ERC BEST PRACTICES MANUAL
CHAPTER 4: EDUCATION PROGRAMS

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-graduate-fellowship.aspx

APPENDIX 4.5
GRADUATE EDUCATION EXAMPLES

4.5.1 Programs to Produce Desired Skill Sets

4.5.1.1 ***Center*****:** ERC for Ultra-wide Area Resilient Electric Energy Transmission Networks (CURENT)
Lead Institution: The University of Tennessee
Center Director: Dr. Kevin Tomsovic, Department of Electrical Engineering and Computer Science
Name of Program: Innovation, Mentorship, Professionalism, Adaptation, Creativity and Technology (IMPACT)

Program Synopsis: CURENT has developed recommendations for the skill sets ERC graduates will need to succeed in energy-related industries. CURENT's proposal states that ERC graduates will be grounded in the fundamentals of the Center's education program and will develop creative characteristics if they are trained to have the following traits: analytical thinking, problem-solving attitude, entrepreneurial bent, is a leader and a mentor, and communicates effectively, behaves professionally, and demonstrates interdisciplinary and global views. The IMPACT program is CURENT's strategy for producing a new generation of engineering graduate students with these desired characteristics to become creative, adaptive, and innovative. As of January 2013, 10 students have completed the IMPACT program at University of Tennessee, Knoxville.

Contact person/website: Chien-fei Chen, Education and Diversity Co-director (cchen26@utk.edu)

Dates of Operation/Timeframe: The program was initiated in August, 2012 and is a year-round program.

Background: The IMPACT program is a strategy to meet the ERC Gen-3 education requirement. Systematic planning and effective implementation strategies are required to be effective. The proposed skill-sets are based on NSF requirements, the National Academy of Engineering's *Engineer of 2020* recommendations, and discussion with industry members.

Methodology: All students participating in the IMPACT program receive a personal online plan with detailed components to be completed and are expected to regularly meet with the education director or coordinator. For example, students are expected to gain experience working in a team-based research environment, be exposed to professional development opportunities and industry connectivity training, be required to complete an entrepreneurship or technology management course, show professional conduct, complete an engineering ethics course, and participate in education outreach activities.

To implement the IMPACT program effectively and train students to be creative and innovative, CURENT has incorporated industry and research seminars, webinars, meetings, and workshops into its graduate education program. These activities provide students with industrial practice knowledge that assists with their career development. For example, CURENT has arranged a series of seminars relating to intellectual property law and entrepreneurship and innovation. Additional industrial practice puts students in contact with for practicing engineers who have worked in the industry in the U.S., Asia, and Europe and exposes them to interdisciplinary approaches to energy policy and electricity marketing. In general, the IMPACT requirements do not impose a great time demand on the students. For example, educational outreach activities take place only twice a semester, and students are required to attend only one or two seminars or other training for each component.

Impact/benefits: The purpose of this program is to augment graduate students technical education and research with training to be successful in a global environment. It offers effective ways to mentor students' progress on a regular basis. It will benefit the industry and society as a whole by training students to be creative, adaptive, and innovative before entering the workplace. In other words, participating in the program will develop students who are more professional, well prepared, and have already developed a global view when they become practicing engineers.

Evaluation/Assessment: Multiple methods are used to conduct assessment and evaluation, including quantitative metrics (e.g., number of seminars and participants, topics of seminars/trainings), interviews, and a longitudinal tracking survey to measure the effectiveness of program. In addition, the education team and faculty analyze program design and logistics.

Sustainability: University, department, or faculty members can sustain this program without much funding from NSF. Seeking funding or collaborating with industry members would be another way to sustain the program. Obtaining buy-in from faculty and administrators for student participating in IMPACT is key to its sooth operation.

Tips:

- The effectiveness of this program requires several individuals' support including the Center director, engineering faculty, and student leadership council.
- Collaborating with the Center's industry director or industry liaison is important. In addition, personal networks or informal communication with industry members, faculty, and graduate students are ways to get people to participate in or implement the program.
- Tracking students' progress is challenging. Systematic data management and an effective evaluation program are the keys to success.

4.5.1.2 Center: Nanosystems ERC for Advanced Self-powered Systems of Integrated Sensors and Technologies (ASSIST)

Lead Institution: North Carolina State University
Center Director: Dr. Veena Misra, Department of Electrical and Computer Engineering
Name of Program: Translational Engineering Skills Program (TESP)

Program Synopsis: TESP focuses on teaching specific skills and attributes that graduate students need to become creative, adaptive, and innovative engineers with the ability to translate fundamental research into products and systems. These translational and professional skills enhance their ability to use their knowledge of medical devices and systems in the real world. They are clustered into "skill blocks" that include: systems thinking, entrepreneurship, industry/manufacturing, mentoring and leadership, communication, diversity awareness, and engineering ethics. Each of these skills is taught through a series of activities that are developed by the education directors with significant contribution from our technical Principal Investigators (PIs), industry liaison officer, medical director, and assessment coordinator. Some examples of activities are: a) invention disclosure workshop, patent mining session, and market research projects to improve entrepreneurship skills; b) mock journal reviews to help with students' written communication skills; c) ASSIST mind mapping activity to improve students systems thinking and understanding of the center's vision; and d) internships and industry visits that increase understanding of industry and manufacturing practices. The program requires successful completion of ten activities from a variety of skill blocks. All ASSIST graduate students are required to complete this program prior to graduation.

Contact person/website: Dr. Mehmet Ozturk (mco@ncsu.edu) and Dr. Elena Veety, http://assist.ncsu.edu/

Dates of Operation/Timeframe: This is a year-round program. Students participate in activities of varied length throughout the year. Most activities require a half-day time commitment.

Background: The program was initiated as a portfolio program designed to teach graduate students skills and attributes that are not taught in the classroom. Based on lessons learned from our first year, we re-focused the program and renamed it. We zeroed in on the aspects that are unique to our center (translation and a medical focus), simplified the program requirements, and concentrated on creating meaningful activities that teach specific skills with clear learning outcomes.

Methodology: The program and its activities were designed by the education directors in collaboration with our technical, industry liaison, medical, and assessment personnel, as well as other experts in the field. The education directors at all partnering institutions are responsible for assuring that activities are scheduled regularly, administering activities and assessments, and meeting with students twice per semester to monitor their participation in the program.

In the beginning, some faculty members were concerned about the time the activities would require and we had to spend quite a bit of energy and time discussing and optimizing. Eventually we adjusted the expected time commitment. In the end, what mattered most were four things:

1) Creating activities that add to the students' experience. For instance, patent mining, market research, creativity workshop, etc., were new to the students and they welcomed the information they received from them. The assessment surveys we give them after the events allow them to critique the activities and we try to improve them. If the students see the TESP activities as a waste of their time, it is hard to have their enthusiastic support.

2) Support of the center leadership. If the leadership puts their seal of approval on the program, the faculty follow. The leadership team must openly demonstrate their ownership of the TESP program.

3) The role of the education leader. At ASSIST, Dr. Mehmet Ozturk is the Education Director but also a Center PI. He is able to be more persuasive with the other PIs because his own students are participating in the activities. He has an assistant, Dr. Elena Veety, who assists full-time with the implementation of the TESP program. She too has an engineering PhD and connects well with the students. We are also getting help from our Industry Liaison Officer, who is running some of the TESP workshops himself. In the end, this is a team effort. However, the people responsible for the implementation are members of the center leadership and are in weekly meetings with the technical leaders, providing updates to the Center leadership just as the thrust leaders do.

4) Student Leadership Council. Their support of the program is vital to its acceptance.

Impact/benefits: The program provides our graduate students with a set of skills that is crucial to their development as creative, adaptive, and innovative engineers and scientists, both in industry and academia. The set of translational skills that TESP teaches gives students the skills to take fundamental research and translate it to marketable products and systems. These are skills and experiences that students may not ordinarily be exposed to in their normal classroom or lab environment.

Evaluation/Assessment: We are working with our assessment coordinator to create appropriate assessment tools for each activity in the program. Any activity we add to the program must be designed with appropriate goals and explicit learning outcomes to facilitate this process.

Sustainability: The program itself does not need funding to continue, other than support for an education leader at each campus. However, the program relies on faculty involvement in creating and administering activities. Therefore we believe that as long as there is continued research funding supporting faculty and graduate students, this program can continue.

Tips: It is crucial to have the buy-in of both faculty and students in any program like this. When creating activities, both students and faculty must clearly see the value of the activity, otherwise participation may be low.

4.5.1.3 ***Center:*** Future Renewable Electric Energy Delivery and Management Systems Center (FREEDM)
Lead Institution: North Carolina State University
Center Director: Dr. Alex Huang, Department of Electrical and Computer Engineering
Name of Program: FREEDM Graduate Student Portfolio (FGSP)

Program Synopsis: The graduate student portfolio program is the Center's effort to guide graduate students toward acquiring the knowledge, skills, and experiences needed for success in an innovation and technology-driven, global society. It meets the Center's education hypothesis for developing a diverse, adaptive, creative and innovative engineer. Components of the program include identifying accomplishments and training in areas of analytical, business management, communication, leadership and mentoring skills while cultivating global connections in both university research and education. The program also strengthens the understanding of innovation, professionalism, and ethical standards in engineering.

Contact person/website: Dr. Penny Jeffrey, Director of Education (pmshumak@ncsu.edu) 919-513-3435, www.freedm.ncsu.edu

Dates of Operation/Timeframe: This program began in the Center's first year. It is a year-round program for any FREEDM graduate student. All incoming MS thesis and PhD students who are financially supported by FREEDM core funding are committed to participating. Participation is optional for MS thesis and PhD students who are not financially supported by FREEDM core funding or began their program prior to Fall 2011. The portfolio program has been designed to be completed within 3 academic semesters.

Background: Typical graduate students develop core expertise in a very specific field but gain little experience in the broader topic area. As a result, those engineers face a more difficult challenge in integrating their knowledge into working in a real world industry setting. FGSP graduates develop a greater sense of the environment that their research will be incorporated into and develop the needed knowledge, skills, and experiences in the areas of renewable energy, energy storage, and power semiconductor devices. The Center includes five domestic and two international partnering universities and over 50 industry members. These connections enable graduate students to engage with energy and power systems engineers both domestically and internationally and give them a network that enhances future opportunities in the workforce and academia. In addition, upon graduation, a certificate of completion is awarded to each student.

Methodology: Key components developed by the National Academy of Engineering in its *Engineer of 2020* report were modeled for the program and requirements for each component were identified. The program was approved as a separate course at North Carolina State University (NC State) that grants one to three credit hours for completion of the components.
www.freedm.ncsu.edu/files/portfolio_program.pdf

Impact/benefits: Graduated students have reported the benefit of the portfolio in preparing them for professional development in the workplace, connecting with industry prior to employment, and helping them understand what innovation and entrepreneurship entail.

Evaluation/Assessment: The program is evaluated using post-program exit surveys along with direct input from currently enrolled FREEDM graduate students.

Sustainability: The program does not require a budget. Additionally, the program has been granted course status at NC State and our goal is to expand this offering in our partnering universities as well.

Tips: The commitment to participating in the graduate student portfolio should not be taken lightly because it requires accomplishing several activities. It can become a large time commitment for the student if not appropriately planned. It is imperative to “sell” the idea and importance of the portfolio program to Center faculty so they can help to implement and guide their graduate students through their selection of activities, especially if they have a large graduate student population within the Center. The portfolio should be readily accessible and easily updated (i.e. through website internal portal). Since the portfolio is heavily weighted in developing essential 21st Century skills relative to engineers, it is important that support is received from University program administrators, ERC faculty, and staff. The components of the portfolio program directly align with activities most ERC students are already participating in (seminars, webinars, education outreach events, etc.). Due to this close alignment and support from administrators, it is possible to create the portfolio program into a one to three credit special topics course that can become an option for the student's plan of work.

4.5.1.4 ***Center:*** ERC for Ultra-wide-area Resilient Electrical Energy Transmission Networks (CURENT)
Lead Institution: The University of Tennessee
Center Director: Dr. Kevin Tomsovic, Department of Electrical Engineering and Computer Science
Name of Program: CURENT’s Innovation, Technology, & Entrepreneurship (CITE) Workshop

Program Synopsis: CURENT designs a series of workshops regarding innovation, technology and entrepreneurship for graduate students. These activities provide students with industrial practice knowledge that assist with their career development. All the seminars are shared among all partner universities through WebEx on a regular basis. One of the purposes for organizing the workshops is to train our students to gain a more interdisciplinary and global view through innovation and entrepreneurship training.

Note: The CITE workshops are among the professional development activities that CURENT students participating in the IMPACT program attend. See example 4.5.1 in this appendix.

Contact person/website: Chien-fei Chen, Co-director of Education and Diversity (cchen26@utk.edu)

Dates of Operation/Timeframe: Five to six workshops are held per semester over several consecutive weeks.

Background: To succeed in the ERC and be prepared as a future engineer and researcher in the field, an ERC student should have certain desired characteristics. CURENT designs a series of workshop to train our students to be professional and well adaptive in a global environment.

Methodology: CURENT’s Student Leadership Council (SLC) industry committee, education directors, and director of industry and innovation design the workshop together. Researchers from research institutions and universities as well as experts from industry present regularly at this workshop. For example, presentations on professional training, intellectual property law, and the process of commercialization have been given as part of the workshop program. Most of the seminars are shared across all campuses through WebEx.

Impact/benefits: This program provides graduate students with opportunities to gain technical, professional, and commercial training beyond their own research. Students are better prepared and knowledgeable after attending the CITE workshops.

Evaluation/Assessment: We track the number of students attending the seminars each time. A post-workshop survey is used to evaluate students' interest and learning. CURENT's directors of industry and innovation and education and diversity evaluate the overall structure and content of the workshop. SLC members also provide feedback.

Sustainability: Collaboration with the host department, other departments, college of engineering, university and industry partners is a good way to sustain the program.

Tips:

- Early invitations and planning is crucial.
- Inviting industry partners to present is effective.
- Sending two to three reminders to the students can increase the attendance.
- Designing an attractive email-announcement also helps.
- Providing pizza to the students after the workshop is an effective incentive.

4.5.1.5 ***Center:*** Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC), a graduated ERC (1998–2008)
Lead Institution: Georgia Institute of Technology
Center Director: Dr. Robert M. Nerem, Department of Biomedical Engineering
Name of Program: Technology Innovation: Generating Economic Results (TI:GER)

Type of Program: Program teaching students how to commercialize technology

Program Synopsis: The GTEC program known as TI:GER (Technology Innovation: Generating Economic Results), created in 2002, brought together PhD, MBA, and law students in the classroom and research lab to learn about the challenges of commercializing innovative technologies. The program was a unique collaboration between Georgia Institute of Technology and Emory University Law School, and as such it was nationally recognized for its success at developing entrepreneurs. As an example, under TI:GER, then engineering graduate student Jeff Gross and three other students (two of them in Business and one in Law) formed EvIslet. The concept was developed as part of research aimed at producing cell-based therapies for insulin-dependent diabetes. Support from the ERC grant through GTEC was critical at establishing this research program, which continues to date with support from other funding sources.

Contact person/website: Jennifer Jacobs, Program Manager; Phone: 404.385.3275

Dates of Operation/Timeframe: 2002-present.

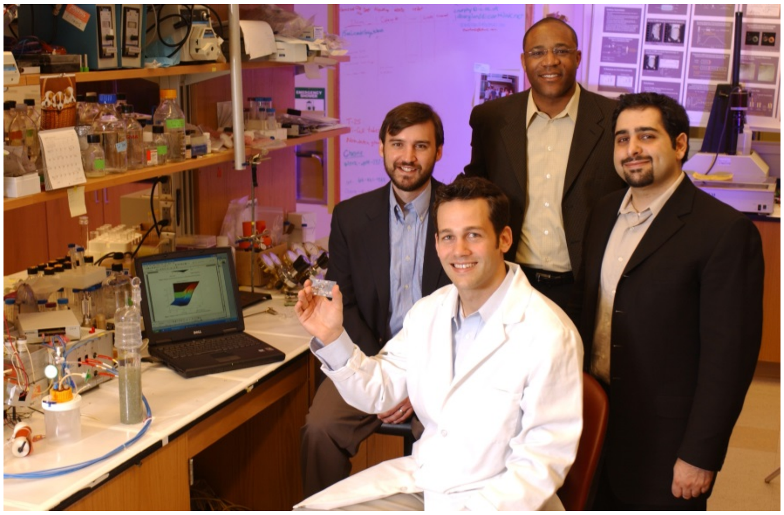
Methodology: A team of four students, one pursuing a PhD at Georgia Tech, two pursuing Business degrees and one pursuing a law degree, team up to devise a strategy to commercialize an application or product based on the graduate student's PhD research. Students typically work 10-20 hours per week on their project.

Impact/benefits: PhD students in this program develop an awareness of innovation processes—particularly as they relate to the business and legal activities necessary to commercialize new technology— and build skills that will help them succeed, whether they remain in a university environment as a researcher or move into an industry setting. Some of these endeavors are actually successful at commercializing products based on research conducted at Georgia Tech.

Evaluation/Assessment: Development of intellectual property; technology commercialization; development of successful small company startups.

Sustainability: The TI:GER program has been sustainable by itself through separate NSF and other funding.

Tip: This type of program is an outstanding educational tool for the students involved. However, students should be aware that the success rate at developing a commercial startup is low, and should not take the inability to launch a startup as a failure.



GTEC PhD student Jeff Gross (front) was a member of the award-winning TI:GER team that developed the medical device R&D company, EvIslet™.

4.5.2 Curriculum Development/New Degree Programs

4.5.2.1 ***Center:*** ERC for Collaborative Adaptive Sensing of the Atmosphere (CASA), a graduated ERC (2003–2013)
Lead Institution: University of Massachusetts-Amherst
Center Director: Prof. David McLaughlin, Electrical and Computer Engineering
Name of Program: Collaborative PhD programs between the University of Puerto Rico-Mayagüez (UPRM) and the University of Massachusetts (UMass) and UPRM and Colorado State University (CSU)

Program Synopsis: Through a Memorandum of Understanding (MOU) between campuses, the Collaborative PhD program allows students from UPRM to go to UMass or CSU to take graduate courses and start their research, and then return to Puerto Rico to continuing their research work at UPRM. They finish their doctoral degrees in Electrical and Computer Engineering. The collaborative PhD program is one of several measures UPRM is taking to build and expand their research and teaching capacity.

Contact person/website: Leyda Leon (leyda.leon@upr.edu), Sandra Cruz-Pol (cruzpol@ece.uprm.edu), Paula Rees (rees@ecs.umass.edu)

Dates of Operation/Timeframe: The MOUs were signed in the Center's second year, 2004.

Background: UPRM lacked a PhD program in Electrical Engineering at the time, and our goal was to enable students from UPRM to pursue a PhD as well as to serve as role models for undergraduate and MS students at UPRM, thereby increasing the pipeline of Hispanic/Latino(a) students pursuing PhDs.

Methodology: The MOU was developed through negotiations involving the upper administration of the participating universities. The initial MOUs were championed by Dave McLaughlin (CASA Director), Kathy Rubin (Education and Outreach Director at the time), and UPRM faculty member and CASA research thrust leader Sandra Cruz Pol and Jose Colom-Ustariz (CASA Co-PI at UPRM). Former CASA student Leyda Leon, now a faculty member in Electrical and Computer Engineering at UPRM, was enrolled in the joint PhD program with CSU. She has since led the effort to renew the MOUs at both institutions.

Impact/benefits: The MOUs provide a mechanism for UPRM to expand their research and teaching capacity.

Evaluation/Assessment: We mainly use the annual Student Leadership Council (SLC) surveys, discussions with faculty and students, and the Student Test Bed representatives on the CASA Executive Committee for evaluation.

Sustainability: The MOUs were renewed recently. However, UPRM now has a PhD program in Electrical Engineering. We anticipate collaborations and exchanges of students between UMass and CSU will continue, but that more students will use the newly established degree program at UPRM

Tips: We haven't had as many students take advantage of the MOUs as we would like—they get to the other campuses and get snapped up by their programs.

4.5.2.2 ***Center:*** ERC for Collaborative Adaptive Sensing of the Atmosphere (CASA), a graduated ERC (2003–2013)
Lead Institution: University of Massachusetts-Amherst
Center Director: Prof. David McLaughlin, Electrical and Computer Engineering
Name of Program: Puerto Rico Student Test Bed (STB)

Program Synopsis: This project, led by an interdisciplinary group of students from CASA's partner campuses, developed the foundation for a test bed in Puerto Rico using a solar-powered radar and wireless communication infrastructure. The CASA Student-Led Test Bed (STB) introduces students to system level engineering and allows them to explore high-density Distributed Collaborative Adaptive Sensing (DCAS) networks while advancing CASA's strategic planning and goals in developing low infrastructure radar networks. As one of CASA's focus area research programs in its strategic plan since the Center's second year, the STB was designed to address the application of radar precipitation estimation and flood forecasting in complex terrain. Specifically, the project provided a tool to test the DCAS concept in a dense deployment scale, in a tropical environment, and on variable terrain. The STB also honed students' leadership, decision-making, communication, and business skills. The target audiences were both the students and the research community.

Contact person/website: Jorge Trabal (jorgetrabal@gmail.com), Sandra Cruz-Pol (cruzpol@ece.uprm.edu), Paula Rees (rees@ecs.umass.edu)

Dates of Operation/Timeframe: The STB started in January 2004 with a multi-disciplinary, multi-level, multi-campus team composed of 15 students from BS through PhD levels. The STB operates year-round.

Background: The concept for a student-led and -run test bed was initiated through conversations between PhD student Brian Donovan and Director David McLaughlin. Brian held that the best way to fully hone students' leadership, decision-making, communication, and business skills was to put them in control of the budget and research agenda for a test bed. The STB addressed the challenges of designing low-cost radars that are capable of running high quality Quantitative Precipitation Estimation (QPE) applications, as well as deploying large numbers of radars in regions where adequate infrastructure (e.g., power, data backhaul) is either not available or too costly to use in a dense network. The standard approach to rainfall estimation using radar involves using observations taken aloft (e.g., 2 km or more above the ground) and extrapolating them toward the ground in order to estimate rainfall amounts close to the ground. Current effort focuses on quantitative precipitation estimation (QPE) through the use of dual-polarization waveforms and related retrieval algorithms. The innovative STB takes a different approach, recognizing that some degree of rainfall monitoring close to the ground is better than no monitoring (i.e., the present situation). Based this approach and the current limitations described, participants in CASA's STB team designed a radar network based on very low-cost (e.g., less than $30,000 [USD] in parts), single-polarization radars that are not dependent on any existing power line, computation, or data communication infrastructure. The network layout and radar sites were systematically studied by incorporating social and physical vulnerability and climatological analysis by a cross-disciplinary team of social science and engineering students. CASA students explored the emerging technologies in the process of STB system architecture design and development. The major goals of the CASA STB include:

- The analysis, development and deployment of an OTG radar network in western Puerto Rico;
- The construction of short range (15-20 km) renewable energy powered radar nodes; and
- The development of theory and software for the operation of high-density, resource-aware radar systems capable of providing qualitative precipitation estimates.

Methodology: The STB project was started in January 2004 with a multi-disciplinary, multi-level, multi-campus team composed of 15 students from BS level through PhD. CASA's Executive Committee made the decision to redefine the budget and goals of CASA to facilitate the STB. Since 2005, the Project Leader has been PhD student (recently graduated) Jorge Trabal. Prior to that, PhD student Brian Donovan was the primary STB leader. In this role, Jorge and Brian also sat on CASA's Executive Committee and participated in all aspects of the management of the CASA ERC. The faculty advisor for the project is currently Dr. Jose Colom of UPRM.

Impact/benefits: This project has contributed significantly to the recruitment of a diverse group of students, aided by a diversity supplement received by CASA in the second year as well as Louis Stokes Alliances for Minority Participation (LSAMP) and Alliances for Graduate Education and the Professoriate (AGEP) funding. Since its inception, 15 to 26 students have worked on the STB each year. Major accomplishments of the STB include:

- Initiated the concept of a student-led test bed as a key educational element of an ERC.
- Envisioned and developed the concept of a very low-cost, single-polarization, "Off-the-Grid" (OTG) radar system to monitor rainfall and provide useful data.
- Developed a vulnerability to disaster model tool to select the radar locations.
- Developed a site survey tool to account for physical characteristics, including site accessibility, topography, signal blockage, and beam height from ground level to assist in site selection.

- Conducted a proof-of-concept demonstration of the OTG design during the 2010 Central American and Caribbean Games in Mayagüez, in conjunction with the San Juan National Weather Service (NWS) Weather Forecast Office (WFO).
- Installed an OTG radar network composed of three nodes with overlapping coverage over the town of Mayagüez, Puerto Rico. Deployment of fourth radar is underway.
- Developed and tested a hydrologic prediction model and Quantitative Precipitation Forecast (QPF) algorithms.
- Developed and tested a design to modify the OTG radars to include Doppler measurements.
- Implemented ground clutter algorithms to mitigate clutter effects in the radar data.
- Designed a resource-aware scheme to predict energy harvesting opportunities based on hourly weather forecasts, which are informed to OTG nodes through the closed-loop system.

Graduates of the Center have launched a startup company to manufacture and sell small radars and have won several entrepreneurship contests.

Evaluation/Assessment: We mainly use the annual Student Leadership Council (SLC) surveys, discussions with faculty and students, and the Student Test Bed representatives on the CASA Executive Committee for evaluation.

Sustainability: The students developed a sustainability plan that included identification of potential markets for the OTG radars. Jorge Trabal led efforts to explore opportunities with several Central American countries, the NWS, the World Weather Research Program, and others to secure post-CASA funding. These efforts are ongoing.

Student researchers in Mayaguez, Puerto Rico installing solar panels to power their OTG radar system.

4.5.2.3 ***Center:*** Biomimetic MicroElectronic Systems ERC (BMES ERC), a graduated ERC (2003–2013)
Lead Institution: University of Southern California
Center Director: Dr. Mark Humayun, Department of Ophthalmology and Biomedical Engineering
Name of Program: BMES ERC Graduate Degree Programs: MS-MDDE Masters and MS-BME, MD PhD program with the California Institute of Technology (Caltech); and the Health, Technology and Engineering at the University of Southern California (USC) (HTE@USC) program

Program Synopsis: The BMES ERC has developed over the last ten years a new comprehensive Master's degree program (MS-MDDE), a specialization (neuroengineering) track in the MS-BME program, and an elective track (neuroengineering) in the undergraduate Biomedical Engineering (BME) curriculum. The Center also partnered with two MD/PhD programs, one housed entirely at USC and one in conjunction with Caltech (a BMES partner institution), whereby a student obtains an MD from USC and a PhD from

Caltech. This program has become a solid foundation for new courses and programs, such as BME 556: "Topics in Health, Technology & Engineering", which provides an introduction to second year PhD engineering students on topics of unmet clinical needs and introduces first year medical students to technological advances in BME. Most recently, collaboration between former alumna of the BMES ERC, Dr. Deborah Won, who is currently an Assistant Professor of Electrical Engineering at California State University in Los Angeles (CSULA) and the BMES ERC faculty resulted in CSULA's EE 454: "Biomedical Signal Processing". BMES faculty serve as guest lecturers, offering an additional mechanism for recruiting interested and qualified underrepresented minority students to work on ERC- related projects as well as to enroll in one of the ERC-Related Master's programs. Within the last three years, USC developed a program for students interested in biomedical research and medicine, called the HTE@USC. This program is a partnership between the USC Viterbi School of Engineering (VSoE) and the USC Keck School of Medicine (KSoM). In this program, engineering PhD students learn unmet clinical needs by working with MD students and faculty as a team. Similarly, M.D. students learn engineering principles by teaming with VSoE students and faculty. In addition, VSoE students take medically relevant courses at KSoM and vice versa. These teams receive supervision from one or two VSoE or KSoM faculty.

Contact person/website: Gigi Ragusa (ragusa@usc.edu) or Diana Sabogal (dsabogal@usc.edu).

Dates of Operation/Timeframe: We started these programs in the Center's first through third years. They are all ongoing and fully developed.

Background: These comprehensive undergraduate and graduate programs support BMES ERC research foci and advance collaboration among engineering, biomedical research, and medicine to produce knowledgeable and effective people who will achieve the Center's goals over time. New courses are being added to increase engineering students' understanding of unmet clinical needs and introduce medical students to technological advances in BME. The creation of the HTE@USC program offers new opportunities for interaction between people involved in biomedical research and medicine. Activities associated with these programs facilitate professional development and growth, including networking with industry, providing internship and future employment opportunities, and seminars that bring together students and faculty from engineering, medicine, neuroscience and biokinesiology for lectures and discussion of research and clinical topics of common interest.

Methodology: In the first several years of BMES ERC, as we worked through the course creation process, programming provided us the opportunity to establish collaboration with our partner institutions. By Year 3, we successfully established a graduate course, "Neural Implant Engineering", which is being offered at both USC and UC-Santa Cruz. This was the first opportunity to utilize the existing Distance Education Network at USC, thus opening the door for further inter-institutional collaboration. At present, all ERC courses that are lecture-based have been video-archived, courtesy of the USC Distance Education Network (DEN), and the archived videos are available for access by students in ERC partner institutions through the BMES ERC website. Since the inception of the center, the BMES ERC has capitalized on the ongoing biomedical engineering seminar series which was enhanced to include more talks on ERC-related topics. By Year 6, the center developed and implemented the Engineering Neuroscience and Health weekly seminar series. The seminars are also video-archive and available for access by students and faculty from the ERC and its partner institutions. Additionally, the Keck School of Medicine at USC has introduced a seminar series inviting all students to attend lectures on the newest findings in engineering research and medicine. All seminars are available via live feed and are archived and made accessible for future viewing. Lastly, BME533: Seminar Series Mondays, where faculty, visiting lecturers and current students present their research to the BME community at USC. This has included several BMES ERC students presenting their thesis work. To support ERC graduate students, we have developed a series of annual major events aimed at providing our students at all levels the opportunity to network with local biomedical industry representatives. This has proven useful in helping some of these students find summer internships or permanent positions. Activities include: a) the Annual Corporate Dinner, organized by the Associated Students of Biomedical Engineering (ASBME); b) the Annual Grodins Graduate Research Symposium, featuring research presentations in oral and poster forms by BME PhD students, held in the academic spring semester each year; c) student presentations on testbeds and thrusts presented at the Annual Industry Advisory Board Meetings; and d) student participation in directed research meetings with Senior Partners.

We recruit for the programs via the universities, our website, our partner and affiliate universities, and those Minority-Serving Institutions with which we have relationships.

Impact/benefits: The focus of these programs is on diverse students (undergraduates and graduates). The students gain much experience in engaging in interdisciplinary research, complete a full degree(s), and increase their engineering creativity and propensity for innovation (per our metrics of impacts). The majority of the students taking our undergraduate courses have gone on to graduate school. Many of our MS graduates now work in industry. Some have pursued PhDs and gone on to work in academia and industry. Over the past 10 years, the MDDE program has enrolled over 200 students and as of 2013 had graduated just over half.

Evaluation/Assessment: We have an annual questionnaire that includes interdisciplinary impact scales and innovation and creativity scales (ECPII). We have also developed course specific concept inventories to measure knowledge in our undergraduate courses. We pair this quantitative data with an annual program focus group that we analyze thematically. We also annually track all students at all levels upon completion of the program into graduate schools and careers.

Sustainability: This program has been institutionalized at USC and is offered via DEN to our partner universities.

Tips: Start designing courses and degree programs early and work at sustainability early on (at least by the third year).

4.5.2.4 ***Center:*** ERC for Structured Organic Particulate Systems (C-SOPS)
Lead Institution: Rutgers University
Center Director: Prof. Fernando Muzzio, Department of Chemical and Biochemical Engineering
Name of Program: Master of Engineering in Pharmaceutical Engineering (within Chemical and Biochemical Engineering)

Program Synopsis: The Master of Engineering in Pharmaceutical Engineering program provides training through course work and research/internship experiences in pharmaceutical engineering leading to an advanced professional degree. The degree is not intended as a stepping-stone to a PhD—the MS program is designed for that. The target population is primarily part-time students from industry or full-time international students with backgrounds in engineering and the life sciences.

Contact person/website: The program is managed through the chemical and biochemical engineering graduate program directed by Professor Charlie Roth (cmroth@rci.rutgers.edu). The website for additional information is http://sol.rutgers.edu/.

Dates of Operation/Timeframe: The program was started in 2008 and runs on a regular academic schedule.

Background: The program evolved from the regular MS programs in chemical and biochemical engineering, where a particular set of courses were designed and introduced to emphasize modern pharmaceutical engineering practice.

Methodology: The program was established using the regular mechanisms for introducing new degree programs and courses at Rutgers University. Input and funding from industry helped drive the creation of the program in its earliest stages. We are now developing an online format for the courses offerings leading to a completely online degree program by 2015.

Impact/benefits: The program has attracted a number of industrial professionals and international students. We currently have around 15 students in the program.

Evaluation/Assessment: Programs and courses are assessed according to the usual practices of the graduate school at Rutgers. Course evaluations are done every semester, student employment is tracked, and Middle States Accreditation process takes place every 6 years.

Sustainability: This program runs as a regular graduate program. Going forward, we are also looking to put the entire program online to allow students the opportunity to complete the degree without a formal presence on campus.

Tips: New degree programs take several years to introduce at Rutgers and the process needs constant stewardship. The courses add to the teaching loads of the faculty in the ERC, so coordination with the department chair is required. The courses are also excellent mechanisms for bringing in industry faculty to the teaching program and we have several courses with extensive industry input, as well as one course taught entirely by industry adjunct faculty.

4.5.2.5 ***Center:*** Smart Lighting ERC (Smart Lighting ERC)

Lead Institution: Rensselaer Polytechnic Institute
Center Director: Prof. Robert F. Karlicek, Jr., Dept. Electrical, Computer, and Systems Engineering
Name of Program: *Illumineer Curriculum* with Mentoring Hierarchy

Program Synopsis: To guide the development of university and precollege programs, a matrix summarizing the desired background for all graduates (including graduate students) pursuing careers in Smart Lighting was developed with the assistance of all center constituencies, with the largest impact coming from industry partners. This matrix, called the *Illumineer Curriculum*, is used to guide the development of all education and outreach activities for the center. To facilitate the delivery of the education and outreach programs while building the 21st Century Skillset in our graduates, we are also guided by our hierarchical student-to-student mentoring structure. All students, whether doing research in the lab or participating in a K-12 program, are mentored by and mentor other students. This adds to their educational experience and helps prepare them to be active ambassadors for Smart Lighting and Science, Technology, Engineering, and Math (STEM).

Contact person/website: Ken Connor (connor@rpi.edu), Elizabeth Herkenham (herkee2@rpi.edu)

Dates of Operation/Timeframe: This program is ongoing.

Background: Smart Lighting is broadly multidisciplinary and involves background not generally found in traditional STEM disciplines. Examples include lighting and other types of building design, human physiology and health, economics and business, etc. Our industry partners were finding that students graduating from excellent universities were not conversant in the basics of lighting and those who knew something of lighting design (e.g., from schools of architecture) knew nothing of the science and engineering of solid state lighting. We defined a new discipline we call *Illumineering* to advance understanding of Smart Lighting by differentiating it from traditional Illumination engineering. The matrix we developed was designed for the development of modules for education and outreach, but its usefulness is not tied to any particular delivery approach.

Methodology: We began developing the *Illumineer Curriculum* by holding informal discussions with industry partners and then sharing the ideas identified with all of our constituencies. The first versions of the curriculum matrix were produced collaboratively by ERC Director Bob Karlicek and Education Director Ken Connor. Feedback on the matrix is now being obtained annually at our industry meeting, our faculty-staff-student planning retreat, and continuously from everyone using it to guide the development of education and outreach content. One of the key steps in any of our programs is to identify the aspects of the matrix that are included. Mentor training and mentoring activities are also formally included in all programs, with the present exception of those at the middle and elementary school levels. However, even the K-8 students are given information and tools they can share with their friends and family. They are not told explicitly of their mentoring opportunities but rather are empowered to show others what they have learned.

Impact/benefits: One of the most difficult tasks for those working to develop new disciplines and industries is helping people understand what we are doing. The *Illumineer Curriculum* has been very helpful in telling our story. The student-to-student mentoring hierarchy helps students understand how to be better engineer and scientist citizens in 21st Century society.

Evaluation/Assessment: Each program has a specific assessment process that uses surveys and general commentary from participants. We also utilize our student portfolios to track student development.

Sustainability: The methodology facilitated by the *Illumineer Curriculum* and our mentoring structure is not tied to any particular funding and thus will continue as long as it is useful.

Tips: These ideas must be used in every activity and must become part of the everyday vocabulary for everything in the Center. They must be seen as essential, not an add-on, to achieve the best results.

4.5.3 Other Student/Industry Interactions

4.5.3.1 ***Center:*** ERC for Structured Organic Particulate Systems (C-SOPS)
Lead Institution: Rutgers University
Center Director: Prof. Fernando Muzzio, Department of Chemical and Biochemical Engineering
Name of Program: Industry Mentor Program

Program Synopsis: The C-SOPs Industry Mentor Program provides graduate and post-doctoral students with ongoing industry contacts aligned with their research area. The program currently involves 22 projects distributed throughout our research thrusts and three testbeds, providing a total of 129 industrial mentors. Graduate students, along with post-docs, hold regular (monthly) conference calls to update participants and mentors on each research project. A non-faculty project coordinator is responsible for the logistics and reporting of these meetings. The program also has face-to-face meetings and a happy hour in conjunction with the annual Industrial Advisory Board (IAB) meetings.

Contact person/website: Doug Hausner, Associate Director for Industrial Relations and Business Development (doug.hausner@rutgers.edu), Henrik Pedersen, Education Director (hpederse@rutgers.edu)

Dates of Operation/Timeframe: The program was started in 2009 and runs year-round. Monthly commitments of one hour and follow-up at the IAB meetings are expected.

Background: The program was developed to better connect graduate students and post-docs with industrial practitioners. The industry group also wanted a mechanism to be in better contact with the individual research projects that were most closely aligned with their areas of interest.

Methodology: The program was established at an IAB meeting where the company representatives, by lottery, each reserved mentor slots for different research projects. The top tier members were assigned progressively more slots. A total of 129 members now participate in 25 projects/testbeds—about 5 mentors per project. The center had over 30 industrial members as of 2013.

Impact/benefits: The program has helped graduate students network with industry professionals who advise on research directions and may help secure additional equipment and supplies. As a result, the students are better informed about research methods in the pharmaceutical industry.

Evaluation/Assessment: We do not have formal assessment tools in place at this point. The program activities are logged in terms of the number of meetings taking place and the participants involved.

Sustainability: This program requires little cost to operate and is infused throughout the research activities of the Center. A project coordinator is assigned the task of maintaining the meeting schedules and action items.

Tips: The program was implemented very formally with slots allocated to different member companies, according to their level of support, with companies choosing which projects to align with. As companies changed emphasis, the movement of mentors and replacement of mentors was ab with much less formality.

4.5.3.2 ***Center:*** ERC for Quantum Energy and Sustainable Solar Technologies (QESST)
Lead Institution: Arizona State University
Center Director: Dr. Christiana Honsberg, Department of Electrical Engineering
Name of Program: International Characterization and Modeling Workshop

Program Synopsis: QESST convened the International Characterization and Modeling of Solar Cells (CMSC) Workshop at Arizona State University (ASU) in May 2012 to bring together people from academia and industry who are involved in solar cell processing, characterization, and modeling. Participants included forty-nine people from ten countries, ranging from first year graduate students to professors and other experts in the field. In all, fourteen universities and four companies were represented at the workshop. The technical program consisted of five modules: antireflection properties, doping profiles, lifetime, cell performance, and modeling. Lectures were given by leading global experts, who also assisted attendees during hands-on demonstrations. Lectures and demonstrations were followed by roundtable discussions where participants could share their experiences and expertise. Students also spent time touring the SIMS lab, Solar Power Lab, and viewing the new Sinton Tracker that was recently installed behind the MacroTechnology Works Building at ASU Research Park.

Contact person/website: Dr. Jenefer Husman, (jenefer.husman@asu.edu)

Background: Photovoltaics (PV) is cost competitive in a number of markets, but advances in cell technology are necessary to spread PV systems worldwide and reach terawatt scale. A leap ahead in PV technologies requires strategies for facilitating the rapid implementation of advanced device structures such as selective emitters and rear point contacts. Furthermore, integrating new processing techniques and materials, such as laser doping and aluminum oxide surface passivation, into mainstream production requires innovations in modeling and characterization. However, in many cases, the training and knowledge necessary for such improvements is dispersed among different groups and research areas. Interaction among these groups was needed to foster greater understanding of the tradeoffs involved in the operation and production of new solar cells and guide the design of future devices. All this led to holding a workshop on characterization and modeling of solar cells.

Methodology: The workshop aimed to achieve two main goals: 1) to develop best practices for measuring material and device parameters necessary for device simulations and 2) to provide stakeholders with the opportunity to learn from leading world experts in the simulation of solar cells as they apply to the measured parameters in a device simulator. Thus, the workshop went beyond the typical conference by providing a hands-on experience with the latest tools and an opportunity to work with tool experts on characterization and modeling issues.

Impact/benefits: The CMSC Workshop brought students and experts from around the world together to learn from each other and advance the art and science of solar cell characterization and modeling.

Evaluation/Assessment: Not available

Sustainability: Not available

Tips: Not available