Section 4.5: Graduate Education Programs

There is a specific set of expected ERC-wide characteristics of graduate students who participate in any ERC. These are:

1. The ability to take a systems-level approach to problems;
2. Superior skills at working in teams;
3. Ability to apply an interdisciplinary problem solving approach;
4. Exceptional communication skills;
5. A solid grounding in the industrial perspective of their chosen area; and
6. The ability to contribute immediately and productively to jobs in industry.

In addition to the depth of training in their particular discipline, ERC students are also expected to have a breadth of knowledge that crosses disciplinary boundaries. These content-specific knowledge and skill sets will be specific to the particular ERC, and these desired skill sets should guide the development of the ERC's graduate education program. To assure that ERCs strategically address this challenge, Gen-3 ERCs are charged specifically with developing strategies to achieve those skill sets, and in addition, skill sets that will lead to greater creativity and innovation in a global economy.

Each center must first identify those skill sets using input from all their constituencies. While each center can select the mechanism for soliciting, distilling, and arriving at a consensus with respect to the desired outcomes, it is critical that this step be conducted in the first year of the center, to help focus the ERC's education strategy and its education program development. Several examples of how existing ERCs have accomplished this task are described in Appendix section 4.5.1. These include the CURENT ERC, which has identified skill sets and a program of activities that leads to certification of achievement related to the appropriate mastery of the items and traits that define the skill set. The FREEDM ERC has also organized the skill set acquisition into a portfolio program that serves as a guide as well as a mechanism for review of their graduate students' progression through the program.

4.5.1 Recruitment

The graduate program should contribute to the overall diversity goals of the center and actively recruit students. It is recognized that centers are not directly involved in admissions decisions and must be ever mindful of the relationship between the ERC and the associated departments, programs, or colleges. However, a center's presence on campus can be a key factor in attracting graduate students to apply to the institution. For this reason, center faculty can advise and monitor a potential recruit's application process and, once the student has been accepted in an academic unit, encourage them to join a center research group.

Tips for recruiting include:

1. Students and faculty traveling to conferences should be provided with brochures or fliers to spread

information about the center.

2. Set up tables at conferences that offer the opportunity to meet with a diverse group of students, such as the NSF Louis Stokes Alliances for Minority Participation (LSAMP) regional meetings.

3. Faculty and staff should involve themselves in Departmental/College programs (such as the admissions committees) to guide decisions to be mindful of the ERC's needs and to be aware of newly available students.

4. Center personnel should keep a network of contacts in Departmental or College recruiting offices (particularly special offices for women or underrepresented groups) who have regular interaction with prospective students, and be sure that they have current information about what the center can offer new students.

5. A regularly updated website (particularly including opportunities for graduate students at the ERCs) is essential.

Other venues for recruiting on-campus include campus chapters of national organizations—and the annual national meetings of these organizations. ERCs often collaborate, through the activities of the ERC Education Directors, in securing a booth or a general presence at national meetings.

4.5.2 Student Financial Support

All ERC graduate students are supported financially by the center. Affiliated students are supported from other funding, often generated by the ERC or faculty involved in the ERC through funding from associated projects. 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. It is recommended that new students be encouraged to apply for Graduate Research Fellowships from the NSF, DOE, and other competitive fellowship programs.

ERCs should also encourage graduate students to apply for professional society or industry scholarships, or in some cases to 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, and give the students valuable experience in grant writing. Grant writing is yet another professional development opportunity offered to ERC students (see section 4.5.8, "Student-led Proposals," below).

In addition to the technical and research skills acquired, what distinguishes the graduate experience of an ERC student from a traditional program is the professional development components offered. In addition to the skill sets described above, ERC students also have the opportunity to develop leadership and mentoring skills through a variety of activities described below.

4.5.3 Role of the Student Leadership Council

The Student Leadership Council (SLC) is an integral part of the center leadership and management structure. It not only provides students with leadership skill development but also serves as a required liaison between the students and Center Director and center Leadership Team. Each council should include members from each partner institution that supports the graduate and undergraduate research efforts and should have a governing structure to coordinate the group. Interactions take place in face-to-face formats at regularly scheduled research meetings, such as the center's Industry Advisory Board meetings, NSF annual site visit, and the NSF ERC biennial meetings, as well as by social media and internet-friendly online formats.

An important function of the SLC is the annual SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis that they conduct of their center. This provides center management, the Industrial Advisory Board, and the

NSF site visit teams with valuable feedback about center activities. The SLCs are charged with carrying out activities to address the weaknesses that are under their control and to communicate with the Center Director about significant weaknesses, opportunities and threats that the SLC feels threaten the success of the center. Other activities that may be coordinated by the SLC include mentoring of undergraduates, K-12 teachers, K-12 students, and managing the center seminars. It is important for center faculty to recognize that the SLC is a critical and required feature of an ERC, and to support their students as they take part in SLC activities.

As students come and go in their leadership roles of the SLC, it is important to have one person on the Education Leadership Team assigned to mentor the SLC to provide for continuity and support. In addition, each SLC should have a budget to support their activities. A few have research budgets and hold competitions for exploratory research projects relevant to the ERC's strategic plan.

4.5.4 Mentorship Training

Mentoring of undergraduate participants in the ERC's research program, as well as participants in the Research Experiences for Undergraduates (REU), Research Experiences for Teachers (RET), and Young Scholars (Gen-3 only) programs , often falls under the purview of a graduate student. Post-doctoral researchers and faculty are also involved, but direct interactions are typically mediated through advanced graduate students. Some programs have mentoring requirements built into the expected activities of the graduate students, especially for the supervision of summer REU Site participants. Please note: Mentorship training should be provided to all graduate students as part of their professional development activities, prior to allowing them to assume these responsibilities. See section 4.4.1 above.

4.5.5 Seminars

Presence and participation in seminar series are part of every graduate student's education. Often, the student's home department will have seminar series that require some attendance regimen. There are typically two types of center seminars. An ERC-wide seminar series is an important way to integrate the research teams and it is recommended to incorporate graduate student selection of topics and speakers in some meaningful way. Additionally, students often develop an independent seminar series that serves to connect research thrusts across departments as well as institutions. These series may be student-only forums that have a more informal feel. Both of these venues are important to connect often geographically dispersed students and help to instill a center identity.

4.5.6 Curriculum Development

One of the most lasting institutional changes an ERC can offer an institution(s) is by integrating center research into the curriculum. ERCs introduce curriculum changes in many different ways. Course revisions can take place at the undergraduate and graduate level based on the natural tendencies of ERC-affiliated faculty assigned to regular courses. New courses derived from the research program are expected outcomes of the ERC program. In some cases, new degrees are introduced. Here we focus on graduate-level curriculum development.

New Degree Programs, Masters/PhD level.

Many of these are described more fully in the examples in Appendix section 4.5.2.New master's programs are often the easiest to implement. They do, however, present challenges. Suggestions for developing one include:

1. M.S. or M.E. (Master of Engineering) programs that build upon an existing traditional M.S. degree, e.g., M.S. EE or M.S. ChE, may be developed by adding an area of emphasis to the existing program, perhaps leading to a certificate. They may also evolve into full-fledged programs. Departmental and/or graduate program buy-in from the beginning of the development process for this kind of new M.S. program is required, as is buy-in from all stakeholders.
2. 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 in different ways with ERC faculty. This can be a valuable selling feature for the program.

3. Industry professionals can be valuable adjunct faculty.

4. New degree programs may take time to go through the approval processes that are specific to each institution.

5. New Ph.D. degree programs often require the longest lead times to get established. Before proposing a new Ph.D., the same process used to establish the center's expected skills set should be utilized to determine that all stakeholders view the center's field as one that should become a distinct degree or one that is an add-on to an existing degree program.

As an example, The Center for Structured Organic Particulate Systems (C-SOPS) has an emphasis in pharmaceutical manufacturing technologies. To better serve the needs of their graduate students, the partner institutions have various versions of a Pharmaceutical Engineering course sequence, leading to certificates or degrees at the Masters level. At Rutgers, the effort was directed at introduction of a new degree program (see example 4.5.2.4)

Another example is the Biomimetic MicroElectronic Systems (BMES) ERC at the University of Southern California. BMES has introduced several new graduate degree programs over the course of a decade. The programs are in response to training needs associated with new and novel medical devices. The training was best served by coordination between the School of Engineering at USC and their medical school as well as medical schools at other institutions. Specialized M.S. degrees and rigorous M.D./Ph.D. programs have also been introduced. See appendix example 4.5.2.3.

New Courses, Course Revisions, and Curriculum Coordination

The introduction and revision of courses based on the research findings of the center, as well as to introduce newer skill sets to graduates, are common in an ERC's curriculum development activities. Revision of courses has lowere barriers of approval and effort than the development of new courses, and thus in many cases provides greater return on investment. New course content and materials are often left to individual faculty to implement, but when the need for a coordinated curriculum is apparent, a broader effort is required. The Smart Lighting ERC has developed a curriculum matrix that facilitates the ability of students, as well as industry, to understand the relationships between the different requirements. Smart Lighting's *Illumineer* curriculum summarizes the desired background and skill set of graduates pursuing careers in smart lighting. See appendix example 4.5.2.5.

Course Articulation Between Partner Institutions

When partner institutions have course sequences or even entire degree programs already available, articulation agreements may be an efficient route to expanding their impact. The articulation usually emphasizes tuition payment/revenue agreements, but the inclusion of courses in the core or as electives in other programs should be carefully described as well. Students may be in residence at partner institutions and take courses for credit or they may participate by online delivery of the material between partner institutions. At the Collaborative Adaptive Sensing of the Atmosphere (CASA) ERC, students were able to enroll in coordinated Ph.D. programs that were otherwise not available to them through collaborative agreements. See appendix example 4.5.2.1.

Online Delivery

The acceptance of online formats for course delivery has been significantly elevated in recent years with the inclusion of free content from established institutions and recognized faculty experts. The major emphasis in the media has been associated with Massive Open Online Courses (MOOCs), but the standard course can also benefit from online formats. This is particularly useful when the partner institutions are sharing instructional expertise or have inter-institutional course requirements. It can be expected that a more widespread adoption of online, modular, or blended course formats will be prevalent in the near future.

Workshops

Almost all ERCs develop and run workshops to highlight recent advances in research, as well as to showcase new equipment or devices that are integral to their research thrusts. The workshops serve to bring together practitioners, outside experts, international teams and various vendors with graduate students in a concentrated learning environment. Workshops can be regularly scheduled or responsive to timely new innovations. Two examples are described in Appendix sections 4.5.1.4 and 4.5.3.2.

Innovation and Entrepreneurship

Gen-3 ERCs have additional requirements and a broader mandate to include training related to innovation, creativity, and entrepreneurship. While many ERCs infuse this training throughout their various programs, some have developed specific courses or modules/activities. The CITE workshop described in example 4.5.1.4 (Appendix 4.5) is one example. The ASSIST ERC has proposed a required set of activities associated with the specific skills and attributes particular to their graduates that includes this type of training. The identification of innovation and entrepreneurship training is a key component and the program is required as part of the completion of studies for students in the ASSIST ERC. See appendix example 4.5.1.2.

4.5.7 Industry Mentorship of Graduate Students

Industry plays a well-established central role in the guidance and relevance of ERC research thrusts and testbed activities. The degree of involvement of industry in the execution of research projects by graduate students can range from service on thesis committees to oversight of research on a regular basis. While it is difficult to ensure continuity of programs that have a very direct involvement of industry in a student's work, some coordinated mentoring can be very effective. The C-SOPS ERC has established a formal mentoring program for graduate students, as well as post-doctoral researchers, that connects students and post-docs to industry peers and experts. Regularly scheduled meetings with teams of academic and industry partners can also facilitate advancement of projects and make Industry Advisory Board meetings more focused. See appendix section 4.5.3.1.

4.5.8 Student-led Proposals

Opportunities for students to develop funding proposals can be a valuable experience that some ERCs have taken advantage of. Students recognize the value of coordinating a team to guide the proposed work and to interact with different groups associated with getting the project off the ground. In some cases, the funding for the project has come from the ERC and aligned with the testbeds identified for the technology development that was needed. For example, the CASA ERC nourished a student-led testbed (STB) in radar precipitation estimation that was well received by the research team and by the technology users. The project was funded through a diversity supplement as well as Louis Stokes Alliances for Minority Participation (LSAMP) and Alliances for Graduate Education and the Professoriate (AGEP program funding. See appendix example 4.5.2.2.

Other opportunities for student-led funding include stipend and tuition support opportunities such the NSF and DoD Fellowships,[1] proposals to SBIR and STTR programs for development of innovative research ideas, and proposals to industry that may allow for company-specific testbed development or provide a service contract using the expertise of the students. Internships and part-time employment may also be beneficial if well-coordinated to the student's academic experiences.

4.5.9 International Experiences via Internships and Student Exchanges

Gen-3 ERCs have a mandate to provide opportunities for center students and faculty to collaborate in a globally connected university research and education environment. This is an opportunity for the ERC researchers to collaborate with "best researchers in the world" in areas where complementary expertise strengthens the efforts in the ERC while providing an opportunity for cultural and engineering practice experience for the students in global environment. This can be accomplished formally through a Memorandum of Understanding (MOU) or via faculty-to-foreign faculty collaborations. Gen-3 centers must ensure that the foreign collaboration adds value to the research and also offers the ERC students the opportunity to work in a foreign laboratory for a mutually specified period of time. It is essential that the student spend sufficient time in the foreign laboratory to have a meaningful international research experience that is relevant to the student's research in the ERC. In both cases, there should be mutually protective Intellectual Property (IP) policies. These collaborations are not expected to be in place in the proposal; rather they are expected to evolve over time as the research program evolves.

1 See, for example: http://www.nsfgrfp.org/ ; http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13646 ; and

http://www.onr.navy.mil/Education-Outreach/undergraduate-graduate/NDSEG-...