizing student camps or internships. Most ERCs offer student tours, but only a few offer school visits. Centers offering school visits include the following:

- ERC for Reconfigurable Machining Systems (partnership with the college of engineering for half-day school visits)
- Engineered Biomaterials Engineering Research Center (presentations on biomaterials for community and school outreach and visits).
- Center for Particle Science and Technology ("Scientist Day" visits to area middle and high schools to conduct hands-on presentations).

FEATURED EXAMPLE:
Georgia Tech's ERC for the Engineering of Living Tissues student leadership council has developed "Prosthetic Pete," an interactive display with mechanical devices "for replacements and improvements in the body plus descriptions of

tissue engineered replacements being developed," which they take to Atlanta area high schools. This initiative enables K–12 students to learn about the possibilities available to them in college curriculums. Prosthetic Pete introduces students to what bioengineering is, how to get involved in it as a career, and what possibilities exist for tissue-engineering different parts of the body. Prosthetic Pete is now being developed into an interactive on-line learning module, which will include interviews with graduate students illustrating their paths toward engineering as a career.

FEATURED EXAMPLE:
The ERC on Reconfigurable Manufacturing Systems has assembled a Portable Manufacturing System, which consists of a table-top robot and milling machine, which are interfaced with a personal computer. The system is taken to area middle and high schools to introduce the students to manufacturing engineering through an innovative hands-on engineering program. Students are first taught a course on computer aided design and simple computer programming. Building upon these skills, they then learn about and use a robot and milling machine. This project allows students an opportunity to see a project to completion from the concept and design phase, to manufacturing a simple product. In its first semester the project benefited more than 200 students.

Public Lectures. UWEB participates in a community science event onbiomaterials. Such opportunities to participate in ongoing outreach efforts can be easy ways for ERCs to reach out to communities.

4.3.4.2 Outreach to Teachers

Conferences and Workshops. Several ERCs offer teacher conferences and workshops. Many ERCs feel that it is possible to multiply their efforts and reach more K–12 students by increasing teacher interest and knowledge in science and engineering, particularly exciting new research. Organizing these conferences can also require significant amounts of administrative and research staff effort. Participating in an existing conference requires less effort. Some ERCs offering or participating in teacher conferences are:

- ERC for Environmentally Benign Semiconductor Manufacturing (summer three-day teacher conference)
- Multidisciplinary Center for Earthquake Engineering Research (teacher training seminars on earthquake hazards).
- Marine Bioproducts ERC (teacher workshop in conjunction with state science teacher meeting)

FEATURED EXAMPLE:
In the fall of 1999, the Marine Bioproducts ERC (MarBEC) sponsored a workshop in marine bioproducts for precollege teachers in conjunction with the annual joint conference of the Hawaii Science Teachers' Association (HaSTA) and the Hawaii Environmental Education Association (HEEA). Twenty-seven teachers from across the state participated in the workshop, with presentations

from MarBEC faculty, an industry partner, and several master teachers from private and public systems. Each participant received a loose-leaf resource manual compiled by the MarBEC intern/workshop coordinator. Two participants developed marine-biotech activities for their grade levels. As testament to the effectiveness and impact of this workshop on K–12 students, all three of the MarBEC awardees in the 2000 Hawaii Science and Engineering Fair credited teachers or mentors who had attended this workshop.

Research Experiences for Teachers. Most ERCs offer research internships or experiences for teachers during the summer months. Nine substantial multi-year grants to ERCs were made in summer 2001 under the NSF-wide RET program. Awards went to the ERCs at Northeastern University, Johns Hopkins, the University of Arizona, the University of Washington, Georgia Tech (Living Tissues ERC), MIT (Biotechnology Process Engineering Center), and Vanderbilt University (two awards). See the list of programs in Attachment 4-2 for links to detailed descriptions of these programs.

Again, the purpose of all such programs is to excite and revitalize teachers by providing them with knowledge of cutting-edge research. Some of these programs require teachers to write new lesson plans based on their research experiences. Planning these experiences can require significant amounts of both administrative and research staff time. Graduate student researchers will need to be heavily involved.

Development of Teaching Kits and Aids. Several ERCs have developed curricular materials for teachers based on their research expertise. This approach requires some knowledge of secondary curricular development as well as subject expertise. Partnerships with colleges of education or use of education students may be appropriate. ERCs that have developed curricular materials are listed below:

- ERC in Wireless Integrated Microsystems (set of teaching aids using MEMS hardware)
- Engineered Biomaterials Engineering Research Center ("Guy Simplant," a web-based computer learning environment, and three kits—angiograms, cochlear implants, and cell adhesion)
- Multidisciplinary Center for Earthquake Engineering Research (teacher and student materials and references)
- The Mid-Atlantic Earthquake Engineering Research Center (K–6 instructional materials on earthquakes)
- ERC for Reconfigurable Machining Systems (portable lab to demonstrate the connection between product design and manufacturing).

FEATURED EXAMPLE:
The Center for Subsurface Sensing and Imaging Systems (http://www.censsis.neu.edu) has an ambitious education program, to which the director is passionately devoted. The center's K–12 Education Outreach program has been designed, developed, and implemented in partnership with the Center for the Enhancement of Science and Mathematics Education (CESAME) at Northeastern University http://www.cesame.neu.edu. After 12 years experience in

education programs, the director understood the importance of partnering with other organizations to share their expertise and use their network of contacts. Doing so saves time and resources, and allows the programs to take advantage of the credibility of these established entities.

In selecting projects for their program many aspects are considered, so that a project is not an end in itself. One goal is to have a lasting impact—addressing a real problem rather than just creating a momentary interlude. A second goal is to improve the number and diversity of students moving along the engineering pathway. Finally, the project should connect to the ongoing work of the center.

One project that has taken place in the past two years (2000–2002) is the CenSSIS Challenge "Hidden Worlds" for high school students and their teachers at the annual Massachusetts Pre-Engineering Program (MassPEP) competition. Project coordinators develop a different challenge each year. In 2002, student teams used remote digital cameras to capture information and, from a photo-mosaic, identify objects and structures and measure distances between objects. Prior to the competition, the teachers and students were provided with a digital camera and printer and a list of suggested activities to become familiar with the specifications of the camera and practice the skills necessary to complete the challenge.

This project meets the education program's goals by providing equipment and technology, thus addressing the real problem of infusing technology into the schools. By participating in the MassPEP event, with its extensive network of involved urban schools, diverse student groups are introduced to the engineering pathway in a fun and exciting way. The content of each challenge is based on real problems faced by the center's partner institutions, in this case the mapping of coral reefs.

In the future the center hopes to distribute the project through their partner institutions to other urban areas. Currently the challenge project is funded through a grant from the Massachusetts Department of Education. The center will use core funding if necessary to continue the project, however, because of its systemic impact.

4.4 CURRICULUM DEVELOPMENT

Mounting a successful application to NSF to establish an ERC is a major undertaking, requiring substantial coordination of many faculty from different disciplines. The faculty involved in developing the ERC may already have a vision for new interdisciplinary courses or even a new degree program, and the ERC can help solidify the interactions that lead to course development and administration. The role of the ERC is that of a catalyst; the resources provided by NSF are relatively small compared to those needed to develop and maintain an entire academic program. Still, the catalyst serves an essential

role, and there are examples of ERC programs that have provided the necessary impetus for creation of new degree programs. Degree programs may start as minor degrees, specializations, concentrations, or certificate programs and then evolve into new BS degree programs as the academic infrastructure grows through addition of resources from outside the ERC. The role the ERC plays in developing new degree programs at an institution depends strongly on how intellectually developed the field already is at the time the ERC is funded. If the area is new and just evolving, the ERC may lay the foundation for development of a program that comes to fruition after the graduation of the ERC from NSF support. If the ERC is funded in an area where faculty members are already offering interdisciplinary courses, a degree program may evolve more quickly.

New degree programs require substantial long-term institutional resources and commitment. Institutions have a responsibility to ensure that students are well prepared for life after the degree, and thus typically want extensive intellectual justification for how new programs will allow students to adapt to jobs in industry or academia. A very important role of the ERC in the evolution of new degree programs is to stimulate the development of new courses, particularly interdisciplinary courses. These courses may provide the intellectual basis for a new degree program.

Finally, in addition to a formal curriculum, ERC staff can help with professional development of students by serving as sponsoring administrative units for undergraduate professional society activities, providing essential links to industry contacts, and helping arrange seminars and company visits.

4.4.1 New and Modified Courses

Developing new courses is the first step toward integrating the ERC research objectives into the formal education process. The philosophical and administrative aspects of course development vary widely from institution to institution. At some institutions it may be possible for an ERC staff member to serve as the prime mover. At other institutions, faculty members serve in this role. Ultimately, the university is responsible for paying faculty to teach the course, and for providing additional infrastructure if the course is a lab subject. Thus, courses must fit the overall educational objectives of the degree programs at the institution.

ERC nonfaculty staff, in developing undergraduate and graduate courses, should find the following tips helpful:

- Find an interested professor to be a champion for developing the new course.
- Pay the professor and a student helper to develop the course; or arrange with the professor's department chairperson to give the professor given teaching reduction so that he/she can develop the new course.
- Beta test course materials.
- Work on mechanisms to offer credit for students to take the course at other ERC universities if your ERC is a multi-university center.
- Find a vehicle, such as CD, web, or book, for wider distribution of course materials.

In institutions where ERC faculty bear this responsibility, faculty can take advantage of these suggestions, which build on years of hands-on experience:

- Discuss your idea for a new course with your department head or undergraduate curriculum committee. If the new course is an elective in a hot field and you can demonstrate that students will flock to this course, the department will likely be supportive of your plans to develop it. For untenured faculty, development of a signature course can be a very positive factor in your promotion case.
- If preliminary discussions are positive, determine whether you will be provided with long-term support for teaching the subject. Developing a new course requires a great deal of work, so one should make sure it can be taught several times.
- Find a mechanism for supporting your time in developing the course, and for providing appropriate support, such as teaching assistants. If there is no textbook available (likely), course development requires a substantially greater investment of time than teaching an established course does. Foundation and government grants are available for new course development, and can be identified by asking colleagues.

4.4.2 New Degree Programs

4.4.2.1 Undergraduate Minors

Minor degrees give students the opportunity to develop depth in areas outside their major degrees. The rules for offering minors, as well as student participation in minor programs, vary widely from institution to institution. At some schools interdisciplinary minors are a means to evolve the curriculum toward a new undergraduate major by providing a testbed for courses and development of student professional societies; other schools are not geared toward interdisciplinary minors. If the center is in a cutting-edge research area, and students are excited about a minor degree in the area, chances are it can develop a successful minor even if there are institutional barriers. The key is to build on student interest and enthusiasm. Here are some important considerations:

- The first step is to define the intellectual content of your minor—what is essential for students to learn, and how many subjects are required? Are there subjects already offered that could fit the minor, or do you need to develop several new courses?
- Determine which academic unit is the best home for the minor, whether a single department, a pair of departments, a school or college, or the whole university. An academic unit will be required to handle the administrative details if the minor appears as a degree designation, and the academic unit involved needs to be extremely supportive of the minor.
- The easiest minor to develop is for students from one's own school (e.g., engineering), because those students are likely to have taken the prerequisites (e.g., mathematics, programming skills, and biology) needed to take the more advanced courses in your minor. (Some academic institutions have firm requirements that any student should be able to complete any minor, and one must be cognizant of what your institution requires.)

- If one develops a minor for a diverse student audience (e.g., including both science and engineering majors), it is helpful to define a set of preparatory engineering subjects that provide the necessary background. For example, nonengineering students may need to take differential equations and a mainstream sophomore level engineering subject that uses differential equations to solve physicochemical engineering problems before they can enroll in the subjects in your minor. Alternatively, courses can be developed for non-majors, but this is usually a less attractive option over the long term. Engineering faculty are generally reluctant to develop a course for students who do not have engineering backgrounds, and cannot justify teaching such courses when teaching assignments are made.
- The minor should be well coordinated with the curricula of the major degrees. One must put appropriate advising in place to ensure that students are able to plan early in their academic careers to fit all the minor subjects into their schedules. It is helpful, for example, to write up a special advising document for freshmen and sophomores, to ensure they take appropriate background subjects early on. Conduct advising seminars once per term to get the word out to a broad audience.
- A minor degree curriculum, no matter how well planned, does eat into the unrestricted electives available to students. Some students may even overload on subjects in order to complete the minor. It is thus especially important to have good advising—students must appreciate that the minor is in some sense an honors program if it requires substantial technical work. It is a choice the student makes. Students who are weaker academic performers might be encouraged to focus on their majors first.
- Create a curriculum committee that meets regularly to review the content and administration of the minor, and invite all the advisors for the minor to serve on the committee.
- Create a community of students involved in the minor by having lunches with students and faculty once per term.

4.4.2.2 BS Programs

New bachelor's degree programs must be developed with a different set of considerations in mind:

- Find out what new degree program in engineering or science was most recently approved at your institution, and use that program as a benchmark. Some institutions are conservative and develop new degree programs only once every few decades in response to new disciplines.
- The faculty who teach the courses and who will be responsible for the degree program after the center's NSF funding expires must be key drivers in developing the new degree program. Be sure to get the support of key faculty members, who can provide sustained efforts to convince the chair, provost, curricular committees, and other decision makers.
- Identify the constituencies for your program, and make sure you have enthusiastic buy-in. Equally important, identify any other academic programs that will be significantly affected (positively or negatively) and discuss your plans with the

faculty involved. For example, if you are developing a program that depends on core science classes offered by another academic unit (such as chemistry, math, or physics), they need to be involved if their enrollments are likely to increase as a result of your plans.

- Make sure to contact your university's appropriate office (e.g., the provost) to find out whether prior approval is required for a new undergraduate degree program. There is no point in developing an entire program if it will not pass this first hurdle.
- Work as closely as possible with the chairperson of your school's curriculum review/approval committee, as well as your university's undergraduate curriculum committee, before submitting all of the paperwork to those committees, to be sure that they buy into your new program. Doing so can save a lot of time in getting your new program approved, because these committees frequently deny or delay approval because of incomplete forms or unclear descriptions.
- Involve undergraduates in developing the new curriculum, to understand their interests and needs from the outset. This can be accomplished by presenting a proposed curriculum at a meeting of the professional society for the area related to the program. Some universities require participation by undergraduate students during the development and evaluation stages of your new program. Neglecting undergraduate input can cause very long delays in getting the new program approved.
- Be sure that your program satisfies criteria of the Accreditation Board for Engineering and Technology (ABET), if one of your goals is to have an accredited program. Review and update this program on a regular basis.

4.4.2.3 MS Programs

New master's programs present their own challenges. These suggestions should ease the labor of developing one:

- The easiest MS programs to develop are those that build upon an existing traditional MS degree, e.g., MSEE or MSCSci. They do so by adding an area of emphasis to the existing program, e.g., MSEE (Multimedia and Creative Technologies). Be sure to get departmental buy-in from the beginning of the development process for this kind of new MS program, because you will be tinkering with an existing departmental program.
- Include opportunities for students to do some directed research with ERC faculty and to receive credit for it. The uniqueness of your ERC will permit students to do directed research with ERC faculty. This can be a valuable selling feature for the program.
- To break down the barriers of existing traditional MS degree programs—which all have specific requirements that may be viewed as barriers—one usually must create a new degree program.
- If you do create a new degree program, you must also find an administrative home for it. Do not underestimate the importance of this requirement, because it has budget implications to the unit that accepts this new responsibility (e. g., a person must be identified to administer the program, space may be needed for student files, etc.).

- Be sure to have a group of faculty willing and ready to advise students for your MS program(s).
- One model for a practice-oriented MS program is a three-component program that includes (a) an engineering component, (b) a management and business component, and (c) an internship program. Students who complete the engineering component could also receive a certificate (e.g., in Microelectronic Packaging).
- Review and update these programs regularly.

4.4.3 Professional Certificate Programs

New professional certificate programs will be more effective if their developers follow the following suggestions:

- Conduct market surveys to evaluate industry interest and demand for short courses and topics.
- Advertise the short courses in trade publications and with mass mailings. Purchase mailing lists.
- Find commercial and industrial partners to co-sponsor courses.
- Use your center's industrial advisory board to champion and publicize offerings.
- A very effective way to reduce expenses is to offer short courses at conferences.
- Anticipate economic downturns (during which too few students may sign up to offer the course); demand for short courses is highly variable.
- Pay professors to offer (develop, organize, and teach) short courses.
- Seriously consider using the internet to deliver the short course. Such courses could be recorded and made available on demand.
- A certificate (given to a student for completing a certificate program) avoids some of the problems encountered with official degrees and can serve a center's objectives for recognition of its involvement and professional certification.
- Professional certificate programs should be created if they enhance the visibility of the center and make real contributions to the engineering profession.
- Short courses and certificate programs may be created based on a sound understanding of current professional demands, especially as they pertain to licensure issues.
- Certificate programs may be structured as terminal programs (which will not undermine the efforts of the department to draw students into graduate programs), or they could be given upon completion of part of a degree program.
- The developers of a short course or a certificate program should also look at pre-existing certificate programs offered by other departments or schools to see how they complement one another. If competition exists, it will be necessary to identify champions within the respective departments, and to develop a cooperative relationship so that each department sees a benefit from the program.

4.4.4 Center/Department/College Curriculum Relationships

Nonfaculty ERC staff should bear in mind the organizational relationships of academic units:

- Assure department chairs that your ERC is not an academic unit, so that your center is not competing with it for tuition revenue. (This may not be an issue at some universities.) NSF strongly encourages centers to develop new academic programs that reside in some department (or departments).
- Keep the department chair (and education associate chair, or faculty and administrators) in whose department the new program will reside aware of your plans. They will have to approve the program, so the program should not come as a surprise to them, especially since the new program will most likely mean additional work for departmental student affairs personnel, and may require some budget to administer.
- If your new program will require departmental resources (e.g., space, equipment, teaching assistants), involve someone from the administrative staff of the department hosting the new program as part of the development of the program, so that resource issues can be adequately addressed. In most ERCs, staff, and increasingly students, carry out the outreach functions.
- The basic concept should be to use NSF money as seed funds to help departments establish new courses or programs—not the other way around. The challenge is to convince the majority of the faculty members that the effort is worthwhile and will benefit them and the department.
- Keep in touch with the participating school chairs, undergraduate and graduate education committee chairs, and graduate coordinators.

4.5 EDUCATIONAL OUTREACH TO INDUSTRY AND COMMUNITIES

Educational outreach efforts for an ERC must be designed to reach industry as well as the wider community. This section explores these topics, with examples featuring successful and original approaches and suggestions.

The center's relationship with its partners in industry is crucial and direct. Through it the ERC gains by learning about industrial perspectives, practices, and needs, which it can then incorporate in education and research. Industry gains by learning about new research and technology, by direct interaction with students (the best channel of technology transfer), and by the opportunity to work with and recruit highly trained ERC students and graduates. Industry and ERCs must cooperate closely to tailor programs that meet the interests and needs of the students, faculty, and industrial members of the ERC. The education coordinators/directors should keep abreast of industry programs in detail, and of trends and particular requirements and developments in the relevant industries.

The industry-education link has several goals. The process of learning in this relationship is a mutual one, in which the ERC and industry serve alternately as teacher and learner. Education programs provide opportunities for student-industry and faculty-industry interaction via mentoring, internships, co-advising on theses and doctoral programs,

recruitment, employment, visiting scientist programs, seminars, workshops, and presentations. Industry may directly sponsor education programs or educational innovations relevant to industry needs and goals. As part of the lifelong learning aspect of their education programs, ERCs also sponsor seminars, workshops, and short courses to bring industry to the center (or take the ERC to industry), transfer technology and ERC research to industry, and encourage faculty exchanges with industry. Certificate programs (discussed in Section 4.4, "Curriculum Development") are an increasingly useful way to bring industry to the ERC (and take the ERC to industry). Many ERCs use distance learning to link both multiple ERC institutions and industry partners (see Section 4.7, "Delivery Systems for Education Programs").

Special community outreach programs aimed at specific groups can enrich the diversity and extend the impact of the ERC. Examples of such programs are those targeting at-risk groups, such as high school students or high school dropouts, or targeting dislocated workers via retraining programs, or targeting technical students via community college programs. Continuing education programs are also relevant for the wider community audience and the general public, as well as for academia. Educating the public about the value and meaning of engineering and science in daily life is a role that ERC education programs must increasingly address.

The ERC's education coordinator/director should have a close relationship with its industrial liaison officer, because the two activities overlap strongly and affect each other's results. The education programs should serve as student advocate, and the industry program as advocate for industry. Developing common goals and a relationship that ensures joint input into programs is essential to a strong education program that is relevant to industry and meets industry's demands and needs. The ERC director must aim to meet industrial needs while ensuring that ERC educational programs meet student needs, degree requirements, and educational goals.

The value of the industry-education link to ERC success and ERC sustainability cannot be overemphasized. The link between industry and education is one of the determining factors in the success of an ERC, and the strength of this link is a crucial element in the longevity of the center. It can also provide a strong base for a successful sustainability plan, and this element should be incorporated into ERC strategic plans at an early stage of the center (see section 4.2.4, "Strategic Planning," and 4.2.5, "Graduating Centers").

4.5.1 Student/Industry Involvement

Industry is involved in all aspects of the ERC education program. Industry representatives may serve as mentors to undergraduate, outreach, or graduate students. They may present lectures, course sections, or entire courses, or teach courses in partnership with ERC faculty members. Industry experts may serve on the student's masters or doctoral committee. Industry may sponsor undergraduate or graduate internships in industry, or sponsor students' undergraduate or graduate degrees in whole or in part. Industry input will help shape curriculum, develop original courses, and shape the very nature and approach of the engineering curriculum of the future. Industrial

representatives may serve on review panels evaluating and shaping the ERC education program. Industry interaction with ERCs may result in new employment and internship opportunities for students, and even lead to the development of new research projects and thrusts for the ERC.

Many creative approaches have been developed to strengthen the link between industry and students in the ERC program and provide opportunities for industry to mentor students. Teams of students and faculty may travel to companies for presentations, meetings, and tours. Industry also may design projects or suggest problems for study by a team of students in the ERC. For instance, a team approach to industry problems is used at the University of Washington.

> **FEATURED EXAMPLE:**
> *The Industry-Student Partners in Research (INSPIRE) program of the University of Florida's ERC for Particle Science and Technology allows industry partners to propose an undergraduate project. If the project is accepted, undergraduate(s) given the project are provided with an industry mentor as well as an ERC faculty mentor.*

Many ERCs offer industry a "membership structure" (a sliding scale of involvement based on the degree of a company's contribution or participation). Various levels of membership may include industry involvement with student projects, internships, and recruitment, as well as attendance at workshops, seminars, and short courses. The membership structure plan is discussed in detail in Chapter 5 of the ERC Best Practices Manual, "Industrial Collaboration and Technology Transfer." For example, the Center for Power Electronics Systems at Virginia Polytechnic Institute and State University offers a range, depending on the company's contribution: summer undergraduate and graduate internships in industry, an industry-in-residence program, and finally an industrial fellowship program for $30,000 per year in which the sponsor specifies a research area and works closely with a graduate student.

Education coordinators/directors may provide advice on the structure of industry participation, and may suggest changes in the plan as an ERC matures. One important issue is the nature and amount of student interaction that corresponds with various levels of the membership structure (since industry often comments that ERC students are the most important product of the ERC.) As the ERC grows, balancing supply and demand can prove challenging. The education coordinator/director may wish to consult with the education coordinators/directors and industrial liaisons at other ERCs regarding these issues of balancing industry demand for students with the ERC's ability to supply them.

One of the most valuable mechanisms of industry-education interaction is the student internship experience, in which the student is sent to the industry site. The student may be an undergraduate, an outreach student such as a Research Experiences for Undergraduate fellow, or a graduate student. The industrial internship formalizes industrial collaboration and ensures that the fellows' education prepares them to contribute effectively upon graduation. The student gains from exposure to the real

world of industrial product development and access to industrial researchers, and the company benefits from direct access to the student/technology inventor. There is no better mechanism for technology transfer than this direct personal contact. Industrial advisors of these interns commonly report innovative products, shortened development cycles, leveraging of industry resources, and joint research projects. This experience also has several benefits for the student. The relationship with an industry engineer provides a unique and essential educational experience. Work in an industrial environment provides the base for a student's career in industry or academia, enables him/her to experience a team/systems approach to research and development, and cements professional relationships. This process also extends the influence of the ERC into the industrial sector.

Almost all ERCs offer or require a graduate student internship experience, ranging from a few weeks to six months or longer, as part of the student's predoctoral experience. Every ERC reports that the industry internship is enthusiastically received by industry. It gives companies the opportunity temporarily to employ students who are highly trained in new technologies, and also offers recruitment opportunities for longer-term employment at a reasonable cost. For students, internships give training in industrial methods and approaches. Students learn to work with industry, to present and defend their work in a professional way, to work in teams, and to set and meet goals and timetables. Many centers require internships as part of students' doctoral programs. Frequently, the industry mentor is a member of the student's PhD thesis committee. Clemson University's Center for Advanced Engineering Fibers and Films offers an Industrial Residency Program for in-plant research for graduate students, a highly successful method of technology transfer. Some centers offer industry an opportunity to support the doctoral candidate for a fellowship, such as the three-year fellowship program at the now-graduated University of Maryland at College Park's Institute for Systems Research (where, in return, the company could name the fellowship for the sponsoring company and appoint a technical liaison to mentor and maintain close contact, identifying significant research results of value to the company, guiding the student, recruiting the student, and receiving public acknowledgement of company support in all publications).

> **FEATURED EXAMPLE:**
> *The Industrial Projects Program offers an alternative channel for student-industry interaction at the University of Florida's ERC for Particle Science and Technology. Industry may submit specific research projects focused on specific industrial partner needs and problems to ERC students and faculty as short-term research projects, which can range from several weeks to one year in length. This program is supplemented by the Center's Industrial Mentors Program, which provides experience in the real world of industry. An online student directory helps industry recruit these trained students.*

To ensure that students meet their degree requirements and to help the industrial internship mesh with the ERC's education goals, the education coordinator/director and staff should work with each student's major department and degree-granting school or unit, and with the ERC's industrial liaison, to coordinate the industry internship. In

addition, he or she must work with housing, relocation, travel, and payment staff to ensure the student's safety and comfort (particularly important for students with disabilities), and help smooth the transition from internship to school and back. Proper handling of these practical details will avoid disruption and ensure enthusiastic student involvement.

Industrial interactions involving undergraduates, while less common, provide important opportunities for younger students to gain perspective on industry. These students often have considerable creativity and energy to offer industry, in lieu of experience. Some creative approaches to industry-undergraduate interactions involve class projects, team approaches, and co-op education.

FEATURED EXAMPLE:
The Industry-Undergraduate Research Opportunities Program (I/UROP) at the Center for Subsurface Sensing and Imaging Systems (CenSSIS) at Northeastern University gives an undergraduate whom a member company is interested in hiring for the long term the chance to complete a co-op program of at least one quarter, and then be supported by the company for six months of school. Students work 10 hours a week on a company research project, with two mentors (one from the faculty and one from industry). The company also provides money for supplies to the faculty mentor and direct payment to the student.

Industry involvement in education can also include "outreach undergraduates," who are not from the ERC's home institution. For example, at the Center for Advanced Engineering Fibers and Films at Clemson University, industry members jointly develop Research Experiences for Undergraduate (REU) projects and co-advise students.

To attract industry membership and support, every ERC actively promotes the possibility that industry sponsors can recruit ERC graduates. ERC graduates are sought after by industry; industry surveys show that graduates are 18 months to two years ahead of the traditional engineering graduates in job skills and experience. The opportunity to recruit ERC outreach, undergraduate, masters, or doctoral students is the strongest force to keep industry involved in ERC education programs.

Industry plays a strong role in shaping and directing curricula and education programs at ERCs. The ERC program is distinguished by curricular innovation; ERCs are often campus leaders in incorporating industry's input and needs into the graduate and undergraduate curricula.

One example, among many, can be found at the "education ERC," Vanderbilt's VaNTH ERC for Bioengineering Educational Technologies. That center includes in its industrial action plan the engagement of industrial partners in identifying needed bioengineering skills and knowledge and areas of continuing education. A summer 2000 conference identified skills in regulatory issues, management training, sales, international business/culture and language training, technical communication, and professional

standards, writing skills, documentation and organizational skills, project management knowledge, and validation issues, among others, as areas needed for inclusion. VaNTH actively seeks such detailed input into educational reform and design, and is exploring computer-based learning with various partners and performing detailed surveys to determine needs for continuing education and short courses on-site as well as at the center.

Industry's specific input into curriculum development is also illustrated by the ERC for Particle Science and Technology, at the University of Florida. In 2000 the center sponsored a Cross-Disciplinary Particle Science and Technology Education and Advanced Training Workshop, in which academic and industrial leaders explored their industry and its needs, to shape curriculum and the future educational program. One identified need was a meeting of advanced students and experts to focus on specialized topics in the field. This meeting became the "Particle Science Summer School in Winter," held in February 2001; students from 20 universities and nine departments and 29 faculty and industry experts met for classes, seminars, poster sessions, panels, and networking opportunities.

Industry can be the focus of a class or section of the curriculum, and this class can provide important training for future researchers. Special class training in industrially relevant areas such as team research, leadership, and project management can greatly facilitate students' progress at the ERC, in their industrial internships and, after graduation, in their industrial or academic careers.

FEATURED EXAMPLE:

Duke's Center for Emerging Cardiovascular Technologies (CECT) developed a formal course in leadership training, which was made a requirement for all graduate students, and was also open to any Duke graduate student. This course, "Principles of Management in Research," was an innovative addition to the center's leadership training program, which carried over into students' careers—whether in academia and or in industry. The objective was to teach CECT fellows to more effectively organize their research projects and to develop an understanding of mutual responsibilities in the research team. The course provided a survey of topics in modern methodologies of effective leadership and research management techniques. Industrial and academic speakers were invited to present issues of leadership, project organization, personnel management, ethics, and levels of responsibility in research, academic, and business environments. This course was required for all CECT predoctoral fellows.

Another curriculum approach is to develop and present industrially relevant classroom projects, which can include smaller team projects in a projects class, or whole classes devoted to a specific project. Industry may design the project or present a problem for ERC researchers to tackle.

FEATURED EXAMPLE:

The Montana State Center for Biofilm Engineering, which graduated in 2001, offers its testbed concept to provide students with learning in the field in a course involving direct interaction and development of research strategies by industry and researchers. The course is "Environmental Engineering Investigations," in which an "industrially relevant setting" is used for field research on remediation technologies, linked to laboratory and fundamental research and industrial needs and interests.

A visiting scientist or industry researcher on campus program can provide intensive, longer term industry-student interaction. The industry scientist may divide his or her time between the research laboratory and teaching duties in the laboratory or the classroom. He or she may also serve as a student mentor or a member of a thesis or doctoral committee. Many ERCs have programs for visiting scientists under various names. For example, the Packaging Research Center of Georgia Tech has an "engineer on campus" program, and the Biotechnology Process Engineering Center at MIT offered a "visiting scientist sabbatical." The value of an industry representative on site at the ERC makes the effort to arrange these visiting scientists' tenures on campus well worth the effort to the ERC.

Visiting scientist programs must include mechanisms for determining and handling administrative details such as salaries, responsibilities, and payments; relocation expenses and issues; housing and family placement; office space; computer access; and university privileges such as parking and athletic facilities. Additional issues (such as visas) apply to visiting scientists from foreign countries.

4.5.2 Seminars and Workshops

ERCs' education programs, like their industrial programs, promote faculty exchanges with companies via visits, seminar series, workshops, degree and certificate programs offered on campus or at industry sites, or in professional meetings and events attended by ERC faculty and relevant industries. Every ERC holds an industry meeting at least annually, and this meeting is an important arena for faculty-industry and industry-student exchanges at poster sessions, meetings, and panels. (See Chapter 5 of the ERC Best Practices Manual, "Industrial Collaboration and Technology Transfer.")

Seminars and workshops are among the quickest, most efficient, and most economical ways to promote industry-ERC interaction involving students and faculty. These events can involve students presenting research to their peers and faculty and/or industry; ERC faculty giving formal or informal presentations to industry and vice versa; invited distinguished speakers from academic or industry; and poster sessions for students to present work to industry, among many other variations. A customized workshop at the request of industry is often one of the benefits of industry involvement with the ERC, with fees for special topics determined on a project-by-project basis. Many ERCs provide this service. Students and faculty may be involved in workshop development and presentation. These workshops are an excellent way for the student to obtain specialized training in specific industry topics of interest.

Many ERCs present formal seminar series, which vary in format. Seminars and seminar series are sometimes videotaped and cataloged for industry use as part of the industry sponsorship package, or even for purchase by the public. The graduated Duke Center for Emerging Cardiovascular Technologies has held an ongoing videotaped seminar series since 1988, and maintains a large library of tapes accessible to industry and students. In every ERC, ERC graduate and undergraduate students present in these seminar series, along with industry, faculty, and business experts. One innovative approach is the weekly teleconferences of the ERC for Environmentally Benign Semiconductor Manufacturing at the University of Arizona, which is accessible to ERC faculty and students and is structured to allow instant feedback from industrial partners.

4.5.3 Lifelong Learning Programs

Lifelong learning, or continuing education, is an important outreach channel for ERC education programs—particularly significant in view of the interdisciplinary, industrially relevant research of ERCs and its goal of a diverse, multicultural workforce. It is not enough for an ERC to train students and send them out into industry and academia. The center's mission also includes educating the public in the developing frontiers of science, engineering, and technology; retraining engineering and industrial workers in new technologies and research areas; and designing programs to reach new audiences with new engineering and technological innovations. Continuing education is central to many ERC industrial and education programs. For example, Clemson University's Center for Advanced Engineering Fibers and Films offers short courses for industry personnel through continuing education programs, and the Packaging Research Center of Georgia Tech offers continuing education to employees of its industry partners.

Many ERCs develop short courses or workshops for industry, often co-taught by ERC faculty and industry. For instance, the ERC for Particle Science and Technology, at the University of Florida, typically offers four to six such short courses yearly. The Packaging Research Center offers two-week modularized courses every May, co-taught by faculty and industry. The Multidisciplinary Center for Earthquake Engineering Research at the University of Buffalo offers its Professional and Continuing Education (PACE) series of short courses for professionals, to inform them of advanced technologies in earthquake engineering.

Professional programs offer lifelong learning, particularly for career development and presenting ERC educational innovations to impact the young or established industrial engineer. These programs are attractive to industry as means of keeping their work forces up to date and minimizing retraining time loss. With constantly changing technology and current trends towards industrial downsizing, the professional engineer is more and more pressured to be aware of current and relevant research trends. Industry needs the best quality and most efficient continuing education possible, and ERCs are well positioned to deliver this service.

FEATURED EXAMPLE:

The Multidisciplinary Center for Earthquake Engineering Research (MCEER) offers a Professional and Continuing Education (PACE) program, which provides engineers with practical knowledge about current and emerging technologies and design procedures that will enhance their career skills, while improving the safety of the built environment from earthquakes and other hazards. Since MCEER has five participating universities, courses can be offered at locations around the nation. MCEER launched PACE in the fall of 1996 with a short course on Passive Energy Dissipation for Seismic/Wind Design and Retrofit, which was offered in Seattle, San Francisco, and the Los Angeles/Irvine area. The second course session was held in the Los Angeles/Irvine area, in February 1997. Past and potential course participants can subscribe to a mailing list for upcoming courses.

ERC education programs, in conjunction with industry, have developed certificate programs and distance learning models. Courses developed for university credit can be offered as distance learning classes. For example, the ERC for Environmentally Benign Semiconductor Manufacturing at the University of Arizona offered a distance learning class in Microelectronics Manufacturing and the Environment in spring 2001, via the University's distance learning program and the National Technological University (NTU). In 2002 a series of web-based modules, each on a single topic relevant to industry and taught by experts, is being piloted by the ERC for Particle Science and Technology in conjunction with the distance learning department of the university's College of Engineering. The Georgia Tech/Emory Center for the Engineering of Living Tissues is working with the Center for Distance Learning and the Interactive Media Technology Center, both at Georgia Tech, to develop an internet course in tissue engineering for graduate students at other universities and for industry. The Packaging Research Center of Georgia Tech offers several web-based courses accessible worldwide, in a joint program with the IEEE Components, Packaging, and Manufacturing Technology Society.

The trend toward globalization and internationalization has affected ERC education programs, particularly in the industrial area. Many ERCs bring in visiting foreign scientists and engineers and provide mechanisms and assistance for this process. The now-graduated ERC for Net Shape Manufacturing at the Ohio State University offers a visiting scholar's program for international engineering students, resulting in a master's thesis on an industrially relevant research project, which is recognized by the student's home institution. In working out international exchanges of students, faculty, or industry representatives, special planning is needed to manage issues such as immigration, visas and work permits, international travel, and security. The education coordinator/director may need to work with industrial liaison and administrative director on various aspects of this planning and coordination.

4.5.4 Special Community Outreach

As the impacts of education programs grow, increasing numbers of ERCs are designing programs for community outreach (broadly defined as the general public or specific

targeted groups, such as dislocated or unemployed workers, at-risk high school students, or high school dropouts). The goals of these community outreach efforts range from raising the scientific interest and understanding of the general public, to specific aims to retrain a group of unemployed workers or to provide career training and career potential for high school dropouts or at-risk students.

FEATURED EXAMPLE:
Several of the most innovative and comprehensive community outreach efforts among ERCs are offered by the Integrated Media Systems Center of the University of Southern California. These offerings include degree and certificate programs for worker retraining and at-risk students:

- *The Multimedia University Academy is an "educational incubator and training program for out-of-school youths who may or may not have completed high school" and who are at risk because of poverty, academic deficiencies, and lack of career goals. The two-semester program in multimedia and office computing tools serves as an employment training program, and includes an apprenticeship with a potential employer, along with advanced employment or educational training. Graduates of the 900-hour program earn certificates and 15 to 30 credit hours transferable to community colleges or other institutions.*
- *The center offers three retraining programs: a program for dislocated engineers and computer scientists (degree programs), and two programs for dislocated local people who are unemployed and who have limited computer skills. Upon completion of training, participants receive certificates in internet development or multimedia skill development. All three of these programs are offered depending on external funding from government or state sources.*

Community outreach for educating the general public is another important part of the ERC educational program. ERCs are increasingly accepting a role in raising the general interest in science and in helping the public understand the value, role, and necessity of science in their lives. The ERC's role is part public awareness, part public education, and part recruitment of the next generation of scientists by raising awareness among both young people and their parents.

For example, the Mid-America Earthquake Center at the University of Illinois at Urbana-Champaign sponsors a variety of community educational events, ranging from involvement with the National Teachers Association and Convention, the Girl Scouts, the Illinois State Fair (with a display there reaching thousands of children and adults), to an exhibit for Earthquake Awareness Week for the state of Missouri. The center is working on a prototype display exhibit that can be used at different sites as an interactive or stand-alone display, or used as part of a website. When testing is completed, display plans will be available for public duplication by museums, science centers, or schools.

The ERC for Reconfigurable Machining Systems at the University of Michigan at Ann Arbor is planning two community outreach projects involving broad public education.

The first is an interactive software demonstration for installation at national museums, on issues in systems-level and machine-level design. The second is a traveling demonstration of an automated reconfigurable manufacturing cell, initially for use in a robotics competition, but eventually for use in science fairs, expositions, conferences, and National Engineer's Week.

Community college students—a vital source of technological workers—are the target of an outreach effort by the Optoelectronic Computing Systems Center at the University of Colorado at Boulder (a "graduated" ERC). The center has produced a new Center for Advanced Photonics Technology (CAPT), which has an educational component, working with Colorado's community college system to train students in this area.

As the ERC matures and graduates from the ERC Program, it may focus more specifically on specially targeted groups relevant to its research area. Many graduated centers have evolved into permanent laboratories or facilities for training working engineers, students, and faculty in specific technologies. Two examples are the Microelectronics Laboratory of the University of Illinois at Urbana-Champaign and the Advanced Technology for Large Structural Systems (ATLSS) ERC at Lehigh University.

4.6 EDUCATIONAL COLLABORATIONS AND PARTNERSHIPS

NSF expects ERCs to disseminate their educational innovations nationally and internationally, to spread their successes as widely as possible. The NSF announcement for the ERC Program says that every ERC must, among other things:

- "Develop a team-based, research-inspired, and industrial practice-oriented culture for the education of graduate and undergraduate students. [ERCs] enrich education at the university, precollege, and practitioner levels by integrating their research findings and knowledge of cognitive science into new courses, course modules for insertion into existing courses, and new degree programs or degree options, where appropriate. All ERCs must evaluate their curricular contributions and disseminate those that are successful."
- "Have educational and research outreach programs involving college and precollege level students and their faculty and teachers in the ERC's research and education programs. The purpose of precollege outreach is to motivate students to study engineering and to bring engineering concepts into precollege classrooms by involving their teachers in research."

It is by these means that a center can contribute to the reform of science and math education at all levels and help to bring more students into the pipeline for engineering.

Transferring these curricula and methods successfully, so that they take root and bear increasing fruit over time, is a challenging task. By working directly with schools, other ERCs, academic institutions, and companies, in collaborative partnerships, ERCs can propagate their successes through first-hand human contact—the most effective channel

for transferring educational know-how or technology. Sustained collaboration is the key to success in this part of the ERC's mission. These arrangements allow ERCs to share their best practices and thus enrich the learning experiences of students and the professional development of faculty and staff at all levels of education.

For the centers, too, these collaborations have important benefits,. They give them, and the ERC Program, a reputation for innovative excellence. They allow the centers to leverage resources and avoid "reinventing the wheel." They can help assure self-sufficiency after NSF funding ends.

This section reviews some of the most creative and successful partnerships.

4.6.1 Local Collaboration

ERCs, if they wish to have meaningful and lasting impacts, must first of all take advantage of the programs and resources that can be found closest to home—in their own local schools, communities, and universities. These activities have several advantages:

- Generally they are cheaper and easier than working with partners who are farther afield.
- Colleagues in the ERC and in the university at large can help identify sources of funds and expertise.
- Local partners are potential sources of support for the ERC education programs. (Such support can be increasingly important as the center approaches the end of its NSF funding cycle).

4.6.1.1 Collaboration Within the University

One vital secret of success for ERC education programs is to work closely with existing programs (such as in the college of engineering).

The Center for Engineered Biomaterials at the University of Washington (UWEB), for example, takes full advantage of the college of engineering's programs to prepare, recruit, and retain underrepresented minorities in engineering by working closely with the Mathematics, Engineering, Science Achievement (MESA) program and the Minority Science and Engineering Program (MSEP).

The Center for Neuromorphic Systems Engineering (CSNE), at the California Institute of Technology, provides research fellowships to deserving undergraduates through the university's SURF (Summer Undergraduate Research Fellowships) and MURF (Minority Undergraduate Research Fellowships) programs, which provide financial and housing support for students from Caltech and other institutions. Students are required to submit a progress report, abstract, and final report.

4.6.1.2 Collaboration with Community Groups, Local K–12 Schools, and Community Colleges

ERCs can play vital and satisfying parts in their local communities in reforming science and math education (and education more broadly), improving the diversity of the population drawn into science and engineering research, and enriching the scientific literacy of the general public.

ERCs are in a pivotal position to do all of these things. Their expertise and their missions give them entrée to both industry (which is impatient for reform) and the teachers and administrators who must carry it out. They are able to draw on funds—from NSF, nonprofit charitable foundations, and industry—that may seem small but can have great impact if they are used strategically to leverage other resources.

For example, the Local Educators' Network (LEN) of CSNE (a board of representatives of local schools districts) are used as advisors in developing and implementing CNSE educational products and projects for precollege and undergraduate education. A pilot project, this new network will form the nucleus of a broader program, which will support science teachers in their districts with useful tools, programs, and products to improve science education and to motivate students. The LEN concept will be expanded to help a variety of other research groups on campus whose mission requires educational outreach.

CASE STUDY:
UWEB is developing a rewarding and innovative partnership with the middle school at the African-American Academy (AAA), a public alternative K–8 school in the Seattle school district. The goal, when the project began in the winter of 2000, was to provide a group of these students—members of an ethnic group that is seriously underrepresented in science and engineering careers—with rich learning experiences that would inspire them to seek such careers. The success of that informal beginning has brought more funds and steadily expanding programs.

During the first term, students and their families were exposed first-hand to the possibilities of fulfilling careers in science and engineering. Students made a field trip to the university's engineering open house and carried out self-directed scientific research in a middle school science fair, judged by UW students and staff.

In the fall of 2001, supplemental funding from NSF made possible the launch of an after-school science and engineering club, field trips to local scientific institutions, increased science and math training for AAA teachers, and the development of a National Society of Black Engineers chapter at the school. UWEB and MESA jointly funded a half-time science specialist to support teachers.

During the winter of 2002, UWEB kit materials were used in 7th grade classrooms and in the after-school program at the AAA. A small team of girls participated with a team of women from the UW Virtual Design Center in a technology design project. The AAA Parent Teacher Association received a presentation on how parents can provide science learning experiences at home.

Spring 2002 brought the second annual middle school science fair (this time paired with a family science night for the K–5 families). Scholars from the Academy also participated in a citywide MESA math and engineering competition, and visited the University of Washington campus for both the engineering and health science open houses.

In addition, the Director of UWEB was recently awarded the Washington Research Foundation (WRF) endowed professorship in Bioengineering. Because he feels that increasing the diversity among the student population in our engineering program should be a top priority, the Director has committed to use part of the yearly funds awarded for his endowed professorship to develop a program of "WRF Biomaterials Scholars." In spring 2002, UWEB inaugurated the "Scholarship in Engineering Training in the UWEB Program" (SET-UP) for the AAA's middle school students. Eighteen SET-UP students each year (6 in the fall, 6 in winter and 6 in spring) will work closely with the Director and his staff to learn about the excitement of research and also be tutored in basic science subjects. The students are given transportation to and from the UW Campus every Friday afternoon, along with snacks, lab coats, lab notebooks, and a $250 check and framed certificate of graduation upon completing the program.

CSNE also supports the Caltech Precollege Science Initiative—a long-established and wide-ranging program to enhance science and math teaching in local middle schools and high schools, drawing on the energies of Caltech's scientists and engineers. CSNE in particular funds a postdoctoral fellow to develop software and curriculum materials, and has funded an effort to equip a pilot science lab and to permit teachers to use simulation and data-analysis software with an entire classroom of students. Now confined to grades K–6, it is being extended to grades 7–10. By integrating mathematics and science and stressing the use of computers, the program expects that all students will progress through algebra and geometry by grade 10.

Links with community colleges are another very promising channel for partnership with the community. For example, UWEB has established a partnership with Seattle Central Community College to conduct two programs, Research Experience for Community College Students and Research Experience for High School Teachers. Both will be initiated in Summer 2003. See section 4.3.3 for other examples of community college partnerships.

4.6.2 Collaboration on a National Scale

ERCs by their nature have both a national and international scope, like the industries they work with. Their member companies must survey the whole world in recruiting and training the best personnel and in tracking markets and technologies.

Education programs at ERCs must reflect that scale of vision in identifying the best educational practices. Partnerships with other ERCs would seem highly promising, since the partners are sure to have parallel educational missions, and parallel problems. But institutions other than ERCs are also fertile ground.

4.6.2.1 ERC-to-ERC Collaboration

The CISST at Johns Hopkins has an ongoing collaboration with the VaNTH ERC for Bioengineering Education Technologies that is aimed at strengthening CISST's Research Experiences for Teachers (RET) program, now (2002) in its second year. This relationship involves several active collaborators from VaNTH. A professor from MIT is heading up the RET teacher assessments. One of VaNTH's own RET teachers will meet with the CISST's second-year teachers and introduce new course materials in bioengineering for the K-12 student. Another VaNTH faculty member, from MIT/Harvard, serves on the strategic advisory board of the CISST ERC. Finally, an MIT graduate student on the VaNTH team is working on the CISST K–12 student outreach programs.

4.6.2.2 Collaboration With Non-ERC Institutions

The Packaging Research Center (PRC) at Georgia Tech has established education programs with a wide range of professional organizations, other universities, and the microsystems packaging industry nationally and throughout the world. This initiative has funded ten educational programs—four international and six national—over a four-year period in strategic technical areas to address the engineering students' needs as well as the professional development of practicing engineers. For example, PRC is working with the Components, Packaging and Manufacturing Technology (CPMT) Society of the IEEE to develop distance learning suited to the industry's fast-moving needs. The PRC pioneered the first educational sessions at the International IEEE Electronic Components and Technology Conference (ECTC), with graduate and undergraduate education sessions. The conference selects and funds several different education programs each year. The goals are to:

1) achieve innovative curriculum developments to address the needs of packaging students and working professionals, and
2) implement shared or multimedia courses, modules, simulations, and/or virtual labs.

CSNE has launched an innovative program with a neighboring art institute. The frontiers of art meet the frontiers of engineering design at a new collaboration of CNSE, Caltech, with the Art Center College of Design, also in Pasadena. Over a year's time six contemporary artists will explore the knowledge and the technology resources of CNSE. The results of this year-long collaboration will be documented in NEURO, an exhibition and publication scheduled to begin on both campuses in April 2003.

Undergraduate research fellowships in microelectronic packaging are the goal of a new partnership of the PRC working with the International Microelectronics and Packaging Society (IMAPS). The team has designed and developed a national fellowship program in microelectronics packaging. The goal is to expose undergraduate students, who have taken some fundamental courses in physics, chemistry, and engineering to system-level studies of microelectronics and packaging technologies and to give students an industry perspective, leading to careers in the industry. The core of the program involves student in research projects at any of 200 participating U.S. universities. Students would then participate in the annual IMAPS Technical Symposium and Exhibition, where they would present their research findings, attend one or more short courses, take a special packaging tutorial, and participate in a student/industry panel discussion. Over the past two years, seven students have participated. All commented favorably about the program as a means of professional development.

4.6.2.3 Collaboration with Industry

Collaboration with industry is the core of the ERC's educational program. Industry members are expected not only to serve on the center's industrial advisory board and transfer knowledge, plans, and technology, but also—according to NSF's ERC program announcement—to "provide instructors, advisors, mentors, and faculty and student internships."

Working with industry helps the education director/coordinator find students jobs and industrial internships.

For faculty and students, the partnership brings knowledge of industry needs and perspectives. For the industry partner, the goals are late-breaking news of science and technology; direct interaction with students; and the chance to work with, and possibly recruit, highly trained and motivated ERC students and graduates. Industry and ERCs must cooperate closely to tailor programs that meet the interests and needs of the students, faculty, and industrial members of the ERC.

Working with industry to develop education programs is one of the most challenging tasks of the education coordinator/director. It requires detailed consultation and coordination with the center's industrial liaison and key representatives of the industry partners and the ERC faculty, to find out what companies want and need. This coordination in turn requires awareness of technical and market trends in the relevant industries.

Education programs at ERCs offer rich opportunities for interactions of faculty and students with industrial researchers, which may include mentoring, internships, co-advising on theses and doctoral programs, recruitment, employment, visiting scientist program, seminars, workshops, and presentations. (The details of this relationship are reviewed throughout this chapter.)

4.6.3 International Initiatives

Research and technology development are increasingly international enterprises. Education programs, if they are to give students the tools for productive and fulfilling careers, must reflect this trend. NSF, for example, has encouraged ERCs to increase international experiences in REU programs. A growing number of ERCs have launched international internship programs, augmenting financing of students from international institutes.

4.6.3.1 Programs Involving Graduate Students

The VaNTH ERC in Bioengineering Educational Technologies has established a consortium for exchanges of student industrial interns and academic and industrial expertise in biotechnology and bioengineering education with an alliance of universities and trade organizations in Niedersachsen, Germany.

Caltech's CNSE also has an ongoing collaboration with the Center for Neural Computation (CNC) at the Hebrew University in Jerusalem (a PhD program focusing on understanding computation in neural and neural-like architectures). Individual CNSE laboratories and labs at the Hebrew University as well as visiting graduate students strengthen ties between the two programs.

The Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC) has presented short courses in cutting-edge tissue engineering research in collaboration with the various institutions overseas, including the Smith & Nephew Research Centre, York, UK; the University of Limerick and Trinity College, Dublin; and the National University of Singapore.

4.6.3.2 Programs Involving Undergraduate Students

Providing undergraduates with overseas research and education experiences presents management and logistics challenges, but these opportunities will help attract talented students to the center. Since there are so many REU programs, the students are often beginning sophomores or juniors and may be interested in multiple REU experiences. Such students might be the best candidates for international programs.

The Particle Science and Technology, at the University of Florida, for example, participated in the first NSF-French REU program in 1997. The program has since grown to include Holland and Australia, in addition to France. In 2001, four students were sent to conduct research at the Ian Wark Institute, University of South Australia, and the Technische Universiteit Delft, the Netherlands.

4.7 DELIVERY SYSTEMS FOR EDUCATION PROGRAMS

Several factors have combined in recent years to increase the use of educational technology in engineering education. First is the increased availability and lower costs of the technologies themselves, from videotape to personal computers to television broadcasting via satellite. Larger class sizes and a growing demand for specialized courses for off-site students are also factors. Accompanying the growing demand is a scarcity of faculty to teach these courses (particularly undergraduate courses.)

For ERCs, the existence of nearly identical courses at affiliated universities and the need to provide instruction to industrial affiliates and ERC students on multiple campuses provide incentives to reach remote locations. As a result, the ERCs have pioneered the development and use of innovative educational technologies.

4.7.1 Remote Instructional Delivery via Television

Live television broadcasting of courses can be a daunting challenge. The technical systems are complex; it is difficult to establish natural communication and feedback from a remote site; the professor must perform on-camera; and start-up and operating costs are relatively high. Some ERCs have found it hard to get students involved in distance learning courses. Experienced faculty and staff members stress the need to deal with technical difficulties early, because once the TV link gets a bad reputation, it is hard to overcome. Many ERCs offer distance learning courses through their institutions' central "distance learning" or "outreach" program offices, to help minimize such problems.

Some ERC universities uplink courses via satellite as part of the National Technological University (NTU). NTU was founded in 1984 as an accredited "virtual" university, to deliver academic courses via a dedicated satellite network directly to industry training facilities. More than 15 ERC institutions are NTU university partners.

Many university outreach programs use videoconferencing to bring the live classroom experience to distance participants. Outreach offices may offer a videoconferencing option for distance learningcourses, depending on the particular course, core audience, and enrollment. The Center for Power Electronics Systems (CPES), a five-university ERC, uses videoconferencing to support a team-taught survey course involving faculty and students from all five campuses. In this model, lectures are videotaped for asynchronous delivery, while discussion sessions are delivered by videoconference.

A number of the ERCs use videotape recording to capture some TV-taught courses, seminars, and/or industry presentations for later viewing by students and/or industry at remote locations. If appropriate recording equipment is available, this approach has proven an excellent way to broaden the dissemination of ERC instructional materials.

4.7.2 Computer-Based Instruction

Students of all ages are comfortable using computer-based instructional software. These tools can range from sophisticated interactive simulations to simple tutorial text files that can be used inside or outside the classroom. Several ERCs are also producing CD ROMs

and/or providing web access to computer-based educational modules, workshop presentations, conference presentations, educational games, and other materials.

4.7.2.1 Computer Simulations

Some ERCs are using their expertise in programming and software development to push the state of the art in the use of computers in instruction and visualization. The Pacific Earthquake Engineering Research Center (PEER) sponsored the development and application of OpenSees (http://opensees.berkeley.edu/), a software framework for developing applications to simulate the performance of structural and geotechnical systems subjected to earthquakes. The goal is to improve modeling and computational simulation in earthquake engineering through open-source development.

PEER has a software site for downloading freeware software and links to commercial software. *Dr. Layer*—a computer program designed to illustrate the behavior of shear waves in layered media—provides an interactive environment for analyzing and visualizing the propagation of one-dimensional shear waves in linear and nonlinear layered soil masses. Although simple to use, it provides quite general modeling and visualization capabilities. In addition to *Dr. Layer*, this site contains a full set of exercises and tutorial materials for learning about wave propagation. These materials are structured around *Dr. Layer*, and are set up to encourage self-study and hands-on exploration. The target audience for these materials is senior undergraduate or graduate-level students interested in studying wave propagation in soil and rock masses, but many of the phenomena and concepts presented are applicable to wave propagation in general.

USC_RC (University of Southern California–Reinforced Concrete) was developed as a tool to address the analytical needs of research on the seismic behavior of bridge piers under various loading patterns (through an NSF-funded research program at PEER). It can handle two different systems, four major cross-sections, different steel properties, unconfined and confined concrete, and monotonic or hysteretic stress-strain relationships.

4.7.2.2 CD-ROMs and Downloadable Computer-Based Educational Materials

The Mid-America Earthquake Center (MAEC) has developed a CD-ROM series based on earthquake-related technical reports and workshops. The audience is mainly graduate students and earthquake researchers. The center released six in this series in 2000 and seven in 2001. The MAEC has also produced instructional materials at several different levels, including:.

- ED-7—Teaching modules for nontechnical majors
- ED-8—Teaching modules for graduate education
- ED-9—Instructional earthquake simulations
- ED-5—Virtual learning center (VLC)
- ED-4—Innovative undergraduate teaching methods
- ED-2—K–12 instruction materials.

The Multidisciplinary Center for Earthquake Engineering Research provides several educational resources that can be downloaded from their website, including "Making a Shake Table," "Soil and Earthquakes," and "Designing Structures to Perform Well During an Earthquake." They also provide fact sheets of general interest, such as "Be an Earthquake Detective," "Designing Structures for Earthquake Performance," "Earthquakes and Careers," and "Earthquakes in Eastern North America during 1976-1996." This center also maintains a "Frequently Asked Questions" area, for elementary and middle school children.

Some of the ERC faculty at the Center for Reconfigurable Machining Systems have developed interactive multimedia education modules in manufacturing and related areas, which are currently accessible through the worldwide web. By the end of year 4, the ERC website will provide links to these modules. They plan to extend their offerings to include interactive software designed for graduate, undergraduate, vocational/community college, and high and middle school students. Tutorials will be developed to help students understand how analysis of a system may be done from a variety of perspectives and a number of levels of abstraction, all of which produce "right" answers. The manufacturing community, and the public as a whole, will be informed of the availability of the modules on the web through conference presentations, demonstrations, workshops, and other means.

The ERC for Environmentally Benign Semiconductor Manufacturing has developed materials, available on its website, that focus on basic semiconductor manufacturing processes and their associated environmental impacts and are available to center members and affiliates. The class materials consist of PowerPoint lecture slides, reading materials, exercises, and references. They are aimed at upper-level undergraduate and graduate students. This center also used a high school student to develop a math/chemistry computer module for high school students. Several of the teachers at the University of Arizona teacher institute worked with this student in 1999. The module contains a schematic of an ultrapure water system. The student can click on any of the unit operations and learn how they work. Some are animated. In addition, the student is asked to solve a basic algebra problem. This module was disseminated to teachers at the 2000 and 2001 conferences for use in their courses. The center expects to have it available on its website or to distribute it as a CD ROM.

The Engineering Research Center for Particle Science and Technology is committed to producing and disseminating teaching materials that are accessible to all learners. The ERC Instructional Module Series continues to produce teaching materials in modular format, aimed at a variety of instructional levels. Several modules are currently available, including an introduction to chemicals used in particle systems, principles of size reduction of particles by mechanical means, techniques in rheological measurements, solid-solid separation of fine particles by froth flotation, and separation by physical means. Several other modules are under development.

4.7.3 Use of the Internet for Instruction and Dissemination

The internet is rapidly becoming one of the most popular delivery systems for instruction and dissemination of educational programs. It has several advantages. It provides universal access to highly interactive educational materials for students, whether they are sitting in the same classroom as the instructor or halfway across the world. Access is virtually instantaneous and can be restricted to authorized personnel by implementing a number of effective security systems. Probably the most attractive feature of internet-based educational systems is that materials can be easily and quickly updated or upgraded. This fact is extremely important in science and engineering, where rapid change is the norm. While other delivery systems, such as live broadcasts, videotapes, and books, represent the state of knowledge at the time those materials were developed, a well-maintained website reflects the current state of knowledge in a particular area. Many ERCs are developing web-based educational materials, and one is developing authoring tools and management tools to assist with module development, course management, and delivery.

4.7.3.1 Web-based Education Delivery Systems

The Vanderbilt Northwestern Texas Harvard/MIT ERC in Bioengineering Education Technologies (VaNTH) is creating a web-based system for developing and delivering educational materials (http://www.isis.vanderbilt.edu/projects/VaNTH/index.htm). The system's architecture is shown in Figure 2. It consists of two platforms: eLCMS, (experimental Learning Content Management System) and elms (experimental Learning Management System). These components are modeled on commercial platforms that are beginning to appear in the marketplace. Standards are being developed by government and industry—such as the Advanced Distributed Learning (ADL) Initiative's Shareable Courseware Object Reference Model (SCORM)— to shape the ways learning systems interoperate. VaNTH will employ these standards to enable its educational materials to be used with compliant commercial products. At present, however, these standards are immature, are focused strongly on asynchronous delivery (i.e., distance learning), and are just beginning to transcend the computer-based training (CBT) instructional styles of the past. VaNTH is pioneering extensions of those standards that will support "blended instruction" (the synergistic combination of asynchronous and synchronous learning activities) and more innovative instructional designs motivated by developments in learning science. Given the exploratory status of these extensions, VaNTH has designated its platforms as experimental, denoted by "e".

The eLCMS platform supports the development of educational materials. A key VaNTH innovation in this platform is the Courseware Authoring and Packaging Environment (CAPE). Using CAPE, courseware authors design the delivery of courseware materials (including adaptive delivery and synchronization for blended instruction), define learning objectives and associate them with curricular and domain taxonomies, and supply other metadata required to support courseware delivery.

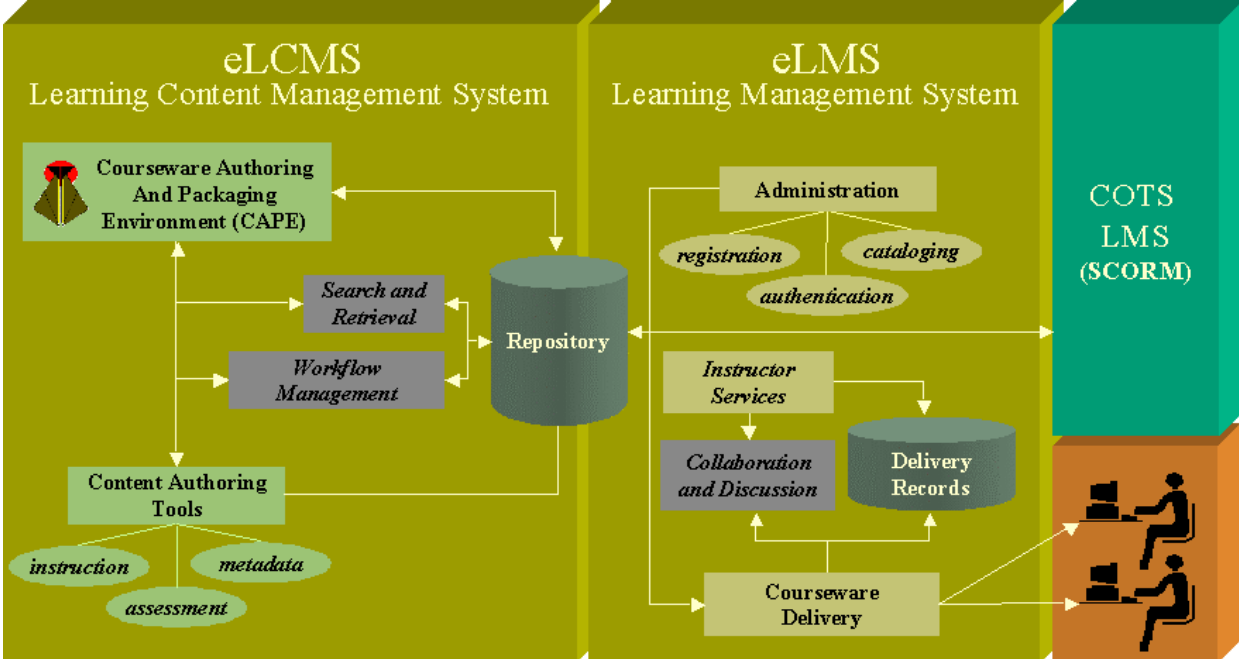

Figure 2. VaNTH System Architecture

The design of CAPE reflects a fundamental change underway in the larger courseware development community: the move away from monolithic, special-purpose instructional artifacts toward modular, reusable materials, in which designs describe how the materials are used to achieve particular learning objectives. CAPE employs a graphical modeling approach to this integration task, and it provides many novel capabilities in bringing to bear materials and assets from all VaNTH thrust areas. Authors can begin their task using instructional design patterns inspired by the work of VaNTH's Learning Science Thrust. These patterns, such as the Legacy Pattern that supports challenge-based instruction, communicate the form of instructional designs and can constrain choices of assessment approaches and provide consistent sets of metadata. Authors can integrate assessment items from "item banks" and use these items diagnostically in adaptive delivery strategies. Domain taxonomies are provided as metadata tagging resources, one of many types supported, and concepts from these taxonomies can be associated with learning objectives for modules and higher-level integrations. Delivery previewing allows authors to obtain feedback on their work without leaving the authoring environment.

Content authoring tools, both commercial and VaNTH-specific, will be used to construct the learning materials that support pattern-based instructional designs described in CAPE. The VaNTH repository provides persistence services for the eLCMS platform, and the CAPE authoring environment will interoperate with the repository to facilitate the use and reuse of its contents. Work flow management and metadata-based search and retrieval complement the persistence and authoring services of the platform.

The eLMS platform supports experimentation with asynchronously delivered VaNTH courseware and "blended instruction." The administrative functionality of this platform is sufficient to support trial offerings of new courseware with small groups of learners. Extensive instrumentation and unsolicited feedback facilities underscore this platform's

use in experimentation. The component-based delivery engine of eLMS supports delivery templates that are the counterparts of instructional design patterns within the CAPE authoring environment. Discussion forums, mediated and unmediated, facilitate collaboration among learners, and individual learners can construct private notes as a complement to the delivery record shared between the learner and instructor. Exploring the effective use of these capabilities is part of the experimentation enabled by eLMS.

The eLMS supports advanced author, instructor, and learner services. For authors, it supports uploading courseware to the platform with version management. Instructors can organize classes, build rosters, assign courseware, mediate discussion forums, and review learner delivery records and unsolicited feedback. Learners can suspend and resume courseware delivery across multiple browser sessions, can review items from their courseware delivery records, and can compose and review items from a notebook of private notes associated with courseware and classes.

The eLMS delivery engine uses the courseware models composed in the CAPE authoring environment as instructions for delivering courseware. The engine is extensible with particular delivery semantics and complementary user interface accessories specific to a CAPE instructional design pattern

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4.7.3.2 Web-Based Education Materials

VaNTH is developing web-based education materials for undergraduate bioengineering courses in the areas of biomechanics, biotechnology, biomedical optics, systems physiology, and other areas of bioengineering. These materials are based on the "How People Learn" (HPL) framework (http://books.nap.edu/catalog/9853.html), and many of the modules that have been developed follow a particular implementation of HPL known as the STAR Legacy cycle (http://www.peabody.vanderbilt.edu/ctrs/ltc/brophys/legacy1.html). Although many of these materials are initially developed for use in class, they can be easily imported into CAPE and delivered over the worldwide web.

The Georgia Tech/Emory Center for the Engineering of Living Tissues has developed interactive web modules for middle and high school students and their parents and teachers. GTEC has also developed a module on receptor/ligand interactions. Prosthetic Pete is being developed into a teaching module, which will include interviews with bioengineering graduate students so K–12 students can learn about various paths taken to college and research. Other engineering and science topics will be developed in a similar teaching module format. With new educational technologies appearing constantly, GTEC is working with the Center for Distance Learning and the Interactive Media Technology Center at Georgia Tech to develop a graduate tissue engineering course in a format that can be delivered effectively over the internet. The target audience will be graduate students at other universities and people working in the tissue engineering industry.

The Center for Engineered Biomaterials at the University of Washington (UWEB) is developing a number of online courses. The center plans to videotape selected courses taught by UWEB investigators and place them on the web for wide distribution. This will be the initial step toward providing a distance learning component to UWEB education, making it easily accessible to industry partners, other ERCs, and interested individuals and groups nationally and internationally. The center also has placed online an interactive bioengineering game, "Guy Simplant," that provides an educational component as students help Guy rebuild his injured body parts, and has made CD-ROMs available for wide distribution.

The ERC for Particle Science and Technology has developed a web-based course designed to ensure that undergraduate students receive an adequate introduction to the fundamentals before conducting research. This 10-hour web-based tutorial was developed from the ERC instructional modules and other materials. The module is being formatively evaluated and will be fully implemented in the spring. The center is also preparing to offer its first international internet-based course this fall. Dr. Brian Scarlett will teach "Particle Technology: Principles and Design," which will be offered synchronously to students at the University of Florida and the University of Delft, the Netherlands. In the past year the ERC has explored various options for meeting industrial and academic needs for instructional materials, to help set priorities for efforts in these areas. The center has decided to supplement the printed instructional module series by developing a web-based e-module series, which will provide single topic materials by experts in the field but will take advantage of new delivery technologies by providing these on the web. The ERC will work with the college of engineering's distance learning department to pilot two modules this fall. In the spring, phase two of the project will take advantage of the 2002 session of the center's Particle Science Summer School in Winter (described in sections 4.3 and 4.5) to produce additional modules, taught by experts who will be on campus for the program.

At the Pacific Earthquake Engineering Research Center, Dr. Stephen A. Mahin has developed an interactive online course that integrates information from various engineering and scientific disciplines to provide a rational basis for the design of earthquake-resistant structures. The course touches on engineering seismology, geotechnical engineering, economics, risk and reliability theory, and architecture in addition to dynamics and the analysis and design of structures. The focus of the course is on buildings, bridges, industrial facilities, and other kinds of structures that may, in a major earthquake, be allowed to respond in the inelastic range. The course emphasizes a theoretical understanding of the fundamental factors influencing and controlling the response of these structures and on the developments of effective, but simplified, design procedures able to achieve specified performance goals.

The Multidisciplinary Center for Earthquake Engineering Research provides two interactive web-based instructional modules, jointly developed with The Notre Dame Virtual Laboratory for Earthquake Engineering (http://www.nd.edu/~quake/java/). The modules provide an interactive framework for students and practitioners to gain fundamental understanding and intuition of a range of topics in earthquake engineering.

Two virtual experiments are available: "Structural Control using TMDs and AMDs," (which allows students to compare the effect of using two different control systems for reducing the structural response of an "uncontrolled" structure subjected to earthquake excitation) and "Base Isolation" (which allows students to study the effectiveness of base isolation for reducing the seismic demands on a structure).

UWEB has established an online journal for publishing undergraduate research. The *Journal of Undergraduate Research in Bioengineering* (*JURIBE*) showcases research results of undergraduate bioengineering students. Articles are intended to document research accomplishments to date; that is, publication does not require completed research projects.

4.7.4 Conventional Publication Media

Most ERCs distribute research reports and articles as part of their industrial programs, and many distribute final theses. Industrial workshops and annual industry meetings are used as forums for demonstrating new research and technological breakthroughs and software developments. Quarterly or biennial newsletters are the most common mechanism for publicizing ERC accomplishments. They feature both achievements in research and technology and educational innovations and programs.

The Integrated Media Systems Center (IMSC) has a contract with Prentice-Hall for the IMSC Press, a book series carrying the IMSC and Prentice-Hall logos. The series has an outside editor-in-chief, who in turn has an editorial board. This is an effective means of disseminating research results so that they will have wider educational impact than journal articles alone. The Center for Power Electronics Systems publishes a series of research reference volumes, each devoted to a specific area of power electronics research.

Similarly, textbooks by ERC authors are being developed; and a number have been completed and are on the market, both as reference books and textbooks.

4.8 SUMMARY: STRATEGIES AND LESSONS LEARNED

As the ERCs have evolved, their education program developers and staff have devised a number of strategies and learned lessons that have benefited the centers' education programs. Many of these are summarized below.

4.8.1 Education Program Planning and Direction

- Funding for education should be consistent with its high priority among NSF ERC program goals. The support of the center director is crucial.
- In planning an education program, the center must align its vision and goals with the center's strategic plan and objectives.

- The choice of an education coordinator/director will determine the success of the education program. The position should be viewed as a full-time professional one, with appropriate flexibility, autonomy, and status.
- An education advisory committee should be established to give center faculty a mechanism to provide input into center education programs and to provide support for them.
- The initial budget should include sufficient funds to cover administrative costs, graduate student support, undergraduate research, travel for recruiting, and editorial and production help for dissemination efforts.
- Adequate baseline funding must be provided to the education program. A collection of supplemental grants alone does not make a coherent program, as not all funding opportunities will fit in the education strategic plan and only those that do fit should be pursued.
- It is prudent to develop an education program in phases that are implemented over several years, beginning with programs for graduate and undergraduate students in the center's home institution(s).
- Strategic planning for education must consider the impact of the 11-year ERC life cycle. As a center "graduates" from NSF support, the education program's survival depends on institutional support (including cash), motivated faculty, commitment to the goals of the education program, and a strong, evolving research program. The continuation of a graduated center in some ERC-like form is essential to maintaining support for the associated education programs.
- As the center matures, the education budget should include increasing contributions from sources such as industry members, NSF supplemental funding, and private foundations. Opportunities should be pursued to leverage the NSF funds using non-federal ERC funds for matching.
- A strong relationship with the personnel of the NSF ERC Program leadership, and especially with the center's Program Director, will greatly enhance a center's education program.

4.8.2 Education Programs

- The ERC Program has innovative educational benefits for students: exposure to a cross-disciplinary systems view, teamwork, direct involvement of industry as faculty and mentors, communications training, mentoring opportunities, and exposure to the latest developments.
- Graduate students are expected to learn how industry operates and understand industrial perspectives, so that they are prepared to contribute immediately on the job after graduation.
- ERC faculty and staff should cooperate with the department and college in recruiting graduate students as broadly as possible (such as at professional meetings, by word of mouth with colleagues, and via the internet).
- Financial support for graduate students can be obtained from a wide variety of sources, including grants from NSF, industry, private foundations, and federal and state agencies.

- Outreach to graduate students in outside institutions can best be obtained by forming long-lived collaborations with the faculty and staff of those institutions. Both domestic and international collaborations are vital.
- The emphasis on undergraduate participation in research is a special feature of the ERC Program. For undergraduates, the ERCs have established their own variant of the competitive NSF Research Experiences for Undergraduates (REU) program, with an emphasis on recruiting from a diverse population.
- An important feature of most ERCs is the student leadership council, which gives students a collective voice in the center's affairs and fosters leadership skills.
- Educational partnerships with community colleges and technical institutes have great potential, but are only beginning to be implemented by a few ERCs.
- ERCs' outreach to K–12 teachers and students (through means such as summer camps, workshops, competitions, lab tours, and school visits) is an important contribution to reforming science and math education at the precollege level and expanding the student pipeline for engineers. Each ERC should determine what precollege offerings make sense in the context of its strategic plan, resources, and community relationships.

4.8.3 Curriculum Development

- Establishing a new ERC curriculum is a challenging and complex task, involving coordinating many faculty members in an interdisciplinary research area.
- New degree programs, in particular, require substantial long-term institutional resources and commitment from the ERC and the parent university.
- Nonfaculty ERC staff who wish to develop undergraduate or graduate courses should find interested faculty to champion them and arrange with the professor's department for a reduction in teaching load to allow the needed time. Beta-test course materials. If your ERC is a multi-university center, work on mechanisms to offer credit for students to take the course at other ERC universities.
- Find a vehicle, such as CD, web, or book, for wider distribution of course materials.
- A new minor degree program must be especially well coordinated with the existing academic standards and structures of the university. The key to successful development is to build on student interest and enthusiasm.
- Involve students (undergraduate or graduate) in evaluating plans and implementing the new program.
- Professional certificate programs, if properly planned and delivered, can help meet the demand for continuing education in the ERC's associated industry and improve the reputation of the center. ERCs that offer such programs, however, must allow for enrollments that fluctuate with swings in the economy.

4.8.4 Educational Outreach to Industry and Communities

- ERCs are expected to carry out educational outreach to industry and the wider community. The link between industry and education is one of the determining

factors in the success of an ERC, and the strength of this link is a crucial element in the longevity of the center.

- Educational links to industry involve mutual learning, in which knowledge flows both ways.
- The ERC's education coordinator/director should have a close relationship with its industrial liaison officer, because the two activities overlap strongly and affect each other's results.
- Establish industrial contacts/partners for the education program as early as possible, to help ensure industrially relevant education and industrial support in the later years of the ERC.
- Develop an interactive program with industry that brings industrial involvement at many levels.
- Industrial internships are one of the most valuable mechanisms for industry-ERC educational interaction. They provide vital technology transfer and educational experience for both undergraduate and graduate students, while giving the industry partners a thorough look at students as potential employees.
- Maximize student interaction with industry through poster sessions and presentations at industry meetings and workshops.
- Short courses provide not only continuing education opportunities for industrial personnel but also technology transfer both to and from the center.
- Seminars and workshops are among the quickest, most efficient, and most economical ways to promote industry-ERC interaction involving students and faculty. They can be recorded on videotape or CD for future access.
- The center's educational mission includes educating the public on developments in science, engineering, and technology; retraining engineering and industrial workers in new technologies and research areas; and designing programs to reach new audiences with new engineering and technological innovations.
- ERCs make special efforts to reach certain groups (including underrepresented minority groups, unemployed or dislocated workers, and at-risk youth). In this role, the ERC seeks to improve public awareness of technology, improve the skills and knowledge of potential science and engineering students, increase the diversity of the engineering student pool, and recruit those students to the ERC itself and/or its associated institution(s).

4.8.5 Educational Collaborations and Partnerships

- Sustained collaboration is the key to success in this part of the ERC's mission. By working directly with schools, other ERCs, academic institutions, and companies, in collaborative partnerships, ERCs can propagate their successes through first-hand human contact—the most effective channel for transferring educational know-how or technology.
- One secret of success for ERC education programs is to work closely with existing programs (such as in the college of engineering).
- Collaboration with local schools, communities, and universities should have a high priority, since it is generally cheaper and easier than working with partners who are

farther afield. It also builds relationships with local partners that are potential sources of support for the ERC education programs.

- ERCs are in pivotal positions to work with local communities to reform science and math education (and education more broadly); improve the diversity of the population drawn into science and engineering research; and enrich the general scientific literacy. Their expertise and their missions give them entrée to both industry (which is impatient for reform) and the teachers and administrators who must carry it out.
- The opportunity to act locally should not blind ERCs to their national and international opportunities, which reflect the technology and market scopes of the industries they serve.

4.8.6 Delivery Systems for Education Programs

- ERCs have pioneered the development and use of many innovative educational technologies. Their impetus has included the need to deliver nearly identical information to scattered locations (various affiliated universities and industry sites) on diverse schedules; larger class sizes; and a growing scarcity of faculty.
- Live television broadcasting of courses faces severe challenges, including the complexity of technical systems, the difficulty of establishing two-way communication; and the need to "perform" on camera. It is sometimes difficult to get students involved in such courses, or to stay involved if technical difficulties give the link a bad reputation.
- Some ERCs use videotape recording to capture some courses, seminars, and/or industry presentations for later viewing by students (including industrial personnel) at remote locations.
- Computer-based instruction—distributed through CD ROMs and/or web access—offers convenient access to educational modules, workshop presentations, conference presentations, educational games, and other materials.
- For web-based learning systems, standards are being developed by government and industry, but these standards remain immature.
- New ERC-initiated web-based authoring and delivery systems are under development that should influence standards and ultimately improve the development and delivery of educational materials on the web.

ATTACHMENT 4-1
EFFECTIVENESS OF ERC GRADUATES IN INDUSTRY AND OTHER SECTORS

Assessments of the extent to which the ERC Program is succeeding in preparing graduates who are effective in industry were obtained from two independent sources: (1) the industrial representatives to ERCs whose firms had hired ERC students or graduates; and (2) the supervisors of engineers who had had ERC experience in graduate school. Both groups compared specific skills, capabilities, and knowledge of ERC graduates with those of peers. The views of industry representatives whose firms had ERC students as temporary employees (21.8% of the firms) and graduates as full-time employees (27.3% of the firms) were obtained as part of a second study of ERC-industry interactions. Supervisors' assessments were obtained in a separate survey process under this Effectiveness study that included surveying of the graduates as well. Four hundred thirty-three ERC graduates working in industry, academia, the Federal government, and other sectors responded to a written survey. Table 4-1 provides demographic data on graduate survey respondents.

At the time that these surveys were conducted, ERC graduates had been working for the same organization for an average of about four years and had had the same supervisor for an average of two to three years. While the primary interest was in the effectiveness of ERC graduates in industry, individuals employed in other sectors and their supervisors were surveyed as well. Where findings relating to individuals working outside industry differ from those for individuals employed in industry, those findings are noted.

Table 4-1: Demographics of Graduate Survey Respondents

	Male	Female	African Amer.	Asian Amer.	Hispan	Native Amer.	Pacific Islander	White
Masters Graduates	88%	12%	1%	23%	1%	0%	1%	72%
Doctoral Graduates	90%	10%	0%	30%	2%	0%	0%	66%

Overall Assessment of ERC Graduates

As Table 4-2 shows, supervisors of ERC graduates and corporate representatives of firms that had hired ERC graduates or students judged their ERC-trained employees to be better than peers on six key performance dimensions; between a third and a half of the same respondents characterized their ERC-trained employees as "much better" than their peers.

Table 4-2: Supervisors' and Representatives' Rating of ERC Graduates As Superior to Peers

Dimension	Supervisors	Representatives
Overall preparedness	89.4	80.2
Contribution to technical work	84.8	77.3
Depth of technical understanding	85.0	80.2
Ability to work in interdisciplinary teams	80.3	64.3
Breadth of technical understanding	80.7	74.3
Ability to apply knowledge and use technology	69.9	72.3

SCALE: 1 = much worse; 2 = somewhat worse; 3 = about the same; 4 = somewhat better; 5 = much better

NOTE: Values shown in table are percent responding at level 4 or 5.

On all other performance dimensions—familiarity with engineering systems approach; ability to use knowledge to develop technology; the amount of training the employees needed when hired; and ability to solve problems within time, money, and human restraints—half to two-thirds of supervisors and corporate representatives rated their employees with ERC experience as superior to their peers (4 or higher). There is little overlap between supervisors and industrial representatives, as only 17.5% of the latter had supervised any ERC students or graduates.

Corporate representatives whose firms received significant benefit from hiring ERC students and graduates described the results of such hires in a variety of ways, including:

> *"We have had a significant technology transfer through a recent graduate from the ERC. This has given us new and better approaches to R&D (product development) and a new focus on claim substantiations."*
>
> *"Since the formation of the ERC, we have hired four of their graduates. They are top contributors to our R&D and were well prepared to work and contribute in industry. This is the primary benefit of the ERC."*
>
> *"The most significant benefit has been access to students for cooperative education programs and full-time employees. ERC students have excellent applied skills in our company's competencies as a result of the academic and research environment of the ERC. The ERC is the best source of technical talent we have experienced."*
>
> *"As a small company, we have had relationships with graduate students that have been powerful for them and us. Students' projects at our company have educated*

both the students and our employees. We have been able to develop practice-oriented engineers."

Graduates' Employment Characteristics

Career Paths

A number of differences exist across employment sector with regard to graduates' career paths up to the time of the survey. Nearly all of those working in industry and most of those in academia at the time of the survey—92% and 86%, respectively—began work following their final degree in that sector. In contrast, less than three-quarters of those employed in federal laboratories or other sectors began work there. Of those moving into these non-industry, non-academic sectors, nearly two-thirds had previously been in industry and the rest came from academia.

Overall, ERC graduates had developed stable but varied career paths with the same organization. Graduates employed in industry and academia in 1995 had worked on average around four years with their present employer, while those in federal laboratories and other sectors had been with the same employer for an average of five years. The extent to which they identified the field in which they were working as the same as that of their final degree varied. Not surprisingly, 86% of academics were working in their field of training. However, non-academic graduates were more likely to have shifted to another field, as 75% of those in industry and 70% of those in federal laboratories or other work settings no longer considered the field of their work to be the same as that of their highest degree.

Job Activities

ERC graduates working in industry[1] reported responsibilities in a wide range of activities, with the emphases being process and product engineering, manufacturing, fundamental or basic research, and technical management. Marketing/sales and general management were not prominent among their responsibilities. In their current jobs, they were most likely to use knowledge or techniques learned through their ERC work and to make use of specific ERC research results. They are unlikely, however, to continue working on things that they had been doing at the center. This is not surprising, given the variety of their current responsibilities and the likelihood that their jobs fit in with a broader corporate strategy or agenda that has little relation to ERC activity. In addition, since the graduates had worked an average of four years with their existing industry employer at the time they were surveyed, most had moved on in their careers and were not new degree recipients.

Graduates working in industry engaged in a variety of activities with and without academic involvement. Approximately half of these graduates reported having both

[1] The analysis of employment characteristics focuses on graduates working in industry, unless otherwise noted.

applied for patents and had articles accepted for publication, and over 70% also made presentations at professional meetings that did not include academic participation. On the other hand, more than two-fifths also indicated that they were involved in collaborative work with university researchers and over half have obtained technical advice from academic faculty or research staff; approximately one-third of those involved in such activities were collaborating with ERCs. Finally, approximately a quarter of the ERC graduates had made presentations based on collaborative work with university researchers or were coauthors of publications with academic researchers. The majority of these activities were performed with individuals and groups not associated with an ERC.

In certain respects, graduates working in federal laboratories and those in industry were similar. For example, those in federal laboratories were even more likely than their colleagues in industry to collaborate with university researchers and to make presentations at professional meetings about work not related to collaborations with universities; but those in industry generally had a higher level of involvement with ERCs than did those in federal laboratories. Additionally, two-thirds of federal laboratory employees established or participated in cross-disciplinary research and nearly half carried out engineering systems-based research.

Those employed in academia identified their primary job activities as conducting their own research and supervising research performed by students and, where applicable, postdoctoral fellows. Less important duties included administration not related to research, industrial liaison, and outside consultation. Faculty had, on average, a medium level of responsibility for teaching; but individuals tended to have either a high or relatively low level of teaching responsibilities.

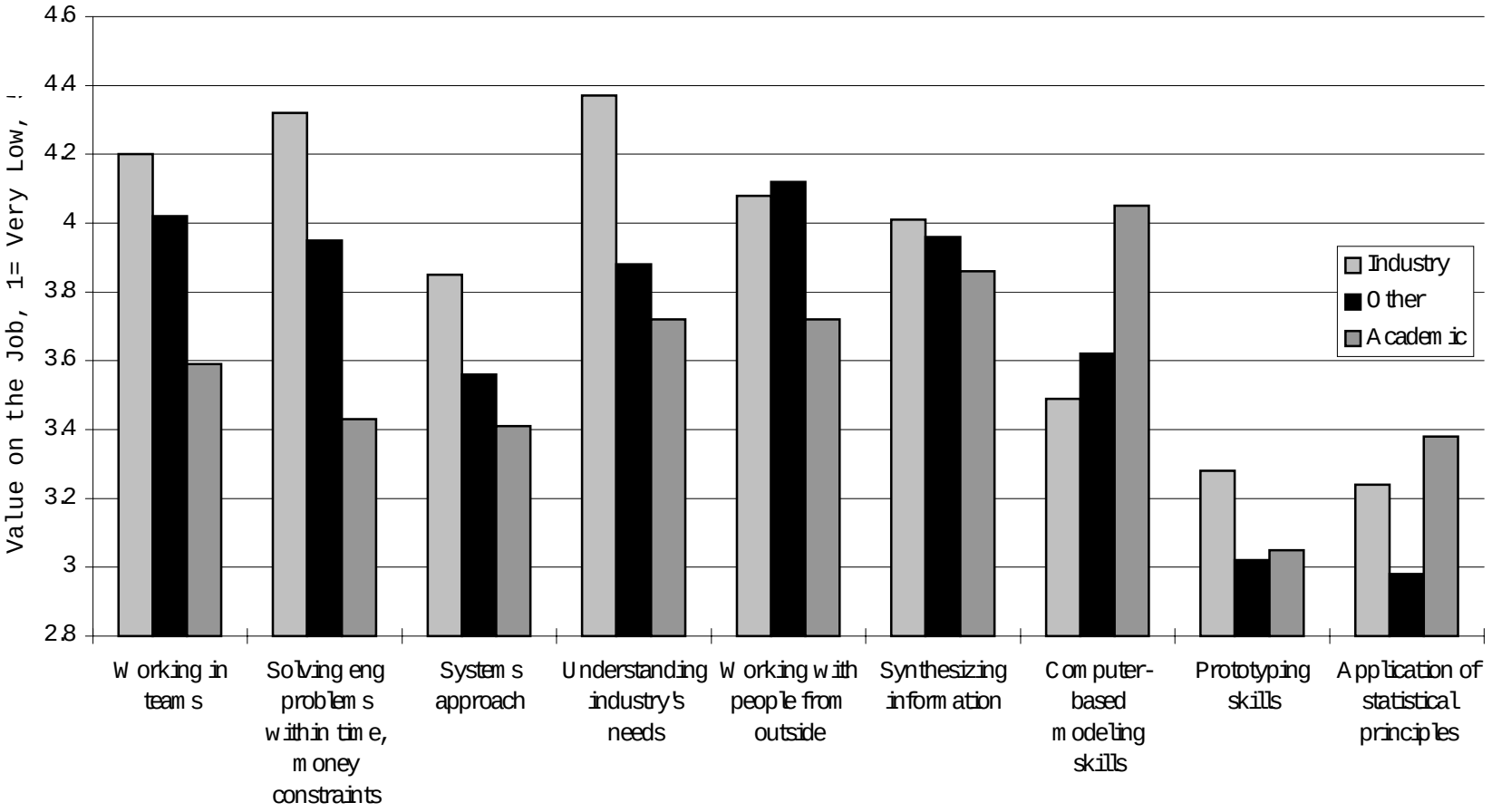
As with those working in federal laboratories, those in academia participated in activities involving industry and the general approach to research espoused by the ERC Program. Over half pursued collaborative research with industry, served as a consultant to industry, and received research support from industry. Most indicated that these activities were encouraged at their institution. Additionally, nearly 80% had established or participated in cross-disciplinary research groups and about 60% had worked on engineering systems-based projects. A majority also indicated that their research was focused to a substantial extent or entirely on problems directly relevant to industry.

Graduates' Most Valued Job Skills and Capabilities

As Figure 4-1 shows, the sector of a graduate’s employment had a considerable influence on the skills and capabilities that were deemed most useful in his or her present job.

In the case of each skill or capability, however, there were individuals for whom it was very important. These results reflect variation in both the numbers of those for whom each was valuable and the extent of the value to each. (Similar patterns emerged in Section 3, "ERC-Industry Interaction," in discussion of the range and extent of benefit each firm received from interaction with an ERC.)

Figure 4-1: ERC Graduates' Assessment of Value on the Job of Professional Concepts, Skills, and Capabilities



Graduates' Self-Assessment of Job Performance

Using the list of 16 job capabilities and skills with which supervisors rated their employee(s) and that graduates used to identify the items that are valuable in their present job (see below), the ERC alumni also assessed themselves relative to peers in their own organization.

Using a scale in which 1 equalled "much worse than average," 3 represented "about the same," and 5 was "much better than average," graduates ranked themselves highest (mean values of 4.20-4.34) in general capabilities. These include:

- ability to grasp quickly the key features of new problems;
- contribution to the firm's technical work;
- breadth of technical understanding; and
- ability to define the steps needed to solve new problems.

The group of capabilities immediately below this (mean values of 4.02-4.18) included:

- ability to communicate ideas in writing;
- creativity and innovativeness;
- depth of technical understanding;
- integrating and synthesizing information from different fields;
- ability to work in interdisciplinary teams; and
- ability to communicate ideas verbally.

The items in the remaining group were less positively rated (mean values of 3.54-3.90):

- understanding the relationship between work and customer needs;
- meeting business goals while satisfying technical requirements;
- leadership ability;
- solving problems within the constraints of time, money, and human resources;
- ability to transfer outside technology into the firm; and
- networking within the company.

Graduates working in academia rated themselves slightly lower on these skills and capabilities than did those employed in either industry or federal laboratories and other sectors. The general pattern of strengths and weaknesses across all groups, however, was essentially the same.

Overall, ERC alumni gave themselves a mean ranking of 4.32 in job performance compared to their peers. Supervisors assessed the overall performance of their ERC-trained employees slightly higher, at 4.35. In 12 of the individual skills and capabilities as well, the graduates ranked themselves slightly *lower* than their supervisors did. The biggest differentials occurred with three items on which the graduates rated themselves lowest: networking, transferring outside technology into the firm, and understanding the relationship between work and customer needs. Similarly, ability to work in

interdisciplinary teams was rated significantly higher by supervisors than by graduates: 4.27 compared with 4.11.

Average ratings by ERC graduates working in industry were closest to those of their supervisors. In contrast, ratings by supervisors of those graduates working in federal laboratories and especially in academia were more favorable than those of the graduates themselves.

Graduates in industry and their supervisors had slightly differing views of the amount of post-employment training the graduates needed to do their job. Using a five-point scale in which 1 meant "much less training needed than average" to become a net contributor to the company's work and 5 meant "much more training needed" than average, the mean rating by the graduates in industry was 1.96. Their supervisors provided a slightly higher mean ranking of 2.09; although they still placed their ERC-trained employees in the category of needing less training than their peers, supervisors did not see the difference as being quite as large as did the graduates themselves.

ERC Experience and Job Performance

Impact of ERC and non-ERC Graduate Experience on Job Performance

One of the underlying assumptions of the ERC Program has been that significant involvement in ERC activities during graduate study builds upon, or is complementary to, traditional graduate education. To examine the extent to which this has been the case, graduates rated separately the impact of their ERC experiences and non-ERC graduate experiences on their performance in each of the 16 capability or skill areas listed in the preceding section.

Using a 1-to-5 scale in which 1 was defined as "very negative" impact and 5 meant "very positive," graduates described the impact of their ERC experiences as ranging from neutral to somewhat positive, while their ratings for other graduate training experiences were slightly negative to positive. The impact of non-ERC experiences on those working in industry was most noticeable in six capabilities and skills: contribution to the company's technical work; breadth of technical understanding; depth of technical understanding; ability to grasp quickly key features of new problems; ability to define the steps needed to solve new problems; and ability to solve problems by applying knowledge from different disciplines in an integrated fashion. On average, the impact of non-ERC experiences on the graduates' job performance in these six areas was rated by those in industry approximately 0.25 higher than was the impact of ERC experiences. Performance in two other skills—creativity and innovation plus being able to communicate ideas in writing—also was slightly more affected by non-ERC graduate training.

Conversely, ERC experiences had a greater impact on performance of the remaining half (8) of the skills and capabilities, all of which were consistent with ERC Program intentions. The four with the greatest difference between ERC and non-ERC experiences

were: ability to work in interdisciplinary teams; ability to develop solutions that meet business goals as well as satisfying technical requirements; understanding the relationship between their work and the needs of the company's customers; and skill at networking in the company. The differences between ERC and non-ERC impact were smaller in the remaining four items: ability to communicate ideas verbally; ability to identify and transfer useful technology from outside sources such as universities or national labs; leadership ability; and ability to solve problems within constraints of time, money and human resources. Looking across graduates in all employment sectors, the impact of ERC experiences on these items was strongest among those employed in industry.

Graduates also rated the overall impact of both types of experiences on their job performance. Non-ERC experiences were rated to have had a higher overall impact on performance, compared with the impact of ERC experiences. Finally, looking at the ERC and non-ERC experiences across each of the 16 skills and abilities plus overall rating, the grand mean for non-ERC training was fractionally above that for ERC experiences. Given the greater amount of time students spent in non-ERC experiences while in graduate school, these difference are not surprising. Looking at the relative impact of ERC and non-ERC experiences on graduates across employment sectors, the ERC impact was greatest among those working in academia.

Graduate School Activities

Examination of what ERC graduates did while in graduate school sheds additional light on how ERC experiences add value to the rest of their graduate education. Masters and doctoral degree recipients in this study did substantially different things while in graduate school, and with notably different frequencies (see Appendix B). Of the 23 activities in which they might have engaged, only three were identified by more than half of the masters degree holders as things they had done: worked on research projects with ERC faculty, attended one or more professional meetings, and took non-ERC cross-disciplinary or interdepartmental course. Note that there is a roughly equal balance between ERC-related and non-ERC activities in which 25%-49% of the masters graduates engaged. Doctoral graduates were split relatively evenly between ERC and non-ERC activities throughout the full range of activities.

Note that the second most frequent activity for both masters and doctoral graduates was attending professional society meetings, and that in many cases respondents from both groups also presented papers at such meetings. While the graduates were not asked how the trips were financed, it is safe to assume that at least some of the graduates received funds from their ERC to attend such meetings. This is particularly likely if the individuals were making presentations about their ERC research projects.

Looking across all of their graduate activities, ERC graduates engaged in a surprising amount of ERC-like activities *outside* of ERCs as well. Table 4-3 provides some comparisons for both masters and doctoral graduates in terms of rates of participation in ERC and non-ERC activities.

Table 4-3: ERC and non-ERC Graduate School Activities of ERC Graduates

Activity	Masters Graduates ERC	Masters Graduates non-ERC	Doctoral Graduates ERC	Doctoral Graduates non-ERC
Collaborated with corporate researchers	24%	15%	37%	30%
Made presentations to industrial audiences	23	24	50	55
Published papers with industrial coauthors	5	5	21	15
Industrial internships - 20% of masters	25	75	-	-
Industrial internships - 18% of doctoral	-	-	48	52
Cross-disciplinary/cross-dept. courses	28	50	44	63
Presented talks at seminar series	18	25	45	60

The following section will examine the extent to which there are in fact differences in the impact of these seemingly similar ERC and non-ERC activities on graduates' subsequent job performance.

Statistical Relationships Between Graduate School Experiences and Job Performance

None of the results presented thus far dealing with the impact of ERC and non-ERC activities on graduates'job performance has been statistically significant. Thus, the possibility that they might be due to chance cannot be ruled out. However, more complex analyses (stepwise regressions) have identified statistically significant relationships between graduate school experiences and job performance.

Looking first at ERC-trained masters degree recipients who went to work in industry immediately upon receipt of the degree, those who took at least one ERC-developed or sponsored course while pursuing that degree rated their communications and leadership abilities somewhat higher than did those who did not take such courses. Among those who received a PhD and took a position in industry, there were several relationships between activities engaged in while pursuing that degree and subsequent job performance. Looking at ERC-linked activities, the following relationships emerged:

- Those involved with ERC prototyping projects assessed their performance in a number of technical areas to be superior to that of peers. Specifically, 60% of those previously involved in such projects identified their job performance as "much better than average" in their contribution to their company's technical work. They also rated themselves comparatively highly on their overall ability to carry out their job responsibilities and their breadth of technical understanding.
- Doctoral recipients who took ERC courses rated their ability to work in interdisciplinary teams significantly higher than did those who took no such courses. Over 40% of all doctoral recipients who took courses developed or sponsored by an ERC rated themselves "much better than average" in interdisciplinary team work.

Conversely, only 28% of PhD graduates who did not take any ERC courses rated their performance as highly on this dimension.

- PhD recipients who had coauthored papers with corporate sponsors of the ERC while in their doctoral program rated themselves relatively higher than did those who did not engage in such coauthorship in their ability to apply knowledge from different disciplines and their ability to transfer useful technology from outside sources.

Several relationships between non-ERC activities and job performance also emerged. Specifically:

- Those who gave talks in non-ERC seminar series and published papers with non-ERC corporate authors while in doctoral programs rated themselves significantly higher in two areas—their ability to communicate ideas both verbally and in writing and their leadership abilities—than did doctoral graduates who did not engage in these activities.
- PhD recipients who presented talks at non-ERC seminar series also rated themselves relatively higher than did those who gave no such talks on (1) a variety of technical capabilities and skills, (2) their ability to apply knowledge from different disciplines, and (3) their ability to identify and transfer useful technology from outside sources.

ERC Aspects with Greatest Career Impact

First, the ERC graduates who participated in this study looked back over their various experiences with an ERC and listed the aspects of their ERC involvement that had the greatest impact on their careers. Table 4-4 contains these aspects in order of frequency of identification:

Table 4-4: ERC Aspects with Most Impact on ERC Graduates' Careers

Internship in industry, "real-world" experience	31%
Specific courses, faculty, advisors	23
Multidisciplinarity; exposure to different disciplines	21
Good facilities and equipment	19
Teamwork	16
Research focus	14
Contacts, networking	12
Presentation, oral, or writing skills	7
Mention of a specific substantive area	6

ATTACHMENT 4-2:
LIST OF EDUCATION PROGRAMS BY CENTER

ERC for Environmentally Benign Semiconductor Manufacturing
University of Arizona
(Education Programs at
http://www.erc.arizona.edu/Education/Education_index.html)

Graduate Programs
Graduate Involvement (http://www.erc.arizona.edu/Education/Grad-Undergrad.htm)
New interdisciplinary courses: Microelectronics Manufacturing and the Environment (MME), and Advanced Topics in Microelectronics Manufacturing (http://www.erc.arizona.edu/Education/MME%20Course%20Materials/MME_Download_Web_Text.htm)

Undergraduate Programs
Undergraduate Involvement (http://www.erc.arizona.edu/Education/Grad-Undergrad.htm)

Precollege Programs
Secondary School Outreach (http://www.erc.arizona.edu/Education/highschool.html)
Secondary School Teacher Institute (http://www.erc.arizona.edu/Education/TeacherInst.htm)
Links for Teachers (http://www.erc.arizona.edu/Education/outreach/index.htm)

Continuing Education
Industrial Courses and Seminars (http://www.erc.arizona.edu/Education/ContinueEd.htm)
Teleseminars (http://www.erc.arizona.edu/seminar/index.html)
Microelectronics Manufacturing and the Environment Course Materials (http://www.erc.arizona.edu/Education/MME%20Course%20Materials/MME_Download_Web_Text.htm)

Center for Neuromorphic Systems Engineering
California Institute of Technology
(Education Programs at
http://www.erc.caltech.edu/Education/index.html)

Graduate Programs
PhD Program in Computation and Neural Systems (http://www.cns.caltech.edu/)

Undergraduate Programs
Summer Undergraduate Research Fellowships (http://www.its.caltech.edu/~surf/2001/)
Minority Undergraduate Research Fellowships (http://www.cco.caltech.edu/%7Emurf/)

Precollege Programs
Jisan Research Institute (http://www.jisan.org/)
Caltech Precollege Science Initiative (http://www.capsi.caltech.edu./)

Continuing Education
Neuromorphic Engineering Workshop
(http://www.klab.caltech.edu/%7Etimmer/telluride.html)

Center for Advanced Engineering Fibers and Films
Clemson University
(Education Programs at http://virtual.clemson.edu/groups/caeff/eduprog/index.htm)

Graduate Programs
Application for Admission (http://www.grad.clemson.edu/page5.htm)
College of Engineering Certificate in Particle Science and Technology
(http://www.erc.ufl.edu/Education/CertificateProgram.htm)

Undergraduate Programs
Research Experiences for Undergraduates
(http://virtual.clemson.edu/groups/caeff/reuprog/index.htm)

Precollege Outreach Programs
Workshop: "Introduce a Girl to Engineering and Science"
(http://virtual.clemson.edu/groups/caeff/eduprog/gsworkshop/index.htm)

Engineering Research Center for Particle Science and Technology
University of Florida
(Education Programs at http://www.erc.ufl.edu/EducIntro2.htm)

Graduate Programs
Particle Science Summer School in Winter
(http://www.erc.ufl.edu/Education/GraduatePrograms.htm)
Teaching Materials: Instructional Module Series
(http://www.erc.ufl.edu/Education/TeachingMaterials.htm)
Certificate Programs in Particle Science and Technology
(http://www.erc.ufl.edu/Education/CertificateProgram.htm)

Undergraduate Programs
Course Offerings (http://www.erc.ufl.edu/Education/UnderGraduate.htm)

Precollege Programs

Summer Engineering Camps for Female and Minority Middle School Students
(http://www.erc.ufl.edu/Education/PrecollegiateOutreach.htm)

Continuing Education
Short Courses and Workshops (http://www.gtec.gatech.edu/education/shortcourses.html)

Center for the Engineering of Living Tissues
Georgia Tech/Emory University
(Education Programs at
http://www.gtec.gatech.edu/education/index.html)

Graduate Programs
Graduate Educational Opportunities
(http://www.gtec.gatech.edu/education/gradedopps.html)
Planned Internet Courses (http://www.gtec.gatech.edu/education/internetcourses.html)

Undergraduate Programs
Undergraduate Educational Opportunities
(http://www.gtec.gatech.edu/education/undergradedopps.html)
Research Experiences for Undergraduates
(http://www.gtec.gatech.edu/education/reuinfo.html)
Undergraduate Research Scholars (http://www.gtec.gatech.edu/education/ursinfo.html)

Precollege Programs
K–12 Outreach (http://www.gtec.gatech.edu/education/k12outreach.html)
K–12 Educational Links (http://www.gtec.gatech.edu/education/k12links.html)

Continuing Education
Short Courses and Workshops (http://www.gtec.gatech.edu/education/shortcourses.html)

Packaging Research Center
Georgia Institute of Technology
(Education Programs at
http://www.ece.gatech.edu/research/PRC/education/index.htm)

Graduate Programs
Practice-Oriented Masters: A Microelectronics Packaging Certificate Program
(http://www.ece.gatech.edu/research/PRC/education/grad.htm)

Undergraduate Programs
Undergraduate Curriculum
(http://www.ece.gatech.edu/research/PRC/education/undergrad.htm)

Precollege Programs

K–12 Programs (http://www.ece.gatech.edu/research/PRC/education/precoll.htm)

Continuing Education
Professional Development Opportunities
(http://www.ece.gatech.edu/research/PRC/education/profdev.htm)
Short Course: Next Generation of Microelectronics and Microsystems Packaging Technologies (http://www.prc.gatech.edu/conferences/shortcourse2002/overview.htm)

Marine Bioproducts Engineering Center
University of Hawaii
(Education Programs at
http://www.marbec.net/education/)

Graduate Programs
Offerings and Admission (http://www.marbec.net/education/graduate.asp)

Undergraduate Programs
Internships and Workforce Training for Undergraduates
(http://www.marbec.net/education/research.asp)
MarBEC/Sea Grant Summer Undergraduate Research Fellowship
(http://www.marbec.net/education/intern/msurf_announce.asp)

Precollege Programs
Outreach Efforts (http://www.marbec.net/education/k12.asp)

Continuing Education
Workshops and Other Industry Outreach (http://www.marbec.net/education/outreach.asp)

Center for Computer-Integrated Surgical Systems and Technology
Johns Hopkins University
(Education Programs at
(http://cisstweb.cs.jhu.edu/web/about/CenterOverview/)[2]

Graduate Programs
Course Offerings (http://cisstweb.cs.jhu.edu/web/students/courses/)
Student Research Projects (http://cisstweb.cs.jhu.edu/web/students/projects/)

Precollege Programs

High School Surgical LEGO Robot Competition
(http://cisstweb.cs.jhu.edu/~cissrs/Activities/LEGOComp/overview.html)

[2] Available by clicking the "Education and Outreach" button on the Center Overview web page.

Biotechnology Process Engineering Center
Massachusetts Institute of Technology
(Education Programs at
http://web.mit.edu/bpec/BPECeducation.html)

Graduate Programs
Biotechnology Training Program (http://web.mit.edu/bpec/biotech/)

Undergraduate Programs
Research Experiences for Undergraduates (http://web.mit.edu/bpec/reu.html)
Undergraduate Research Opportunities Program (http://web.mit.edu/urop/index.html)

Center for Reconfigurable Machining Systems
University of Michigan
(Education Programs at
http://erc.engin.umich.edu/Education/education.htm)

Graduate Programs
Graduate Curriculum
(http://erc.engin.umich.edu/Education/curriculum/curriculum_grad.htm)
Workshops and Seminars
(http://erc.engin.umich.edu/Education/culture/culture_grad_workshop.htm)
Graduate Industrial Interaction
(http://erc.engin.umich.edu/Education/culture/culture_grad_industry.htm)

Undergraduate Programs
Undergraduate Curriculum
(http://erc.engin.umich.edu/Education/curriculum/curriculum_ugrad.htm)
Research Experience for Undergraduate
(http://erc.engin.umich.edu/Education/outreach/outreach_reu.htm)
Undergraduate Mentoring Program
(http://erc.engin.umich.edu/Education/culture/culture_ugrad_mentor.htm)

Precollege Programs
Detroit Area Precollege Engineering Program
(http://erc.engin.umich.edu/Education/outreach/outreach_dapcep.htm)
Greenfield Coalition/Focus: HOPE Project
(http://erc.engin.umich.edu/Education/outreach/outreach_hope.htm)
Middle School and High School Projects
(http://erc.engin.umich.edu/Education/outreach/outreach_musem.htm)
Elementary School Science Club
(http://erc.engin.umich.edu/Education/outreach/sci_club.htm)

Continuing Education

http://erc-assoc.org/educate/umicont.htm

Center for Wireless Integrated MicroSystems
University of Michigan
(Education Programs at
http://www.wimserc.org/edOut.cfm?Map=6)

Undergraduate Programs
Research Experience for Undergraduates (http://www.wimserc.org/edOut.cfm?Map=5)

Center for Subsurface Sensing and Imaging Systems
Northeastern University
(Education Programs at
http://www.censsis.neu.edu/)

Graduate Programs
Seminars and Workshops (available by clicking "Seminars and Workshops" button at http://www.censsis.neu.edu/)

Undergraduate Programs
High-Tech Tools and Toys Laboratory (available by clicking "High-Tech Tools and Toys Lab" button at http://www.censsis.neu.edu/)

Precollege Programs
CenSSIS Challenge- Middle School Children and their Teachers **(**available by clicking "K–12 Pathways" button at http://www.censsis.neu.edu/)
Research Experience for Teachers (available by clicking "K–12 Pathways" button at http://www.censsis.neu.edu/)
Imaging Futures - A Pipeline to College For At Risk High School Youth (available by clicking "K–12 Pathways" button at http://www.censsis.neu.edu/)
Hidden Worlds - Middle School Students, Teachers, and Retired Engineers (available by clicking "K–12 Pathways" button at http://www.censsis.neu.edu/)

Integrated Media Systems Center
University of Southern California
(Education Programs at
(http://imsc.usc.edu/education/education_content.htm)

Undergraduate Programs
Minor in Interactive Multimedia (for all USC students) and Minor in Multimedia and Creative Technologies (for Engineering majors) (http://www.usc.edu/dept/publications/cat2001/engineering/mmct/index.htm)
Undergraduate Research Projects (http://imsc.usc.edu/Personnel/saffairs.html)

Graduate Programs
MS in Computer Science with Specialization in Multimedia and Creative Technologies (http://sipi.usc.edu/~mendel/msp#anchor25809587)
MS in Electrical Engineering with Specialization in Multimedia and Creative Technologies (http://sipi.usc.edu/~mendel/msp#anchor25804590)
MS in Integrated Media Systems (http://sipi.usc.edu/~mendel/msp)

Continuing Education
Multimedia University Academy (http://mua.usc.edu/)

VaNTH ERC for Bioengineering Educational Technologies
Vanderbilt University
(Education Programs at (http://www.vanth.org/vanth_educ.cfm)

Graduate Programs
A Workshop on Teaching and Learning Principles for Bioengineering (http://www.vanth.org/vanth/thrustFiles/164.htm)

Undergraduate Programs
Research Experience for Undergraduates (http://www.vanth.org/reu/)

Precollege Programs
Dissemination Programs (http://www.vanth.org/vanth_dissem.cfm)
Research Experience for Teachers (http://www.vanth.org/vanth/thrustFiles/252.doc)
River of Life: VaNTH SLC Outreach Project (http://www.vanth.org/vanth/thrustFiles/166.htm)

Center for Power Electronics Systems
Virginia Polytechnic Institute & State University
(Education Programs at http://www.cpes.vt.edu/public/education/education.html)

Graduate Programs
Exchange and Fellowship Programs (http://www.cpes.vt.edu/public/E2.html)

Undergraduate Programs
Research Assistantships and Concentrations in Power Electronics (http://www.cpes.vt.edu/public/education/undergraduate.html)

Precollege Programs
Programs for High Schools (http://www.cpes.vt.edu/public/education/high_school.html)

Programs for Elementary and Middle Schools
(http://www.cpes.vt.edu/public/education/grade_school.html)
Partnerships in Engineering: A Robotics Challenge Program for Southwest Virginia, including the First Lego League (http://www.cpes.vt.edu/fll.html)

Continuing Education
Short Courses (http://www.cpes.vt.edu/public/courses/short/courses.html)

Center for Engineered Biomaterials
University of Washington
(Education Programs at
http://www.uweb.engr.washington.edu/education/index.html)

Graduate Programs
Student-Professional-Industry Team
(http://www.uweb.engr.washington.edu/education/gupi/gupi.html)
Industry Internships (http://www.uweb.engr.washington.edu/industry/internships.html)
Courses and Presentations
(http://www.uweb.engr.washington.edu/education/courses.html)

Undergraduate Programs
Summer Research Experience for Undergraduates
(http://www.uweb.engr.washington.edu/education/reu.html)
Undergraduate Scholars in Research Program
(http://www.uweb.engr.washington.edu/education/usirp.html)
Journal of Undergraduate Research in Bioengineering
(http://www.uweb.engr.washington.edu/education/juribe.html)

Precollege Programs
K–12 Classroom Visitation Program
(http://www.uweb.engr.washington.edu/education/k-12/classroom.html)
Laboratory Experience for High School Students
(http://www.uweb.engr.washington.edu/education/k-12/lehss.html)
Middle School Science Teachers Institute
(http://www.uweb.engr.washington.edu/education/mssti/index.html)
Science for Success High School Science Outreach Program
(http://www.uweb.engr.washington.edu/education/k-12/sfs.html)
Guy Simplant Bioengineering Game
(http://www.uweb.engr.washington.edu/education/guysimplant/index.html)

Multidisciplinary Center for Earthquake Engineering Research
State University of New York at Buffalo
(Education Programs at
http://mceer.buffalo.edu/education/default.asp)

Undergraduate Programs
Research Experiences for Undergraduates
(http://mceer.buffalo.edu/education/reu/default.asp)

Precollege Programs
Earthquakes: Frequently Asked Questions
(http://mceer.buffalo.edu/infoService/faqs/default.asp)
Earthquake Exercises (http://mceer.buffalo.edu/education/default.asp)
Soils and Earthquakes (http://mceer.buffalo.edu/education/exercises/soil.asp)

Continuing Education
Professional and Continuing Education
(http://mceer.buffalo.edu/education/keepup1.asp?r=e)

Pacific Earthquake Engineering Research Center
University of California at Berkeley
(Education Programs at
http://peer.berkeley.edu/participants/peereducate.html)

Graduate Programs
Doctoral Fellowship
(http://peer.berkeley.edu/participants/peereducate.html#peer%20fellowship)
Mentoring Program (http://peer.berkeley.edu/students/slc_mentors.html)

Undergraduate Programs
Industry Partners Summer Internship Program
(http://peer.berkeley.edu/participants/peereducate.html#bip99)
Summer Intern Program
(http://peer.berkeley.edu/participants/peereducate.html#summer99)
Earthquake Engineering Scholars Course
(http://peer.berkeley.edu/participants/peereducate.html#eesc)

Precollege Programs
K–12 Educational Outreach (http://peer.berkeley.edu/participants/peereducate.html#k-12%20education)

Continuing Education
Workshops and Short Course for Practicing Engineers
(http://peer.berkeley.edu/participants/peereducate.html - continuing education)

Mid-America Earthquake Center
University of Illinois at Urbana-Champaign
(Education Programs at

http://mae.ce.uiuc.edu/Education/EducationFrame.htm)

Graduate Programs

Teaching Modules for Graduate Students (accessible through "Graduate Students" link at http://mae.ce.uiuc.edu/Education/SLCFrame.htm)

Undergraduate Programs

Teaching Modules for Non-Technical Majors (accessible through "Undergraduate Students" link at http://mae.ce.uiuc.edu/Education/SLCFrame.htm)

Campus Honors Program Course in Earthquake Engineering (accessible through "Undergraduate Students" link at http://mae.ce.uiuc.edu/Education/SLCFrame.htm)

Precollege Programs

Earthquake Awareness Activity Series
(accessible through "K–12" link at
http://mae.ce.uiuc.edu/Education/EducationFrame.htm)

Shake Table Dollhouse (http://mae.ce.uiuc.edu/Education/Dollhouseframe.htm)

Earthquake Resource Links for Teachers
(http://mae.ce.uiuc.edu/Education/Teachers/resource.htm)

Continuing Education

Reducing Seismic Consequences for URM Buildings: Assessment and Retrofit Design
(http://mae.ce.uiuc.edu/Education/ContEd/StLouis2002.htm)

Geotechnical Earthquake Engineering in Mid-America Seminar Series
(http://mae.ce.uiuc.edu/Education/ContEd/Geo2000.htm)

Design Considerations for Buildings in Moderate Seismic Zones Seminar Series
(http://mae.ce.uiuc.edu/Education/ContEd/Atlanta1999.htm)

Public Awareness

Virtual Learning Center (http://moment.mit.edu/maeed/)

Instructional Earthquake Simulations Project (accessible through "Public Awareness" link at http://mae.ce.uiuc.edu/Education/SLCFrame.htm)

ATTACHMENT 4-3
CPES COOPERATIVE AGREEMENT
FOR THE EXCHANGE OF GRADUATE STUDENTS

THIS AGREEMENT is effective this first day of December 1999, by and between Virginia Polytechnic Institute & State University, University of Wisconsin-Madison, Rensselaer Polytechnic Institute, North Carolina A&T University and University of Puerto Rico-Mayaguez (hereinafter referred to individually as a "Center University" and collectively as the "Center Universities").

8.6.1.1 RECITALS

Whereas Virginia Polytechnic Institute and State University, University of Wisconsin-Madison, Rensselaer Polytechnic Institute, North Carolina A&T University and University of Puerto Rico-Mayaguez have successfully received funding from the National Science Foundation for an Engineering Research Center called the Center for Power Electronic Systems (CPES);

Whereas the Center Universities are committed to successful research and educational collaboration through the sharing of research and pedagogical resources;

Whereas the Center Universities seek to encourage students and faculty to exploit the diverse technical strengths of the Center Universities reflected in their course and research offerings;

Whereas the Center Universities need to develop uniform policies and practices regarding student exchange that respect the existing policies and practices of the individual Center Universities.

8.6.1.2 PROVISIONS

In consideration of the premises and mutual covenants contained herein, the Center Universities agree as follows:

1. **Tuition and Fees:** Tuition is paid to the Home University. The Home University is the Center University where the student has matriculated. The Host University is the Center University that offers courses and/or research opportunities of interest to the student. Under student exchange, the student physically resides at the Host University. Fees covering reasonable residence costs (e.g. student health insurance fees and student activity fees but excluding housing) of student exchange will be paid to the Host University by CPES; fees covering reasonable incremental costs of

classroom education for exchange visitors will be paid to the Host University by CPES. The cost of housing is the responsibility of the student.

2. **Billing:** The CPES Education Coordinator for the Home University will report all exchange activity to the CPES Administrative Director at Virginia Tech. The CPES Administrative Director shall disburse the total amount of residence fees due to each CPES University. Such disbursements shall be made once for the fall semester and once for the spring semester.
3. **Prior Approval:** Students shall obtain prior approval of the CPES Education Coordinator at their Home University. Courses and research undertaken taken through Center Universities shall appear on the student's approved plan of study.
4. **Registration:** Students will complete all registration forms required by the Host University to gain access to the CPES courses of interest. The student shall register for appropriate course(s) (e.g., an independent study course) and research activity with the CPES Education Coordinator for the Home University. The course titles selected for the appropriate courses and research shall reflect the Host University and the course title at the Host University.
5. **Courses Covered:** The list of courses covered by this agreement shall be reviewed annually by the CPES Executive Committee and modified to include only courses of direct relevance to the CPES mission.
6. **Transcripts:** At the conclusion of the exchange period, the instructor(s) at the Host University shall provide the CPES Education Coordinator at the Home University with grade information for each student in an exchange program. The CPES Education Coordinator for the Home University shall then post these grades on the student's transcript for the appropriate courses corresponding to the exchange program.
7. **Annual Statistics:** Each CPES University will provide the CPES Education Director with annual statistics at the conclusion of the spring semester. These statistics are to include, at a minimum, the number of courses taken at that Center University by students from other Center Universities, courses taken by students from that Center University at other Center Universities, the length of each exchange period, and the number of credit hours involved in each exchange. This information is needed to encourage balanced participation of the Center Universities, and to detect any structural imbalances that may be developing. This information is also needed for tracking CPES accomplishments and annual reporting of CPES activities to the National Science Foundation. Student names, identification numbers, and any other information that may compromise student privacy shall not be provided.
8. **Entire Agreement/Modifications:** This Agreement constitutes the entire agreement between the parties relative to student exchange programs, supercedes all previous agreements relative to student exchange programs, and may only be modified or amended by a written agreement signed by all parties.

Dr. Harold L. Martin	Dr. Doyle Daves	Dr. Zulma R. Toro Ramos
Vice Chancellor	Interim Provost	Chancellor

for Academic Affairs

North Carolina A&T	**Rensselaer Polytechnic**	**Univ. of Puerto Rico-**
8.6.1.2.1 University	**Institute**	**Mayaguez**
_____	_____	_____
Date	Date	Date

_____	_____
Dr. Michael Corradini	Dr. Peggy Meszaros
Associate Dean of Engineering	Senior Vice President and Provost
Univ. Wisconsin-Madison	**Virginia Polytechnic Inst. & State University**
_____	_____
Date	Date