ERC BEST PRACTICES MANUAL

CHAPTER 4

EDUCATION PROGRAMS

FINAL REPORT

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CHAPTER 4: EDUCATION PROGRAMS

4.1 INTRODUCTION

From the beginning of the Engineering Research centers (ERC) program, ERCs have been focused on creating a culture that integrates research, education, and industrial practice to produce engineering graduates who are more effective in industrial practice, and to infuse new knowledge at the interface of disciplines into the engineering curricula. Third-generation (Gen-3) ERCs—that is, all ERCs established in FY 2008 and after—have an additional mandate, to increase the creativity of engineering graduates and expose them to innovation, entrepreneurship, and research practices in other countries and to produce graduates who will be creative U.S. innovators in a globally competitive economy." Each center is built on three pillars; research, education, and innovation through technology translation/transfer. All three of these components must be fully integrated in a successful center.

ERCs are motivated by an engineered systems vision and structured by a strategic plan that defines a research program to address barriers in the way of realizing the vision. The strategic research plan structures an integrated program of fundamental and applied research that feeds into proof-of-concept enabling and systems technology testbeds.

An ERC's education program is comprised of a university program and a precollege program. The university education mission of an ERC is to prepare students for effective practice in industry and to enhance their capacity for creative and innovative leadership throughout their careers. The precollege education mission rests on long-term partnerships with K-12 institutions to expose science, technology, engineering, and math (STEM) teachers to engineering and deliver engineering concepts and experiences to their classrooms to stimulate student interest in engineering careers. The interface of the research and educational culture of the ERC enriches the participating universities through the transfer of ERC-generated knowledge into engineering curricula.

A team of faculty, students of all levels, and staff who share the ERC's vision develop the ERC's culture. They come from different disciplines and perspectives of research, education, and technological innovation, and they include rich perspectives offered by diversity in gender, race, ethnicity, and other demographics.

According to the ERC Program culture and each center's specific education strategic plan, each center is expected to attract new students to engineering and to produce engineering graduates who will be highly effective in industrial practice and be the creative innovators of the global economy of the future. There are four main target audiences: graduate students, undergraduate students (including community college students and veterans), precollege students, and the general public.

Each ERC's engineering education program is expected to include:

- University undergraduate and graduate education programs strategically designed to produce graduates with the skill sets needed to be creative, adaptive, and innovative, well prepared for effective leadership in industry through knowledge about industrial practice, technology advancement, entrepreneurship, and innovation. "Strategically designed" means that there should be an education strategic plan for the center, and it is especially important for Gen-3 ERCs since there is an expectation that the center develops and implements purposefully the education plan that will produce the type of students that the center is aiming to graduate.
- Advances in curricular materials derived from the ERC's interdisciplinary and systems-focused research;
- Long-term precollege partnerships aimed at exposing K-12 STEM teachers to engineering and to delivering engineering concepts and experiences to their classrooms (either directly or via the teachers) in order to stimulate student interest in engineering careers and increase enrollment in college-level engineering degree programs.

- General Outreach to involve precollege students in the ERC activities.

- Strategies to recruit and retain a diverse body of students who are involved in the education activities carried out by the ERC.

NSF provides guidance with respect to outcomes expected from a successful center education program. These outcomes are clearly articulated in the applicable solicitation and are repeated below:

- The goals of the university education strategic plan will impart skill sets to undergraduate and graduate students so that they will be:
    - Effective in advancing technological innovation in industry
    - Adaptive and creative innovators
    - Effective in innovation in a globally connected, innovation-driven world.
- The strategic plan clearly specifies:
    - Desired characteristics and skill sets of graduate and undergraduate student researchers
    - Approaches to impart these skill sets to students via the education program
    - Measures to assess progress and impacts through longitudinal data
    - Mechanisms to incorporate assessment feedback to improve program content and delivery
    - Actionable plans to mentor students, post-doctoral researchers, and junior faculty.
- The education program will be integrated with the center's research with foreign collaborators so that students have the opportunity to carry out research relevant to the ERC's goals at foreign laboratories for a time sufficiently long to provide knowledge of foreign research practices, equipment, and other competencies.
- Effective plans are in place to integrate the ERC's cross-disciplinary and systems research into courseware and curricula and to disseminate outcomes and curriculum/outreach products to all ERC partners and for workforce training.
- The precollege education program will develop an effective long-term partnership with up to five precollege institutions (school districts or individual schools) nearby the lead and/or partner universities, to incorporate middle and high school teachers and students in ERC-related activities.
- If community college or technical college faculty and students are involved, the experience will add value to the educational capacity of the faculty and students as well as to the faculty and students of the ERC.
- Effective assessment tools are utilized to incorporate feedback from assessments/evaluations into the education programs to improve program content and deliver on program goals.

The development of an ERC education program requires strategic planning, a team of experts, and participation from all stakeholder groups. These teams can benefit from the collective experience of Education Program Directors at existing centers. This chapter has been assembled by these experts in ERCs across the country and is intended as guidance to those considering developing an ERC or ERC-like education program, as well as for new ERC education personnel who join an ongoing center.

It is important that new centers not interpret the contents of this chapter as a list of requirements for ERCs. Instead, it is a resource describing the collective wisdom of multiple ERC University Education and Precollege Education Directors. It can be used to identify programs and techniques

that have worked in the past, being aware that each situation is different. *Specific review criteria for each component of an ERC by age of the ERC are available at the ERC documents website*.[1]

Nonetheless, in addition to the prescribed goals above, the ERC must include a Research Experiences for Undergraduates (REU) Program, Research Experiences for Teachers (RET) Program, and Young Scholars (YS) Program (for Gen-3 ERCs only). However, NSF encourages centers to apply the same creativity and innovation that drive their research programs in determining how they develop and implement these education programs at their particular ERC. Additionally, latitude is given with respect to specific details and programming for other education and general public outreach programs that involve precollege students in ERC activities.

This chapter is divided into six sections: Program Planning, Precollege Education, Undergraduate Education, Graduate Education, Assessment and Evaluation, and Program Sustainability. Each has two parts. The first is a summary of the topic and includes suggestions and recommendations. The second part, a corresponding appendix, is a collection of center-specific program descriptions that offer an example of how that particular center has implemented a given program. These examples describe how a given program works in a specific center; together they illustrate the breadth of programs offered by centers as well as how centers have implemented required programs and developed new ones. Each example includes contact information, and readers who would like to import a given program are encouraged to contact ERC program personnel directly to learn additional details.

Current and prospective ERC Education Program Directors are urged to start with the planning section and follow the steps regarding identifying desired outcomes, identifying local programs that can be leveraged, identifying local opportunities for new programs, including assessment and evaluation in the process, and being mindful of opportunities for sustainability.

Each ERC Education program must support the mission of the center and each component must be consistent with the mission. Additionally, ERCs have historically been leaders in promoting diversity in all of their programs and all centers are expected to continue this tradition of including those who have been underrepresented in the Nation’s science and engineering enterprise.

The following Exhibits provide data gathered by the NSF ERC Program from the ERCs in the portfolio. They give prospective and current ERC Education Directors information on the type of outcomes and investments made in Education by ERCs. The data was obtained from the NSF ERCWEB program database.

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[1] https://www.erc-reports.org/public/library

Exhibit A. Current ERCs in FY2014 and Technology Clusters of the ERCs

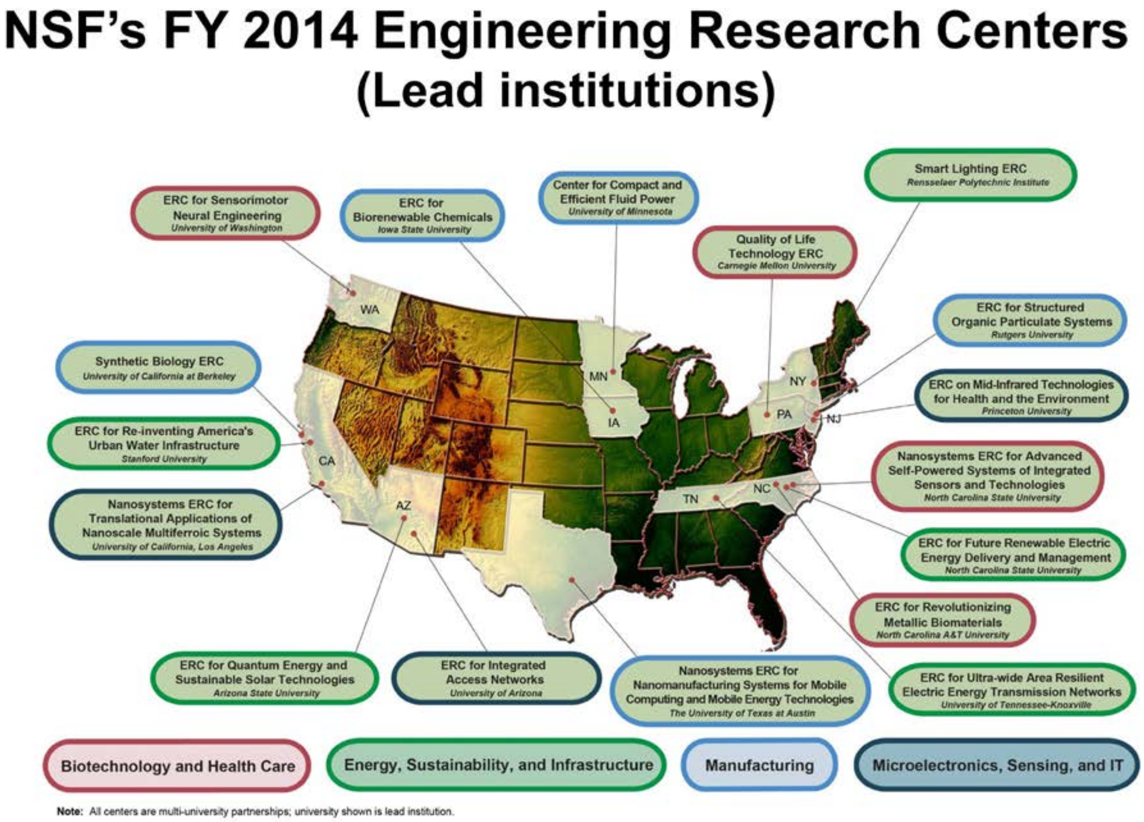


Exhibit B. ERC Influence on University Curriculum, Historical[2]

ERC Influence on Curriculum, FY 1985–2013

	FY 2013 (20 ERCs)		FY 2008–2012 Annualized		FY 1985–2013 (58 ERCs)
Degrees	***Total***	***Per Center***	***Total***	***Per Center***	***Total***
New Full-Degree Programs Based on ERC Research	2	< 1	3	< 1	42
New Degree Minors Based on ERC Research	2	< 1	3	< 1	30
New Certificate Programs Based on ERC Research	4	< 1	2	< 1	28
Courses	***Total***	***Per Center***	***Total***	***Per Center***	***Total***
New Courses Based on ERC Research	63	3	46	3	864
Ongoing Courses With ERC Content	303	15	161	10	1,453
Course Modules Based on ERC Research	30	2	21	1	497
Textbooks	***Total***	***Per Center***	***Total***	***Per Center***	***Total***
New Textbooks Based on ERC Research	10	1	3	< 1	152
New Textbook Chapters Based on ERC Research	13	1	7	< 1	52

Does not include centers from the Earthquake Technology Sector

[2] 20 ERCs in ERC FY2013 are: Center for Integrated Access Networks at University of Arizona (CIAN), ERC for Quantum Energy and Sustainable Solar Technologies (QESST), NSF Nanosystems ERC for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) at North Carolina State University, ERC for Re-inventing the Nation's Urban Water Infrastructure at Stanford University (ReNUWIt), Quality of Life Technology ERC at Carnegie Melon University, Smart Lighting ERC at Rensselaer Polytechnic Institute, ERC for Extreme Ultraviolet Science and Technology (EUV) at Colorado State University, ERC for Structured Organic Particulate Systems (C-SOPS) at Rutgers University, ERC for Biorenewable Chemicals at Iowa State University (CBiRC), Synthetic Biology ERC at the University of California, Berkeley (SynBERC), ERC for Compact and Efficient Fluid Power at the University of Minnesota – Twin Cities, Nanosystems ERC for Translational Applications of Nanoscale Multiferroic Systems (TANMS) at UCLA, Nanosystems ERC for Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT) at University of Texas-Austin, ERC for Ultra-wide-area Resilient Electric Energy Transmissions Network (CURENT) at the University of Tennessee, ERC for Revolutionizing Metallic Biomaterials at North Carolina A&T State University (RMB), ERC for Collaborative Adaptive Sensing of the Atmosphere at the University of Massachusetts (CASA), Future Renewable Electric Energy and Management Systems ERC at North Carolina State University (FREEDM), ERC for Biomimetic MicroElectronic Systems at the University of Southern California (BMES), ERC on Mid-Infrared Technologies for Health and the Environment at Princeton University (MIRTHE), and the ERC for Sensorimotor Neural Engineering at University of Washington (CSNE)

"Annualized ERCs" includes the 20 ERCs above and the following additional 12 ERCs: University of Michigan - Wireless Integrated Microsystems' Vanderbilt/Northwestern/Texas/Harvard/MIT Center for Bioengineering Educational Technologies; Northeastern University Subsurface Sensing and Imaging Systems; University of Hawaii – Marine Bioproducts Engineering Center; Clemson University – Center for Advanced Engineering Fibers and Films; Georgia Tech/Emory Center for the Engineering of Living Tissues; University of Kansas – Center for Environmentally Beneficial Catalysis; Virginia Tech – Center for Power Electronics Systems; University of Illinois– Compound Semiconductor Microelectronics; Johns Hopkins University – Computer-Integrated Surgical Systems and Technology; University at Buffalo Multidisciplinary Center for Earthquake Engineering Research; and University of California at Berkeley – Pacific Earthquake ERC.

Exhibit C. Curricular Impact of ERCs, FY 2007-2013

Curricular Impact of ERCs, FY 2007–2013

	FY 2013 (20 ERCs)		FY 2008–2012 Annualized		FY 2007–2013** (32 ERCs)
New and Ongoing Courses, Workshops, Short Courses, Webinars, and Textbooks Based on ERC Research	*Total*	*Per Center*	*Total*	*Per Center*	*Total*
With Engineered-System Focus	335	17	208	13	1,470
With Multidisciplinary Content	280	14	208	13	1,396
Offered at Undergraduate Level	196	10	125	8	889
Offered at Graduate Level	313	16	176	11	1,264
Used at More Than One ERC Institution	40	2	43	3	267
Team Taught by Faculty in More Than One Department	78	4	52	3	373

Does not include centers from the Earthquake Technology Sector
*** Data collection of curricular impacts started in 2007.*

Exhibit D. ERC Student Degrees, FY 1985-2013

	FY 2013 (20 ERCs)		FY 2008–2012 Annualized		FY 1985–2013 (58 ERCs)
Degree Type	*Total*	*Per Center*	*Total*	*Per Center*	*Total*
Bachelor's	88	4	82	5	3,895
Master's	104	5	87	5	3,750
Doctoral	134	7	135	8	4,151
Total	*326*	*16*	*305*	*18*	*11,796*

Does not include centers from the Earthquake Technology Sector

Exhibit E. ERC Graduate Employment (20 centers) FY2013

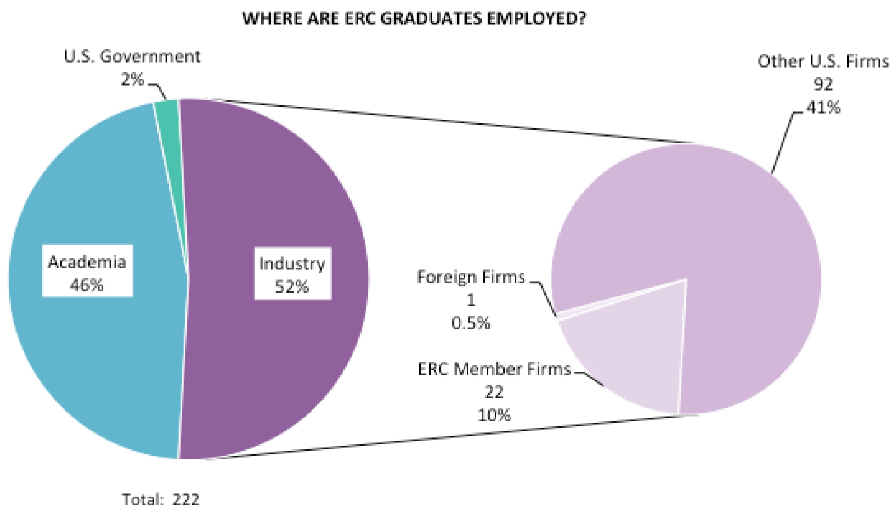
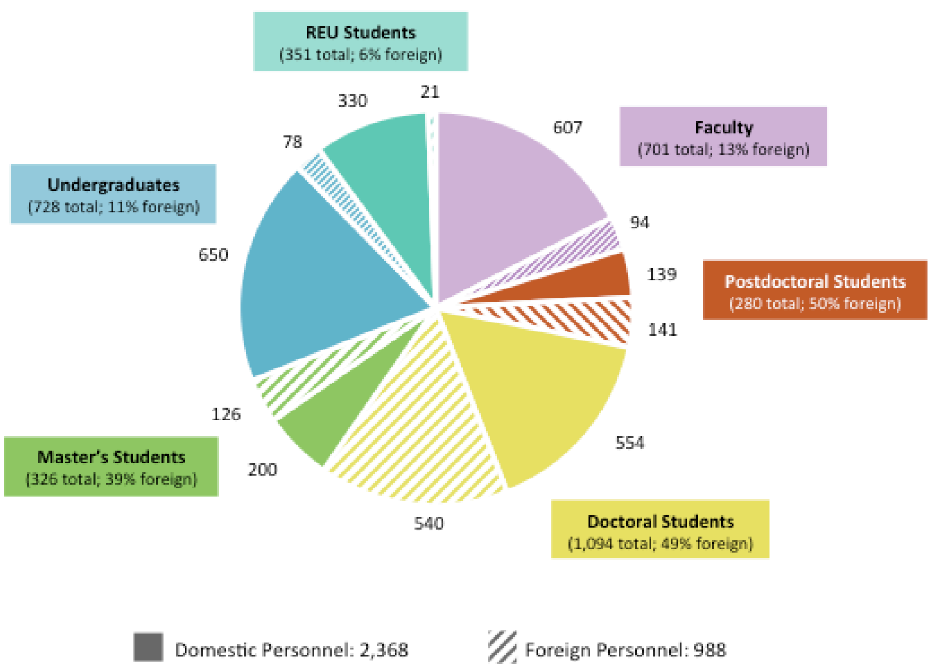


Exhibit F. Personnel Conducting ERC Research FY2013[3]



[3] The sum of the number of personnel for each category may exceed the total number of personnel because personnel may belong to multiple categories. Percentage of foreign personnel is calculated out of domestic and foreign personnel, excluding personnel who did not report citizenship.

Exhibit G. Education Program Expenditures from Unrestricted and Restricted Cash

All ERC Centers

Year	Average Education Total Per Center	Number of Centers	Education Total	Unrestricted Cash									Restricted Cash						
				Precollege Activities	University Education	Student Leadership Council	Young Scholars	REU	RET	Assessment	Community College Activities	Other	Precollege Activities	University Education	Student Leadership Council	Young Scholars	REU	RET	Assess
2002	$391,429	19	$7,437,145	$0	$0	$0	$0	$0	$0	$0	$0	$6,110,864	$0	$0	$0	$0	$0	$0	
2003	$378,613	19	$7,193,646	$0	$0	$0	$0	$0	$0	$0	$0	$6,000,086	$0	$0	$0	$0	$0	$0	
2004	$403,921	23	$9,290,194	$0	$0	$0	$0	$0	$0	$0	$0	$7,156,937	$0	$0	$0	$0	$0	$0	
2005	$491,912	22	$10,822,064	$0	$0	$0	$0	$0	$0	$0	$0	$8,583,696	$0	$0	$0	$0	$0	$0	
2006	$472,110	19	$8,970,098	$0	$0	$0	$0	$0	$0	$0	$0	$7,487,375	$0	$0	$0	$0	$0	$0	
2007	$351,121	23	$8,075,792	$0	$0	$0	$0	$51,415	$0	$0	$0	$6,446,290	$0	$0	$0	$0	$5,085	$0	
2008	$342,188	20	$6,843,753	$0	$0	$0	$0	$361,495	$659,088	$0	$0	$4,693,267	$0	$0	$0	$0	$85,927	$180,374	
2009	$364,212	21	$7,648,450	$0	$0	$0	$0	$1,011,438	$1,030,134	$0	$0	$4,995,065	$0	$0	$0	$0	$53,145	$28,104	
2010	$500,653	15	$7,509,797	$0	$0	$0	$0	$1,067,033	$1,124,125	$0	$0	$4,550,277	$0	$0	$0	$0	$145,720	$117,146	
2011	$509,405	13	$6,622,268	$0	$0	$0	$0	$1,363,379	$763,888	$0	$0	$4,103,925	$0	$0	$0	$0	$106,731	$43,566	
2012	$534,243	17	$9,082,130	$1,370,005	$1,298,604	$256,727	$350,456	$1,583,759	$831,255	$474,437	$106,227	$775,924	$268,192	$4,734	$0	$0	$512,032	$1,102,250	
2013	$488,288	20	$9,765,755	$1,215,938	$1,248,793	$257,421	$435,112	$1,814,481	$964,016	$537,577	$133,885	$885,788	$447,311	$313,981	$11,515	$27,000	$497,581	$951,592	
Average All Years	**$435,675**	**19**	**$8,271,758**	**$215,495**	**$212,283**	**$42,846**	**$65,464**	**$604,417**	**$447,709**	**$84,335**	**$20,009**	**$5,149,125**	**$59,625**	**$26,560**	**$960**	**$2,250**	**$117,185**	**$201,919**	

* REU data was first collected in 2007, RET data was first collected in 2008, and Precollege Activies, University Education, Student Leadership Council, Young Scholars, Assessment and Community College Activities were first collected in 2012.

4.2 ENGINEERING EDUCATION PROGRAM PLANNING AND DIRECTION

4.2.1 Introduction

The Engineering Education Program Planning and Direction section of this chapter provides guidance for teams preparing new proposals, to newly awarded ERCs in their start-up phase, as well as to new Education personnel who join an established center. The section is organized into three main topic areas: (i) strategic planning, (ii) funding, and (iii) programs and Implementation. Specific programming suggestions and examples are detailed in later sections.

Planning the ERC's education programs must be conducted concurrently with the research and industrial/practitioner collaboration/innovation ecosystem components to insure maximum integration. All stakeholders should be included in the process, as education is a critical component of an ERC. Personnel qualified in collegiate and precollegiate education as well as education assessment and evaluation must be included at the beginning stages of the process. The Center Director, and representatives from each partner institution, as well as industry and practitioner representatives, must also be included in the process.

The primary objective of the comprehensive education programs at ERCs is to address the second goal of the ERC Program; that is, to produce graduates with deep knowledge of industrial practice and who will be creative U.S. innovators in a globally competitive economy. To that end, these programs include not only university-level education strategies but also strategies that attract precollege and non-traditional students to engineering careers. The programs will include assessment and evaluation to monitor progress and impacts over time and to improve the program as needed. All ERC education programs are tasked with improving the diversity of the engineering student body.

Each ERC has a strategically designed University Education Program focused on instilling in its undergraduate and graduate students the capacity for effective industrial practice, creativity, and innovation. The primary goal is to produce graduates who are technically prepared, able to integrate knowledge across disciplines to advance technology, knowledgeable of industrial practice, experienced in advancing technology, adept at working in highly functional teams, and effective communicators. An additional goal for Gen-3 ERCs is to deliver graduates who also are creative, innovative, and entrepreneurial and are experienced working in non-U.S. research cultures.

Given this guidance, the university education program must identify the key characteristics and skill sets its undergraduate and graduate students will possess upon graduation. The center should strategically design a set of programs, research training, and other experiences for their students to acquire these desired characteristics and skill sets. The ERC's foreign collaborations will serve as the basis for the overseas laboratory experiences for the students. The university education program impacts the curricula at the lead and partner universities. Based on the center's research, new courses and course modules/content for insertion in new and existing courses are developed. Although not required, the ERC may design and deliver a new degree program and/or certificate programs. If a Nanosystems ERC or an open topic ERC develops nanoscience and nanoengineering courses, course modules, lectures, etc., suitable for hosting on the cyber platform of the Network for Computational Nanotechnology[4] (NCN), those materials will be delivered to the NCN, where a broader community will have access to them in an open source mode for educational purposes.

The university education program will be carried out in collaboration with the ongoing education programs of the domestic partner universities. The program will be structured to involve ERC engineering and associated discipline students at the B.S., M.S. and Ph.D. levels and will be carried out in coordination with the center's Research Experiences for Undergraduates (REU) programs. The ERC may also coordinate university education programs with appropriate outreach to local community colleges and veterans groups for broader impact.

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[4] http://nanohub.org

The goals of the ERC's Precollege Education Program are to stimulate student interest in engineering careers and increase the diversity of domestic students studying engineering at the college level. The program will form long-term partnerships with up to five precollege institutions (i.e., school districts or individual schools). These institutions must be involved in the planning process to ensure that projects proposed will meet their students' needs as well as to facilitate implementation and adoption. Opportunities for precollege institutions to work with the center include:

(1) Involving their STEM teachers in structured ERC research and education programs;

(2) Providing opportunities for research internship experiences for veterans who are teachers at the ERC;

(3) Providing engineering learning and activity experiences for their students;

(4) Integrating new course modules based on ERC research into precollege curriculum;

(5) Developing strategies to involve underrepresented groups, both teachers and students, in engineering experiences with ERCs;

(6) Developing general outreach programs to involve precollege students in the ERC's activities; and

(7) Enabling talented high school students to pursue research experiences in the ERC's laboratories through a Young Scholar program (Gen-3 requirement only).

Through innovative teaching methods and inquiry based-learning enabled by the ERC, these precollege teachers can inform precollege students about the excitement of engineering and technological innovation, and in turn, stimulate them to choose engineering degree programs in community colleges, colleges, and universities.

Although not required, community college and/or technical college faculty and students may be included in center activities to strengthen the skills of the technical workforce and stimulate some of these students to pursue B.S. degrees and beyond in engineering.

It is expected that the ERC's faculty and students will participate in the full scope of the precollege education program and that their mentoring efforts will be recognized and rewarded by their home institutions.

4.2.2 Strategic Planning

In planning an education program, the center's Leadership Team must take into account the following:

- *Center Mission Statement*. An ERC is a unique organizational team that has three mandates from NSF: (a) cutting-edge research, (b) technology transfer of the results of the research, and (c) preparation of the next generation of engineers and scientists. The mission statement should recognize the education component of the center that produces engineering graduates who will be highly effective in industrial practice and creative innovators in a global economy. The ERC's culture evolves through a platform of transformational research and education programs in partnership with industry and other practitioners. It is essential to develop an Education Program Mission Statement as a component of the center's broader mission, to address NSF's mandates.
- *Education Program Goals.* Program goals must be specified at the beginning of the planning process. The Center Director, the Precollege Education Director, and University Education Director must develop the goals in conjunction with input from the center's Leadership Team. (*Please note*: All of these functions are known by different titles at different centers.) This step will ensure integration of research, technology transfer, and education (a hallmark of the ERC Program) and implementation of the program. These goals should be consistent with the center's mission statement and must address the scope of the program, the mechanisms for integrating center research and education, and mechanisms for industry-student interactions. The requirements for precollege educational outreach must be taken into account. Because ERCs

have a particular mandate to ensure adequate representation of women and underrepresented minority students, recruiting measures to meet this mandate must be included. The goals will determine the scope and range of the ERC's education programs.

- *Organizational Considerations.* Initial planning must include the human resources that will be needed. The Director(s) of the Education program(s) should be a professional at the same level on the organizational chart as the research and technology transfer directors. It is recommended that a full-time professional be engaged at the outset and included in the planning stages of the program. While some centers rely on part-time faculty members to serve in this position, employing an individual with an education programming background will allow the center to implement a more complete and effective program.
- *The Actual Strategic Plan.* Given the limited lifespan of an ERC, the center's management must give strategic planning a high priority, beginning in the initial stages of a center's proposal. Strategic plans are dynamic documents that guide allocation of limited resources. They must be revisited annually to ensure that they are able to react to changes in the research and industrial environment and to allow for the exploitation of opportunities that arise during the year.
- *Budget.* The education program should include resources that match the proposed plan. While supplemental funding (e.g., from foundations, NSF, and industry) for particular programs may be available, center core funding resources should be earmarked to support the fundamental components that allow the center to meet its core educational goals. In FY2013, ERCs on average spent $488K each on their education programs (including restricted and unrestricted funds, see Exhibit G in the Introduction Section 4.1).
- *NSF/Center Interface.* NSF has an important guidance and support role to play in the development and growth of ERC education programs. NSF Program Directors and Staff are a resource to the ERC Education Directors in addition to their role in program oversight.

The strategic planning process for education is conducted in different ways at different centers, with a variety of participants, including the Education Director/Coordinator(s), the Center Director and Leadership Team, the center's Diversity Director, an Education Advisory Committee and/or the center administration, and possibly industrial stakeholder/partner or university involvement. See example 4.3.1.1 in Appendix 4.3 for a description of one ERC's planning process.

Some ERCs involve faculty from all of its departments of engineering or representatives from industry in the strategic planning process, as appropriate to the ERC's scope of research. Knowing the state of the art in your ERC research areas provides a base from which to modify and develop courses. Several ERCs use the activities of annual report planning and preparation as the time to review education program strategy and make changes. Some ERCs give the Education Director/Coordinator and staff leeway to make initial plans and decide on strategies, which are then reviewed by the Center Director and/or appropriate committee. Other ERCs form teams consisting of the Education Director/Coordinator, Center Director, some faculty members, and sometimes a graduate student representative. Another means of student input employed by centers is a Student Advisory Committee. Often the membership of such a committee is drawn from the center's Student Leadership Council. (See Best Practices Ch. 8[5] for information on these vital ERC student organizations.)

ERC Education Directors/Coordinators can consult their counterparts at other ERCs for ideas in constructing the initial plan, and they can meet with their Center Director, Industrial Liaison Officer/Industrial Partnership Coordinator, and senior center faculty to gather input on ERC education needs and issues. In addition, the Education Director/Coordinator must become familiar with the curricula at his or her particular school of engineering and other relevant departments within the university. Multi-university ERCs also must accommodate requirements of their affiliated universities' curricula.

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5 http://erc-assoc.org/best_practices/chapter-8-student-leadership-councils

The following is a general model of the process of developing a strategic plan:

Overall Goals/Objectives: The first step is to develop a statement of the overall goals/objectives of the education program, keeping in mind the center's vision (what you want the vision to be) and mission statement (what you do to implement the vision). Such a statement should include what you want to do, whom you want to affect, and how you intend to accomplish it. For example, an education goal/objective might be "to develop and deliver *innovative educational initiatives* to *prepare scientists and engineers* for the challenges of the emerging biology-based industries, *in order to produce a generation of engineers and scientists with a cross-disciplinary team perspective*." The strategy to accomplish this goal could include "a major outreach effort to middle and high school students and teachers."

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

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

The center's program objectives and goals can assist to determine the scope of the program's offerings and to clearly identify projects and activities that consistently achieve ERC program objectives. Each project, activity, initiative or event should meet the following objectives:

1. Motivate diverse citizens to navigate the STEM pathway to expand and promote a talented STEM workforce.
2. Promote the awareness of <*specific area of research*>-- its technology, applications and career opportunities -- through positive, authentic experiences in informal precollege, undergraduate, graduate and industrial contexts.
3. Infuse <*specific area of research*> research and innovation into evaluated curricula and programs in informal precollege, undergraduate, graduate and practitioner offerings.
4. Create a culture that integrates research, education, and industrial practice for undergraduate and graduate students across the center.

The scope of the ERC's Education Programs is broad. It is useful to categorize programs by targeted specific audiences. Typically, as noted earlier, a center's Education Programs are divided into two main thrusts—University Education and Precollege Education—although a center may want to enhance its programs by providing public and professional/practitioner education programming.

Each program proposed under the two main thrusts should touch on one or more of the ERC Program's objectives. Specific programmatic elements of the Education Program portfolio include:

- Undergraduate research opportunities during the academic year in teams with graduate students
- Research Experiences for Undergraduates (REU)
- Research Experiences for Teachers (RET)
- Precollege outreach experiences for students in ERC activities
- Young Scholars research opportunities (Gen-3)
- Innovation and entrepreneurship experiences (Gen-3)
- Foreign laboratory experiences (Gen-3)
- New and modified curricula
- Research Experiences for Veterans/Teachers (NSF ENG/EEC Supplement opportunity)
- Other projects and programs.

Successfully meeting all of these expectations in the first year is not required; instead a focused effort in establishing the core program elements of the Program is recommended in the start-up phase. In fact, the site visit merit review criteria are phased depending upon the age of the center. (See the merit review criteria on this webpage.[6]) Following the first year, a phased approach works best. The University Education Program Director and the Precollege Education Program Director should strategically identify the respective programs that have the highest likelihood of success and sustainability and the appropriate timing of their implementation. A focused effort to design and implement the essential (required) elements of the program at the start-up phase is important. Shortly after the program is established and procedures and protocols, management, and organization are in place, the Education Leadership Team can begin to creatively design and implement programming specific to the needs of the center, its students, its stakeholders, and its researchers. The Education Leadership Team should assess components of the Education Program for risk and reward (success and sustainability) with anticipated timeframe and effort needed to coordinate, launch, and resolve. In the first year, a focused approach is recommended, rather than a shotgun approach. There are a variety of ways the Program could be phased and staged, and each center has unique resources, needs, and stakeholders. The Education Leadership Team should have a clearly devised strategy on how to phase the Program—its programming, its alignment with what's leveraged, and the needs of the center.

4.2.3 Planning for Sustainability

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

As a center approaches the end of the NSF ERC Program funding cycle, these concerns come into sharper focus. NSF intends that the culture of ERC education will continue in the center; but without continuing support from the university, industry, or other programs at NSF, it is likely that most of the ERC's education programs will end. ***The center's Education Director/Coordinator should work with the center leadership to develop a self-sufficiency plan from the outset. This plan can include soliciting education funding from the university, foundations and the private sector (notably industry).*** It is recommended that programs and projects that have a high likelihood of sustained funding and/or support after the 10-year ERC Program funding cycle ends be identified in the initial phases of the ERC's development. It is visionary to consider who the long-term supporting stakeholders will be at the "graduation" of the ERC from ERC Program support, what programs may fulfill the future stakeholders' needs, and might those programs have a 10-year development phase in the ERC in order to provide value and justification to the future support of the center?

See section 4.7 for a more extensive discussion of sustainability of education programs.

The following are a few examples of best practices in the start-up phase that may help strategically align ERC education programs for long-term sustainability. The common theme for success is working to develop productive and lasting relationships from the very start of the center:

- Make the development of the engineering workforce through an ERC's education and research programs as critical to the center's mission as research, innovation, and entrepreneurship. This will create a sustainable education program that will be integrated within the research program, rather than a program independent of the center's research initiatives.
- Form meaningful, long-term relationships with K-12 schools. Over the lifetime of the ERC, outreach programs should become institutionalized at partner schools.
- Establish relationships and collaborations with other ERC Education Directors at the ERC Program's biennial meeting, during the monthly teleconference calls, and during special ERC Education Directors' retreats.
- Search out and build partnerships with existing entities on your campus that have permanent funding to leverage already existing and institutionalized programs.

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[6] https://www.erc-reports.org/public/library

- Ensure that multiple educational pathways are represented in the program (e.g., use K-12 programs to feed the undergraduate and graduate programs).
- Assess the needs of current and future stakeholders. Example questions include: “What are the needs of industry now and anticipated for the future?”, “How can we can fulfill those needs?”, and “What can we uniquely offer that answers to that need?”
- Institutionalize ERC education through new coursework, programs, and degrees. How can these be aligned across partner institutions? Understand curricular development and approval processes early for smoother integration and quicker implementation.
- Study what it takes to be successful in gaining site awards from the NSF REU and RET programs.

4.2.4 Understanding Needs, Context, Stakeholders, and Resources

Leverage Existing Infrastructure: In many cases, there are pre-existing programs, resources, and infrastructure at institutions associated with the ERC that can be leveraged to simplify the start-up process. Identifying and collaborating with these entities can save time and resources, allowing faster implementation of a variety of education programs, and facilitating the sustainability in the long run.

Identify Opportunities and Barriers: The assessment of opportunities for collaborating in education programs should be balanced with the needs of the center and any obstacles to success. While some programs offer the ease of “plugging in” to an existing infrastructure, it is important to ensure the student experience is unique and the educational content is tailored to the mission of the ERC.

Inventory Existing Resources: Some examples of resources that other ERCs have leveraged are listed below. These opportunities are highly dependent on resources available at each institution.

- Many outreach programs are extensions and specializations of prior existing programs. Also, ERC programs can be tied to existing programs by offering expertise and/or opportunities that were made possible through the ERC.
- Example partnerships include:
    1. CalTeach, a UC-Berkeley teacher training/development program, provides professional development workshops to teachers in an RET program at the Synthetic Biology ERC (SynBERC).
    2. The Transfer Alliance Program (TAP) at UC-Berkeley provides transfer advising services to Center community college REU students.
    3. The California Institute for Quantitative Biosciences has co-partnered with SynBERC to develop and run Lab Bootcamps for Undergraduates, a traveling one-day symposium called "What You Can Be With a Ph.D", and a summer industry internship program for undergraduates;
    4. A K–12 robotics camp was successfully integrated into the ERC K–12 program at the Quality of Life Technologies (QoLT) ERC; and
    5. Aligning a center REU program with existing university-wide summer undergraduate research programs allowed the Biomimetic MicroElectronic Systems (BMES) ERC to leverage the many activities being provided to REUs by the University of Southern California, Viterbi School of Engineering, and encouraged students to become immersed in a large and diverse REU community. Many other centers, such as the ERC for Collaborative Adaptive Sensing of the Atmosphere (CASA), based at the University of Massachusetts-Amherst, the EUV ERC at Colorado State University, the Smart Lighting ERC at Rensselaer, and the FREEDM Systems ERC at North Carolina State University, have done the same thing.

4.2.5 Engaging Engineering Education Specialists and Evaluation and/or Program Assessment Experts as “Intellectual Partners”

From the start of the program it is good practice to either engage with, or have on staff, engineering education specialists and evaluation and/or program assessment experts. This communication will ensure that the education program's mission, vision, and program goals align well with the proposed programs and desired outcomes. These experts may also recommend surveying the current and future stakeholders to determine if the elements of the education program meet the needs of industry or other stakeholders.

Best Practices and examples of what others have done include:

- Approach education programs from a research perspective and aim to collect data suitable for publication.
- Utilize assessment experts who are familiar with NSF programs (such as REU and RET) and can bring expertise about what works and what doesn't to the table. This will save immeasurable time and money!
- Hire experienced education evaluators and researchers. For example, when putting the team of precollege leadership together, the BMES ERC put College of Education faculty on the leadership team. Similarly, the FREEDM Systems ERC works with other non-engineering faculty to conduct their precollege and college assessments. The ERC for Revolutionizing Metallic Biomaterials (ERC-RMB) at NCA&T State University has an evaluator who is on the faculty of the NCA&T School of Education. Her role is broad in scope, providing assessment overview for precollege education and outreach, as well as for shaping evaluation research in university education.

4.2.6 Role of Partner Institutions

Clearly defining the roles of partner institutions within the workforce development and education programs is a very important issue, one which has no prescriptive solution. There are many organizational schemes that have been successfully implemented in different centers. For example, the lead institution may centrally oversee the education program activities and manage the budget, with only a single faculty member at partner institutions to oversee progress. Alternatively, partner institutions may have individual education leaders and budgets to implement their own programs within the scope of the overall ERC education program mission and objectives. There is likely a range of solutions that lie between these two extremes. It is important, however, that all partner institutions be involved in these activities.

A few best practices and lessons learned from current and graduated ERCs include:

- The SynBERC ERC has an East Coast and West Coast hub, with one faculty member designed to oversee education program activities at campuses on either coast. All efforts are centrally coordinated at UC-Berkeley, but having faculty responsible for overseeing programs on each coast has been a great help.
- As you decide on the roles of individuals at partner institutions, be aware that it may be challenging to arrange Institutional Review Board Certifications (IRBs) across universities.
- The graduated Virginia Tech ERC, CPES, pioneered multi-university ERC partnership, developing cross-campus articulation agreements that enabled students from one partner campus to take a course at another campus and earn credit on the home campus.
- It is useful to form consortia within or across ERCs for large shared proposals, e.g., equipment.

4.2.7 Developing Partnerships Across the ERCs

Education leaders from other ERCs can be a key resource for centers in their first years. Partnering with other centers to leverage each other's pre-existing infrastructure, or simply seeking advice from someone with a few years of experience navigating the workforce development program landscape can be quite valuable.

Some examples of best practices in collaboration include:

- Attending conferences or seminars where education program representatives from all the existing ERCs will attend. This can be useful for collaboration and network building.

- Using other ERCs as a resource for recruiting teachers and undergraduates for RET and REU programs.
- Sharing a variety of programs, curricula, and assessment tools with partners at other ERCs.
- Partnering with other ERCs to co-sponsor a booth at recruitment conferences. This is an efficient use of resources.

4.2.8 Role of NSF

The Professionals of the Engineering Education and Centers Division are resources to serve the ERC Education Directors/Coordinators in developing and enhancing their education programs. They have the experience to provide guidance and to identify others who might serve as resources to assist in strengthening the education programs. NSF also provides publicity to industry and works through other NSF programs to support the centers.

NSF ERC core funds and supplemental funding based upon competitive proposals serve as a nucleus for developing strong education programs. Recognition of the importance of ERC education programs in the ERC biennial meetings and conferences and during site reviews help Education Directors/Coordinators strengthen their respective education programs. NSF support is philosophical as well as financial and is critical for developing strong ERC education programs and ensuring that education is an important aspect of the centers.

Some examples of NSF's support to ERC education programs include:

- Monthly teleconference calls among the University and Precollege Education Directors and NSF Program Directors responsible for ERC education efforts, hosted by NSF at ERC_E-O@LISTSERV.NSF.GOV.
- Continual emphasis by NSF Program Directors on the importance of education and educational programs in the ERC. In this way, NSF Program Directors emphasize to the leadership and faculty of the ERC the significance of these programs. This greatly helps the education endeavors at the centers.
- Providing opportunities for additional NSF sources of funding and publicizing these funding options to the centers.
- Emphasizing the significance of collaboration between centers and encouraging these collaborations verbally and through funding sources.
- Providing critical insight to centers through annual site visits that help improve center programming.
- Providing guidelines that define the programs, performance criteria that define excellent and poor performance, and reporting guidelines that document annual progress, as well as cumulative progress at renewal and at "graduation."
- Laying the groundwork for the development of education programs with a strong industrial element, by mandating an industrial component to the center's architecture. This component benefits both undergraduate and graduate students,
- Promoting innovative programs that allow cutting-edge technology to be developed to the point where it can be utilized by industry and benefit the general population, through funding of the ERCs. Center education programs are an essential vehicle for disseminating these new technologies into industry, by means of the center graduates and center outreach.

A strong relationship with the NSF ERC Program Leadership, and especially the NSF Program Director who is responsible for the oversight and review of your ERC, will enhance the development and implementation of an ERC education program.

4.2.9 Funding

Budget

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

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

The education budget or the overall center budget must include funds for the leaders of the education programs to attend annually, either the ERC Program Education Retreat or the Biennial ERC Program Meeting.

As the center matures, NSF supplemental funding and leveraged support from other sources, as well as industrial funding, should increase. Ideally, after the first few years, it should not depend entirely on internal ERC core funds.

As the center approaches graduation, the most likely scenario for continuation of the education programs is through leveraged support via additional funds from the university, foundations, industry, and state programs as well as through NSF REU and RET site and other NSF education programs.

Education budget decisions allocating overall resources should be made by the center Leadership Team—including the Director, Deputy Director, Education Director/Coordinator, Thrust Leaders, and Industrial Liaison Officer. In some ERCs, Education Directors/Coordinators submit proposals for funding along with research thrust proposals, and all proposals are considered by an ERC funding committee. Some ERCs have a budget for program development, which includes scholarship/fellowship stipends and seminar and travel expenses. It is recommended that there be an amount, a set-aside for the education programs, that is respected by the other members of the leadership team, many of whom will have competing research proposals in line for funding.

The education program should include resources that match the proposed plan. While supplemental funding (from foundations, NSF, and industry) for particular programs is available, center core funding resources should be earmarked to support the fundamental components that allow the center to meet its core educational goals. In FY2013, ERCs on average spent $488K each on their education programs (including restricted and unrestricted funds, see Exhibit G in the Introduction Section 4.1). Items that should be in the education budget include:

- Administrative costs (e.g. faculty, staff, overhead, printing, and data collection/management)
- Graduate student support
- Support for Student Leadership Council (SLC) activities
- Funding to support the academic year undergraduate research program
- Funding for precollege outreach
- Programmatic funding needs
- Travel (for recruiting, dissemination, and annually to either the ERC Program Education Retreat or the Biennial ERC Annual Meeting)
- Assessment personnel and program
- NSF Requirements
  - ✓ Minimum of $42,000 spent from the core ERC budget on the ERC’s REU Program, regardless of whether or not there are REU site awards.

- ✓ Minimum of $42,000 (Classes of 2006-2012) or $87,000 (Class of 2015) spent from the core ERC budget on the ERC's RET program, regardless of whether or not there is a RET site award.

Other Funding Opportunities

Funding for educational activities may be derived from a number of sources. Specifically, there are occasional opportunities for competitive supplemental funding from the ERC Program, education/outreach awards from other divisions and directorates of NSF, RET and REU site awards, special grants from industry members of the center, funds from the university for diversity-promoting activities, education grants from philanthropic organizations, and possibly state sources. Opportunities should be pursued to leverage the funding received, using non-federal ERC funds for matching. Some centers have been quite successful in leveraging their education budgets with university, state, and other federal resources. External foundation (not NSF) funds may be used for matching funds with NSF-supported activities.

Opportunities from NSF include:

- ERC Program supplemental funds—these are provided for special initiatives, such as the Research Experiences for Undergraduates (REU), Veteran's Research Supplement Program[7], outreach to Historically Black Colleges and Universities (HBCUs), technical schools, and international programs, as well as other special supplemental funds. Such programs significantly strengthen ERC education programs. They provide a focus for center education activities and serve as a fulcrum for leveraging support from other sources, including industry.
- Division of Engineering Education and Centers Active Funding Opportunities
- Research Experiences for Undergraduates Site Award
- Research Experiences for Teachers (RET) Site Award
- Starting in FY2014, the EHR Directorate's Research Traineeship Program (NRT)
- Historically Black Colleges and Universities_Undergraduate Program (HBCU-U).

Industry: There are opportunities for supplemental funding from special grants from industry members of the center to sponsor outreach activities or events, capstone design projects, sponsored research under the center's Education and Outreach Programs. Industry associations are eager to support educational initiatives for the potential workforce.

Other Sources: Other creative routes in leveraging educational and outreach support include garnering investment from other local, state and federal governmental agencies committed to educational development. Examples include:

- U.S. Department of Education
- U.S. Department of Energy
- U.S. National Institutes of Health
- U.S. National Aeronautics and Space Administration
- Local school districts, associated initiatives, partnerships
- National student organizations and local student chapters

Fellowships: Assisting students to apply for fellowship support can greatly leverage the research funding for the ERC, and enhance the student's profile and prospects post-ERC.

Leveraging: Programs that allow for multiple purposes to be satisfied simultaneously are obviously desirable, which is highly dependent on pre-existing alignment, stakeholder needs, and funding. Alignment with other programs was discussed previously, and stakeholder needs should be part of the assessment regarding opportunities and barriers. Leveraging of funds can and should be conducted in

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[7] See Dear Colleague Letter No. NSF 13-047.

the pre-proposal stage, by negotiating a percentage of the indirect costs, space, equipment funds - often as part of a cost-sharing arrangement.

4.2.10 Program Management

Initial planning must include the human resources that will be needed. Each component of the ERC's education programs, University Education and Precollege Education, should have an appointed faculty or senior administrator to direct the program. Cooperatively, the program should be led by a team ("Education Leadership Team" or "Education Task Force") consisting of the Education Director and administrative personnel, including those from the partnering institutions. The Education Leadership Team could consist of other representatives in the center, including the Center Director, faculty not appointed to the education program, the Industrial Liaison Officer, members of the Industry Advisory Board, the evaluation/assessment expert, Student Leadership Council (SLC) members, etc. It is critical to have many perspectives assisting to lead the ERC's education programs. The Directors of the University and Precollege education programs should be professionals at the same level on the organizational chart as the research thrust and Industrial Liaison Officer/technology transfer directors. It is recommended that full-time professionals be engaged for these roles at the outset and included in the planning stages of the program.

Personnel

The choice of Education Coordinator/Director, and the appropriate positioning of this person as a member of the center's Leadership Team, will determine the success of the center's education programs. Both the University Education Director and the Precollege Education Director should be part of the ERC's Leadership Team to demonstrate the importance of these programs to the center. NSF requires that the University Education Program be led by a faculty member to elicit the full respect and cooperation of faculty in programs that directly affect their students and the integration of their research into ERC curricula. This is especially important for curriculum development. The Precollege Education Program may be led by a staff person with expertise in this field and sufficient professional standing to also elicit full respect within the center. The primary focus should be on identifying an individual with an appropriate background to be responsible for the education activities of the center. His or her interest in interacting with students should also be a major selection factor. The University Education leader may be part-time but the Precollege leader should be full-time. Someone who is interested in mentoring students and working with REU students must be a member of this team.

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

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

A variety of organizational structures can lead to successful education programs. In some centers the Center Director monitors the Education Director/Coordinator, to provide oversight, input, and knowledge of the education programs. In other cases, the Education Director/Coordinator has more latitude to manage the education programs with limited oversight. The appropriate management style will vary from center to center.

The organizational structure of the entire education program may creatively reflect the unique arrangements between the lead and partner institutions of the ERC. Some centers operate from the center's headquarters and maintain all administrative and leadership functions of the education program at the lead institution, and distribute the programs, projects and activities across the partner institutions; but the coordinated effort is in one location. One disadvantage of this model is that the challenge of carrying out all education activities is a multi-campus effort, rather than being central to the lead institution. Other centers distribute their education program direction, leadership, and functions across multiple campuses.. However, this may pose a problem in cohesiveness and ensuring that the entire program drives impact by adhering to the education program objectives. Whatever structure is selected, all partnering institutions share equal responsibility for implementing the program.

Evaluation, Assessment, and Research Inquiry

Effective assessment tools are necessary to incorporate feedback from assessments and/or evaluations into the education programs to improve program content, ensure program sustainability, and deliver on program goals. Using an expert in program design, implementation, and effectiveness will ensure the program is meeting its goals and objectives and the center is accomplishing what it has been tasked to do. This expert in program evaluation can assist in mapping the ERC program objectives across all education program goals and will help to determine the success and potential for each project. In addition, plans are to be in place to disseminate outcomes and curriculum/outreach products of the college and precollege /community college programs to the participating partner and outreach institutions and beyond.

4.3 PRECOLLEGE AND COMMUNITY ENGAGEMENT

4.3.1 Purposes and Goals

ERCs have a mandate to contribute to the precollegiate education system by introducing young students and their educators to the field of engineering and the technology impacted by the center's interdisciplinary research. The purpose is to bring knowledge of engineering to middle and high schools where the emphasis is on science education, with little understanding of the field of engineering. Additionally, there is a significant lag in textbook production, so an effort to integrate center research into classrooms brings cutting-edge engineering content to students in a timely manner. ERC K–12 programs are focused on helping to encourage students to consider careers in engineering. Given the limited ERC budget, when compared to the total precollegiate education system, ERCs and NSF recognize the limits of the impact they can have and that they cannot be all things to all constituencies. It is critical therefore that each ERC determine what precollege offerings work in the context of its specific strategic plan, resources, and community relationships.

Precollege education programs can increase student awareness of engineering careers and stimulate student interest in pursuing them. A key element to all ERC precollege programming is the recognition that it is in the national interest to encourage students who are traditionally underrepresented in engineering and technology careers to become involved. Focusing on underserved populations can contribute to efforts to increase the diversity of domestic students studying engineering at the college level.

ERC precollege programs cannot succeed without partnerships with local school districts and/or individual schools. A strong relationship with these partners will create (1) STEM teachers' involvement in ERC research and education programs; (2) creation of engineering-oriented educational modules for their school teaching activities and for integration into their curricula; and (3) strong impact on diversity and broadening participation of underrepresented groups, teachers, and students into these engineering experiences. See examples of such partnerships in appendix 4.3, section 4.3.7.

Some best practices for achieving successful precollege outreach are as follows:

- To make the best use of limited resources for ERCs' precollege outreach, many ERCs work in partnership with other education and outreach programs. For maximum impact, it is best to seek out established programs to which ERCs can add significant value, or to find promising new endeavors with which to partner. Partnerships may include university programs; school and school system organizations; and/or community resources, including informal science centers and public libraries.
- Another key feature of successful programs is the involvement of graduate and undergraduate students as well as the ERC's Student Leadership Councils (SLCs) in activities. These may include school visits and student tours, as teacher or student research mentors. Secondary school students often relate well to university students, who are closer to their own age. Engaging graduate students in outreach enhances their communication and leadership skills.
- To encourage program diversity, it is useful to partner with established campus multicultural programs; for example, ERCs have partnered with chapters of the National Society of Black Engineers (NSBE), the American Indian Science and Engineering Society (AISES), and the Society for Women Engineers (SWE). Additional partners include women in engineering programs and minority/multicultural engineering programs.
- Successful outreach programs are led by teams involving university educators and education faculty, precollege STEM teachers, as well as center engineers and researchers. Each group offers different talents and specialties that contribute to outstanding programs.
- It is best to have an educator with experience in K-12 education responsible for the pre-college program at each participating ERC location. Programs can be administered from a central location, but an on-site educational leader on each campus is desirable. Forming an Education Committee or Thrust with a representative from each campus can be valuable in accomplishing this goal.

The programs described below are for both K–12 students and their teachers. They include the two that are required for all centers, Young Scholar programs (Gen-3 only), and summer Research Experiences for Teachers (RET). In addition to these required programs, centers have developed other programs such as summer camps, courses, internships, science and engineering competitions, lab tours, school visits, lectures, and science and education fairs, some of which are conducted on-campus at the ERC and others on-site at the partnering school(s).

Given the creativity of center precollege personnel at developing innovative student opportunities, and the resulting variability of programs developed, the best way to understand the range of possible offerings is to review the examples that are found in Appendix 4.3 to this section. Contact information is provided and existing center administrators will be happy to share details about any programs that they have developed. All of these programs require significant time and resources to develop and administer. It is important for the center's strategic plan to include timetables that plan for the gradual phased implementation of Education programming over time rather than attempting to bring all these types of effort up to speed in year 1.

4.3.2 Required Precollege Student Engagement

Young Scholars Program (Gen-3 only)

Generation-3 ERCs are required to develop and to offer a Young Scholars (YS) Program to provide opportunities to exemplar high school-age students to participate in ERC summer research programs or internships. The purpose is to get students into research labs early in their careers, in order to excite and interest them in pursuing research and in engineering careers. These programs can require significant effort from administrative and research staff. They generally involve center graduate students who serve as mentors to the students. Please note: there may be existing programs on campus that also serve these students that the ERC can leverage. (See example 4.3.4.1 and section 4.3.11 in Appendix 4.3.)

Student Competitions

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

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

See example 4.4.6.1 in Appendix 4.4 for an international competition involving undergraduates as well as high school students. Example 4.3.4.5 describes ERC faculty involvement in a science fair that led to a high school student conducting research at the ERC.

Student Camps and Courses

Many ERCs have sponsored student camps and courses to involve K–12 students in fun, hands-on science and engineering experiences and thereby interest them in technology and careers inengineering. ERCs may also integrate center research into existing camps as a way to introduce broader audiences to engineering and science. See examples 4.3.4.2, 4.3.4.3, 4.3.4.4, 4.3.5.1, and 4.3.13.1 in appendix 4.3. Field trips and tours of ERC labs are another way to engage young students' interest. See 4.3.12.1, for an example.

In many cases, ERC students go to precollege schools, even at the middles school and elementary school level, to bring fun demonstrations to classes in order to engage young students in engineering concepts. See example 4.3.5.2 and 4.3.6.1.

4.3.3 Precollege Teacher Engagement

Research Experiences for Teachers (RET)

One of the fundamental components of ERC precollege education is the Research Experiences for Teachers (RET) program. The purpose of the RET program is to excite K-12 teachers about engineering by providing them with knowledge of cutting-edge research. Effective programs engage K-12 teachers in developing and modifying lessons to incorporate concepts learned during their research experiences. Graduate student researchers will need to be heavily involved, as they will serve as mentors to these participants. The most effective programs have students who accompany their teachers to campus during the summer and have outreach to the teachers' classrooms during the academic year by teams of faculty and students from the ERC.

See examples in appendix sections 4.3.2 and 4.3.3. Examples of precollege outreach programs that encourage greater diversity among engineering students are in appendix sec. 4.3.10.

Development of Instructional Materials

In addition to K-12 teacher-developed curricular materials, several ERCs have developed curricular materials for K-12 teachers that are based on the center's research. If it is determined that the production of classroom materials is part of the strategic plan, it will require a development team that includes members of the targeted school district, classroom teachers from the targeted grade level, and center personnel. Partnerships with Colleges of Education and the engagement of Education students may also extend these efforts. It is important that educational materials reflect all local, state and national standards and are developmentally appropriate. For example, some states require application of Next Generation Science Standards (NGSS) and the new engineering standards within them. Education Directors should consult the standards that apply in their area.

> **FEATURED EXAMPLE:** *The NSF Nanosystems Engineering Research Center (NERC) for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) has partnered with professors of STEM education and engineers and has created nanoscale investigations that are correlated with science standards. The investigations are teacher-tested and reviewed by scientists and engineers as well as STEM researchers.*

For additional examples in the appendix, see 4.3.1.1, 4.3.4.3, 4.3.6.2, 4.3.8.1, 4.3.11.3, 4.3.11.5, 4.3.13.1, 4.3.14.1, and 4.3.14.2.

Conferences and Workshops

Some ERCs offer K-12 teacher professional development conferences and workshops. Professional development for teachers allows ERCs to multiply their efforts and to reach more K-12 students by increasing teacher interest and knowledge in science and engineering, particularly in exciting new research. Organizing these conferences can also require significant amounts of administrative and research staff effort. Participating in an existing conference requires less effort. For example, the NSF Nanosystems Engineering Research center (NERC) for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) provides professional development to K-12 teachers through on-site workshops as well as sessions for teachers at national and state teachers conferences.

> **FEATURED EXAMPLE:** *The ASSIST NERC provides professional development to teachers through on site workshops as well as sessions for teachers at national and state teachers conferences.*

For additional examples, see appendix 4.3.3.1, 4.3.6.2, 4.3.7.3, and 4.3.14.1.

4.3.4 Community Engagement

Public events such as Science Cafés and science center presentations are effective ways to share research with adults and families in local communities. These types of outreach efforts build support for the ERC and for research. Such opportunities to participate in ongoing outreach efforts can be easy ways for ERCs to reach out to communities. See examples 4.3.6.2, 4.3.9.1, 4.3.9.2, 4.3.9.3, 4.3.9.4, 4.3.14.1, and 4.3.14.3 in Appendix 4.3.

To better engage veterans in engineering projects, NSF is now accepting requests from their active grantees for the Veterans Research Supplement (VRS)[8]. The proposed VRS will afford veteran students, veteran precollege teachers, or veteran community college faculty an opportunity to participate with active ERC grantees to conduct industrially relevant research in order to gain a deeper understanding of engineering.

4.3.5 Precollege Education Lessons Learned

To be effective, precollege outreach requires professional leadership and substantial resources. Furthermore, the outreach program should be included as a key component of the center and the Precollege Director should be included as part of the center's Leadership Team.

Center Directors should schedule regular times to meet with precollege personnel and promote inclusion of the precollege program in center activities.

In order to promote and sustain a more diverse engineering workforce, the center should strive to create an inclusive and supportive work environment for precollege teachers and students.

8 See Dear Colleague Letter Number NSF 13-047.

4.4 UNDERGRADUATE COMPONENT (CORE STUDENTS, REU, COMMUNITY COLLEGES)

Although there are significant expectations for ERC education programs, there is a degree of local variation among centers. This variation arises naturally from the differences in center structure and composition. There are however, underlying similarities in what centers offer undergraduate students. This section will describe the similarities as well as the differences.

4.4.1 Core Students, Academic Year Research

Academic year core students are from the center's lead and core-partner universities. Integrating undergraduate students in the educational activities of ERCs is mandatory, and is perhaps the single most innovative aspect of the ERC education programs. While the research focus and educational vision of ERCs may differ, active involvement of the undergraduates in research has a major impact, not only on their education, but also on those around them. A special feature of the ERC Program is the emphasis on undergraduate participation in research. This is an excellent way to integrate center research into the undergraduate curriculum. Each of the ERCs has one or more programs through which undergraduates from the center's home institution(s) engage in research projects. See appendix section 4.4.2 for examples.

Including undergraduates in center research is the responsibility of all of the center's partner institutions. Undergraduates become part of a center research team and may be paid a stipend or enrolled in credit as determined by each center and institution. A minimum ratio of 1:2 undergraduates to graduate students is required. These core undergraduates are joined by ERC Research Experiences for Undergraduates (REU) visiting students in the summer. (See appendix sections 4.4.3, 4.4.4, and 4.4.5 for examples.) However, it is important to note that these two types of students conducting research are distinct groups for ERC reporting, assessment, and database purposes.

A critical component of the undergraduate research experience is the mentoring that the core undergraduates and REU students receive. Mentoring relationships for undergraduates involved in ERC research may involve faculty to undergraduate, staff to undergraduate, graduate to undergraduate, and undergraduate to Research Experience for Teachers (RET) participants and precollege Young Scholar (YS) students.

Mentors should be carefully identified, with plenty of time allowed for student assignment and mentor training. Being a successful mentor is not an innate characteristic. Therefore, training is imperative. Mentorship training should include everyone involved in the Undergraduate Education program (e.g. faculty, core graduate and undergraduate students, and staff). Training can take place through workshops, seminars, and via podcasts. Suggested topics could include "What is mentoring?," "Why is mentoring important?," "What are the different mentoring relationships in an ERC?," and "What constitutes a "good and bad" mentoring experience?" Importantly, specific "Do's and Don'ts'" related to each program should be clearly addressed. Undergraduate and REU mentor training should be done at the same time. Mentoring is a responsibility of all the partner institutions. See appendix sections 4.4.1.1, 4.4.2.3, and 4.4.3.1 for examples.

To create cohesion of the center's undergraduate researchers, they should be involved in the ERC's Student Leadership Council and should also participate in the NSF site visits and annual retreats.

4.4.2 Recruiting Methods

Undergraduates may be recruited through presentations at student organizations such as the student chapters of professional societies like the Institute of Electrical and Electronic Engineers (IEEE), the American Society of Mechanical Engineers (ASME), the American Society of Civil Engineers (ASCE), the American Institute of Chemical Engineers (AIChE), and through organizations like the Society of Women Engineers (SWE) and the National Society of Black Engineers (NSBE). Non-technical student organization groups may be approached to recruit for specific centers, depending on their mandates. They may also be recruited through announcements in the student newspaper, the ERC's website, printed flyers, and directly from classes and colleague's recommendations. Also, deans and departmental and other university offices may be helpful. Additional mechanisms such as Introduction to Engineering courses (cornerstone) and design courses (capstone) should be considered for recruitment. Participation in internal undergraduate research symposia and leveraging existing formal undergraduate research opportunity programs are also avenues of recruitment. Outeach by undergraduates to precollege schools, especially high school students, can be an important form of recruitment (see appendix section 4.4.11). Participation in contests and symposia relevant to the center's research is another option. See appendix example 4.4.6.1.

ERCs are national leaders in including students from underrepresented groups in engineering in their programming, so there is also a strong emphasis on recruiting undergraduate students from a diverse population, including women, members of underrepresented minority groups, those with disabilities, transfer or dual-degree students, and students from post-secondary technical schools and community colleges. These students may be from the engineering disciplines most prominently represented in the center, or may be studying other fields. Thus, undergraduates who are majoring in physics, chemistry, social sciences, education, and business can be valuable and productive participants. Please note, however, that packing the undergraduate population of an ERC with non-engineering students does not meet the ERC Program's goal of preparing undergraduates to pursue advanced engineering degrees or work as engineers in industry at the B.S. level.

centers should always monitor the diversity of the students who join the center. If the center's group of students is not meeting the center's diversity expectations, it is recommended that a survey of current underrepresented students at the center be conducted to see how they became involved with the center. This information may help the center to develop additional recruiting plans that will broaden the diversity of the undergraduate student group. See appendix section 4.4.10 for examples of programs to increase diversity. Example 4.4.8.1 describes a program aimed at recruiting students with disabilities.

4.4.3 Curriculum Development

Developing an ERC education program is a major undertaking, requiring substantial coordination of many faculty from different disciplines. The faculty involved in developing the ERC may already have a vision for new interdisciplinary courses or even a new degree program that can help achieve the Gen-3 ERC requirement to educate engineering students to be globally aware innovators and entrepreneurs. To that end, the ERC can help solidify the interactions that lead to course development and administration. The role of the ERC education program is that of a catalyst; the resources provided by NSF are small compared to those needed to develop and to maintain an entire academic program. Still, the catalyst serves an essential role, and there are examples of ERC education programs that have provided the necessary impetus for creation of new degree programs. (See appendix section 4.4.1.2, for example.) Degree programs may start as minor degrees, specializations, concentrations, or certificate programs and then evolve into new B.S. degree programs as the academic infrastructure grows through addition of resources from outside the ERC. The role the ERC plays in developing new degree programs at an institution depends strongly on how intellectually developed the field already is at the time the ERC is funded. If the area is new and just evolving, the ERC may lay the foundation for development of a program that comes to fruition in the latter years of the center, whereas if the ERC is funded in an area where faculty members are already offering interdisciplinary courses, a degree program may evolve more quickly.

New degree programs require substantial long-term institutional resources and commitment. Institutions have a responsibility to ensure that students are well prepared for life after the degree, and thus typically want extensive intellectual justification for how new programs will allow students to adapt to jobs in industry or academia. Before embarking on new degree programs, it is essential to arrive at a consensus of stakeholders as to what the expected outcomes of such a program would be. This process will facilitate the adoption of any new program developed. Appendix section 4.4.1.1 provides an overview of this process.

Courses (e.g., new courses, short courses, modules for ongoing courses, senior design)
A very important role of the ERCs is to enrich the core curricula in engineering through course modules for ongoing courses and new courses, particularly interdisciplinary and systems-focused courses. These courses will enrich the engineering curricula and also may provide the intellectual basis for a new degree program.

Developing new courses and/or materials for inclusion in existing courses is the first step toward integrating the ERC's research findings into the formal education process and is a key requirement for all ERCs. As a first priority, centers should look for opportunities to add modules, problem sets, and lectures to existing courses, to create relevant online content (non-course format), or to incorporate work in capstone design or similar courses to further integrate center research into the existing curriculum. This is an important means for ERCs to contribute to engineering education in a broader way, as insertion of new materials in ongoing courses does not require the levels of approval required for new courses. The bar is lower, the overall impact is higher, and center research advances can be leveraged more time-efficiently into the curriculum. The beta test approach is important here as well.

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

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

- Find an interested professor to be a champion for developing the new course.
- Pay the professor and a student helper to develop the course; or arrange with the professor's department chairperson to give the professor a teaching load reduction so that he/she can have protected time to develop the new course.
- Beta test course materials.
- Work on mechanisms to offer credit for students to take the course at the other ERC partner universities.
- Find a vehicle, such as a website or book, for wider distribution of course materials.

In institutions where ERC faculty have this responsibility, they can take advantage of these suggestions, which build on years of hands-on experience in many ERCs:

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

Appendix section 4.4.1.3 provides an example of undergraduate course development.

Degree/Certificate Programs

Minor degrees or certificates give students the opportunity to develop depth in areas outside their major degrees. The rules for offering minors, as well as student participation in minor programs, vary widely from institution to institution. At some schools, interdisciplinary minors are a means to evolve the curriculum toward a new undergraduate major by providing a testbed for courses and for development of student professional societies. If the center is in a cutting-edge research area and students are excited about a minor degree in the area, chances are that it can develop a successful minor even if there are institutional barriers. The key is to build on student interest and enthusiasm. Here are some important considerations:

- Define the intellectual content of your minor first —What is essential for the students to learn, and how many subjects are required? Are there subjects already offered that could fit the minor, or do you need to develop several new courses?
- Determine which academic unit is the best home for the minor, whether it be a single department, a pair of departments, a school or college, or the whole university. An academic unit will be required to handle the administrative details if the minor appears as a degree designation, and the academic unit involved needs to be extremely supportive of the minor.
- The easiest minor to develop is for students from one's own school (e.g., engineering), because those students are likely to have taken the prerequisites (e.g., mathematics, programming skills, and biology) needed to take the more advanced courses in your minor. Some academic institutions have firm requirements that any student should be able to complete any minor, and you must be cognizant of what your institution requires.
- If you develop a minor for a cross-disciplinary student audience (e.g., including both science and engineering majors), it is helpful to define a set of preparatory engineering subjects that provide the necessary background for non-engineering students. For example, non-engineering students may need to take Differential Equations and a mainstream sophomore-level engineering subject that uses differential equations to solve physicochemical engineering problems before they can enroll in the subjects in your minor. Alternatively, courses can be developed for non-majors, but this is usually a less attractive option over the long term. Engineering faculty are generally reluctant to develop a course for students who do not have engineering backgrounds, and cannot justify teaching such courses when teaching assignments are made.
- The minor should be well coordinated with the curricula of the major degrees. One must put appropriate advising in place to ensure that students are able to plan early in their academic careers to fit all the minor subjects into their schedules. It is helpful, for example, to write up a special advising document for freshmen and sophomores, to ensure they take appropriate background subjects early on. Conduct advising seminars once per term to get the word out to a broad audience.
- A minor degree curriculum, no matter how well planned, does eat into the unrestricted electives available to students. Some students may even overload on subjects in order to complete the minor. It is thus especially important to have good advising—students must appreciate that the minor is in some sense an Honors program if it requires substantial technical work. It is a choice the student makes. Students who are weaker academic performers might be encouraged to focus on their majors first.
- Create a curriculum committee that meets regularly to review the content and administration of the minor, and invite all the advisors for the minor to serve on the committee.
- Create a community of students involved in the minor by having lunches with students and faculty once per term.

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

- The academic affairs office MUST be involved from the beginning when considering creating or modifying a new degree (minor or major) or anything that affects undergraduate student credits. They are responsible for shepherding the degrees through governance.
- Find out what new degree program in engineering or science was most recently approved at your institution, and use that program as a benchmark. Some institutions are conservative and develop new degree programs only once every few decades in response to new disciplines.

- The faculty who teach the courses and who will be responsible for the degree program after the center's NSF funding expires must be key drivers in developing the new degree program. Be sure to get the support of key faculty members, who can provide sustained efforts to convince the Chair, Provost, curricular committees, and other decision makers.
- Identify the constituencies for your program, and make sure you have enthusiastic buy-in. Equally important, identify any other academic programs that will be significantly affected (positively or negatively) and discuss your plans with the faculty involved. For example, if you are developing a program that depends on core science classes offered by another academic unit (such as chemistry, math, biology, or physics), they need to be involved, especially if their enrollments are likely to increase as a result of your plans.
- Make sure to contact your university's appropriate office (e.g., the Provost) to find out what approvals are required for a new undergraduate degree program. There is no point in developing an entire program if it will not pass this first hurdle.
- Work as closely as possible with the Chairperson of your school's curriculum review/approval committee, as well as your university's Undergraduate Curriculum Committee, before submitting all of the paperwork to those committees, to be sure that they buy into your new program. Doing so can save a lot of time in getting your new program approved, because these committees frequently deny or delay approval due to incomplete forms or unclear descriptions.
- Involve undergraduates in developing the new curriculum, to understand their interests and needs from the outset. This can be accomplished by presenting a proposed curriculum at a meeting of the professional society for the area related to the program. While some universities require participation by undergraduate students during the development and evaluation stages of your new program, it's a best practice to include undergraduates, whether it is a requirement or not. Neglecting undergraduate input can cause very long delays in getting the new program approved.
- Be sure that your program satisfies criteria of the Accreditation Board for Engineering and Technology (ABET), if one of your goals is to have an accredited program. Review and update this program on a regular basis.

4.4.4 Collaboration with Industry

Industry is involved in all aspects of the ERC's education programs. Industry representatives may serve as mentors to undergraduate, outreach, or graduate students. (See appendix section 4.5.3.1.) They may present lectures, course sections, or entire courses, provide input into the curriculum, or teach courses in partnership with ERC faculty members. Industry experts may serve on the student's masters or doctoral committee. Industry may sponsor undergraduate or graduate internships in industry (see appendix section 4.4.9.1 for an example), or sponsor students' undergraduate or graduate degrees in whole or in part. It is important to allow undergraduates to participate in Industrial Advisory Board (IAB) meetings and interact with industry through social media for networking opportunities. (See, for example appendix section 4.4.1.3.) These experiences provide them a window into industrial practice, and for those who wish to pursue industrial careers after obtaining the B.S. degree, involvement with industry often leads to job offers, due to the richness of the ERC experience. ERC Program-level evaluations have found that industrial supervisors of ERC alumni find them more effective in industrial practice than their single-investigator trained colleagues.[9]

ERC Best Practices Manual Chapter 5, "Industrial Collaboration and Innovation," has a section 5.3.5 on involvement of industry with the ERC education programs.

4.4.5 Evaluation and Assessment

[9] SRI (2004). The Impact on Industry of Interactions with Engineering Research Centers. (http://erc-assoc.org/sites/default/files/studies_reports/Impact%20on%20Industry%20of%20ERC%20Interactions_SRI_12-04.pdf)

The need and scope for program evaluation and assessment varies based on an ERC's education program objectives. It is suggested that a person with experience in program evaluation and assessment be identified and used.

An important component of ERC education program assessment is tracking graduates. Follow-up with former students extends the influence and value of the Undergraduate program and contributes to the participant's involvement in engineering careers and the continuation of their education toward advanced degrees. Former participants can be provided with guidance and assistance with applications for graduate school and for financial aid. Arrangements can be made with the center's industrial partners to assist participants with potential employment opportunities. Maintaining contact with graduates requires considerable effort, but it increases the likelihood that they will continue on to graduate engineering education. Learning of their accomplishments is also rewarding. Social media such as Facebook or LinkedIn can be useful in this effort.

4.4.6 Research Experiences for Undergraduates (REU) Program

ERCs are required to offer a Research Experiences for Undergraduates (REU) Program. This provides a mechanism to extend the integration of center research to students who would not otherwise have the opportunity to conduct this type of research on their home campus. An REU program also provides an opportunity to diversify their undergraduate student population, but cannot and should not be the only diverse group of students involved in center research. These programs can also serve as a fulcrum for leveraging support from other sources, including industry. The programs go considerably beyond the traditional research-focused mandate of university research centers. Indeed, they place a substantial demand on the administrative and financial resources of ERCs. For example, the ERC must allocate a minimum of $42K to its REU program from core funds and may seek an REU Site Award to supplement that effort. However, the center's REU Program is part and parcel of the broader mandate to develop a new and more industry-focused, product-focused culture for academic engineering and to spread that culture through education. In that sense, then, "outreach" to REU students is simply extended ERC education.

Appendix section 4.4.3 provides a number of examples of REU program planning and operation at several ERCs. Section 4.4.5 gives examples of REUs involving community college students.

REU Program Features.

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

- Conduct individual or team research on ERC-related projects
- Develop teamwork skills through interaction with undergraduates, graduate students, and faculty
- Are encouraged to continue their education in graduate engineering programs
- Develop communication skills through written reports and oral presentations
- Participate in ethics and professionalism activities
- Interact with students from other universities
- Publish articles on research or give research presentations at national conferences
- Participate in industrial interactions
- Become involved in mentoring RET teachers and or Young Scholars
- Interact with a truly diverse group of students.

REU Program Structure.

REU students may work as individuals or in teams, which may include the ERC's own summer undergraduate interns and even graduate students. The students' projects should include at least some elements of their own design and should be supervised by ERC faculty and graduate students. In many cases this environment provides first-hand knowledge of how industrial research teams operate. The total number of undergraduates involved in these summer projects from all sources at a given ERC can vary from as few as 4 or 5 to as many as 40 or 50. Some multi-site ERCs may have only a single REU program, so teaming with local students is vital. The mix of backgrounds, cultures, and approaches brought by students from different educational backgrounds is an important part of the REU experience. See appendix example 4.4.4.1. In addition to research projects, a well-rounded program of REU activities can include:

- Field trips to industrial sites
- Workshops on technical writing and public speaking
- Seminars in topics such as programming and engineering ethics
- Meetings with high school students visiting the campus
- Mentoring by graduate students and industrial residents
- Assistance with graduate school admissions applications and scholarship materials
- Exposure to an array of center publications
- A showcase to present the student's research project at the end of the summer program

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

Recruitment Methods

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

- Personal visits to other institutions
- Development of long-term relationships with Historically Black Colleges and Universities, Hispanic Serving Institutions, and other targeted underrepresented Minority-Serving Institutions
- Recruitment efforts by previous REU participants on their home campus
- Recruitment through national organizations (e.g. NSBE, AISES or SWE)
- Use of Women in Engineering (WIE), Minority Engineering Program (MEP) and offices that provide services for students with disabilities
- Participation in career fairs
- Internet postings
- Sharing of information about potential participants among ERC Education Directors/Coordinators across the ERC network.

As centers mature, they interact with other ERCs to help them recruit REU fellows for appropriate research areas. This exchange of applicants has been done on an individual basis, from Education Directors/Coordinators to Center Directors, and (in the past) via an e-mailed ERC Education Digest. Given the strong emphasis on recruiting REU students from a diverse population (i.e., women, members of underrepresented minority groups, students with disabilities, transfer or dual-degree students, first-generation students, and students from post-secondary technical schools), centers must develop/leverage connections with schools that serve these populations. Students may not be from the engineering disciplines most prominently represented in the center, and may not even be engineering majors. Undergraduates majoring in physics, chemistry, biology, social science, and business may be valuable and productive REU participants. Because of the burgeoning REU programs, the competition for top students obtained from traditional sources is intense. Broadening the applicant pool can help to achieve diversity while retaining high standards, thereby attracting a new pool of students to engineering. Diversity conferences such as SWE, Society for Hispanic Professional Engineers (SHPE), NSBE, and Society for Advancing Hispanics/Chicanos & Native Americans in Science (SACNAS) are effective mechanisms for recruitment. Centers have coordinated to co-host "ERC booths" at such conferences. This allows for greater visibility and leveraging of funds (i.e., doing so drastically lowers the cost for individual centers to participate).

REU programs may also benefit from linking with other internship programs on campus. This may allow for supplemental workshops, an expanded cohort, more diversity, and a comprehensive showcase of research projects at the end of the summer programs. One example transition program that uses research as a vehicle to introduce a diverse group of students to STEM is the ELeVATE program at the Quality of Life Technology ERC (see example 4.4.7.2). This program promotes military veterans' transition to campus by linking them with research projects and mentors to help them develop technical skills. Due to shared goals, the ELeVATE participants benefit from the REU program activities and *vice versa*. At the end of the summer, students from both programs can present their research in the same research showcase/forum. This is just one example of the type of program that a center could collaborate with across its campus.

A very effective recruitment strategy is to provide opportunities for Student Ambassadors (past summer interns) to recruit future participants at the target institutions:

- Set up information sessions and workshops
- Present research at information sessions and workshops
- Serve as guest speaker or panelists for information sessions and workshops
- Assist peers with application process
- Recommend peers for future summer internships.

Strategies for Funding

One of the best ways to leverage funding and to improve the efficient use of a center's resources is to join with others in setting up and implementing projects. Once the fixed costs have been met, additional participants bring down the cost per participant and provide cross-fertilization of expertise. A number of ERCs combine REU programs with other programs or funding sources. The availability of supplementary funding allows field trips and extended travel to be included in the students' experience. Many campuses host multiple REU programs and this provides opportunities to co-host ethics and communications workshops, social events, and seminars to the mutual benefit of all of the participants. Also, the considerable expense involved in long-distance relocation has been a barrier to some gifted students, and supplementary funding can be helpful. Again, the best sources of specific information about funding opportunities for attendees are the center websites, and the websites of universities and other centers provide opportunities for co-funding of programs. Providing an interesting research, cultural, and social program for the group require*s* planning and supervision, but the wide availability of campus facilities in the summer facilitate*s* this process.

Mentoring

Mentoring is a strong component of the success of REU students within ERCs. Mentoring roles for REU programs may involve faculty to REU, staff to REU, graduate to REU, existing core undergraduate student to REU, and REU to RET and Young Scholar participants. Mentors should be carefully identified with plenty of time for student assignment and mentor training.

As was noted in section 4.4.1, being a successful mentor is not innate to all. Therefore, training is imperative. Mentorship training should include everyone involved in the REU program (e.g. faculty, graduate and core undergraduate students, staff).

Given the geographic distribution of the partners of most ERCs, special attention should be given to methods to connect student REU participants at multiple campuses represented within an individual ERC. It is recommended that no less than two students be located at a given institution, to avoid isolation. Additionally, web-meeting software can provide a mechanism to support weekly research discussions of the group. One face-to-face meeting of the group, either at the outset to introduce participants and facilitate web communications, or at an end-of the summer research poster session, is recommended.

Evaluation, Assessment, and Follow-up/Tracking

The comments made in section 4.4.5 apply both broadly and also specifically to REU programs. It is recommended to create REU cohort groups that allow messaging to the group and generating discussion among previous participants, allowing them to stay in touch with each other.

REU Lessons Learned

1. Use multiple methods to recruit diverse students into your programs.

2. Be highly inclusive – leverage resources at your university (e.g., other REUs, honors programs, etc.), and at partner universities.
3. Create strong two-way relationships with your industry membership.
4. Search for ways to create community – find a way to showcase undergraduate research results.
5. Mentoring is important; so train your mentors explicitly.
6. Assessment and evaluation are absolutely critical, and it is highly recommended that you partner with professional A&E teams (internal or external) to develop the A&E strategy for your center. You both need to establish the research questions, as well as ensure that the instruments and analyses will allow you to answer the questions (this includes getting human subjects clearance so that you can publish your results).
7. REUs must be U.S. citizens or green card holders

4.4.7 Community Colleges

The Nation's community colleges and technical institutes are valuable and often underused sources of technical workers. Community colleges serve a vast number and diverse population of students. Due to the flexible scheduling, modest cost, and other reasons, community colleges also attract large numbers of women and minority students. It is estimated that half of the Hispanic students attending college nationwide are at community colleges.[10]For these reasons, they are a fruitful and underutilized source of REU students (see appendix section 4.4.5).

In addition, many community colleges have historically close ties with industry. Industry-oriented or industry-sponsored certificate courses and technical training programs are often associated with community colleges rather than four-year colleges. The technicians and skilled workers of the technology industries are likely to be products of the community college systems.

For these reasons, ERC education programs should actively focus on creating links with community colleges. Again, Academic Affairs offices can help; they are resources to try to connect with and/or utilize any existing articulation agreements and partnerships. Strategies to develop such links may include:

- Provide speakers and guest lectures for community college classes, conferences, and events;
- Provide hands-on demonstrations and activities for community college classes, conferences, and events;
- Serve as an advisor or thought partner on STEM curriculum, proposals, transferring to 4-year institutions;
- Organize interested graduate students and postdocs to volunteer as judges for STEM activities and events at community colleges;
- Partner on grant proposals with community colleges, or provide letters of support for proposals submitted by community colleges; and
- Inform community colleges of STEM events at your campuses

Recruiting

A variety of methods are recommended for recruiting community college students. A starting point is to build a relationship with an academic leader (e.g., department head or program chair or senior faculty member) at target institutions. These people can provide invaluable advice on how best to reach their students.

Recruiting should be viewed as a year-round effort involving active, ongoing communication and interaction at target institutions. For example:

- Invite prospective students to STEM events at your campus;

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[10] See http://www.highereducation.org/reports/pa_at/index.shtml

- Attend conferences and other events that focus on the targeted population and follow up with community college representatives and students you meet;
- Host summer internship information sessions for students at community colleges;
- Host virtual information sessions and workshops through online webinars; and
- Send monthly emails to key staff/faculty contacts and student e-lists with opportunities, updates, and reminders.

Organizations or groups that can leverage your efforts include:

- MESA (Mathematics, Engineering, Science Achievement) is nationally recognized for engaging educationally disadvantaged students so they excel in math and science and graduate with STEM degrees. MESA partners with all segments of higher education as well as K-12 institutions. See appendix 4.4.10.1 for an example.
- Veteran's offices.
- Transitional programs (e.g., 2 + 2) are a powerful way of bringing community college students into 4-year research-oriented institutions. The maturity of such programs varies greatly state-by-state and therefore developing such opportunities will be highly variable amongst centers.
- Your campus' transfer office (if you have one).
- Advanced Technological Education (ATE) centers are NSF-funded centers that endeavor to strengthen the skills of technicians, whose work is vitally important to the nation's prosperity and security. In ATE centers and projects, community colleges have a leadership role, and work in partnership with universities, secondary schools, business and industry, and government agencies, to design and carry out model workforce development initiatives. Given the complementarity of the ATE and the ERC mission, ATE centers may represent a viable location for outreach to community college communities by the ERCs. Please note: The location and subject matter for each ATE center varies by geographic location, so the opportunity for development of connections between ATE centers and ERCs will be highly variable.

Mentorship & Training

Community college students may require additional mentoring to ensure success when involved in summer-research programs populated primarily by students from research-intensive institutions. Take steps to ensure mentors are well trained, and consider doing "boot-camp" or similar orientation/immersion programs to help these students adjust. Community college students are likely best served by experiences within a cohort. Therefore, we discourage sending these students to partner sites where a cohort does not support them.

Other Activities

Community colleges offer extensive opportunities for ERC educational activities. For example, community college students—and possibly faculty members—can be participants in short-courses/workshops/RET programs/design competitions offered by the ERC. Community-college faculty/instructor participants could then become on-site recruiters for opportunities in the ERC, and student participants in short-courses can interact with center-faculty to build relationships. Community colleges may also be fertile grounds for ERC graduate student presentations and teaching.

Community College Lessons Learned

Don't overlook campus outreach and recruiting professionals, who often have budgets and staff that have expertise in community college recruiting.

4.4.8 Veterans' Opportunities for Engagement in the ERCs

NSF recognizes that veterans represent a potential underutilized workforce for the U.S. science and engineering research and industry communities. Many veterans are transitioning from active military service to civilian careers and exploring education options through the post-9/11 GI Bill. At a time when the U.S. is challenged with a science, technology, engineering, and mathematics (STEM) workforce shortage, NSF is exploring alternate pathways of veterans' engagement into STEM fields.

To better engage veterans in engineering projects, NSF is soliciting requests from their active grantees for the Veterans Research Supplement (VRS)[11]. The proposed VRS will afford veteran students, veteran teachers, or veteran community college faculty an opportunity to participate with active ERC grantees to conduct industrially relevant research in order to gain a deeper understanding of engineering. See appendix section 4.4.7 for examples.

[11] See Dear Colleague Letter Number NSF 13-047.

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,[12] 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.

[12] 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

4.6 ASSESSMENT AND EVALUATION

4.6.1 Rationale and Definitions for Assessment and Evaluation

NSF recognizes the importance of assessing the impact of all ERC University and Precollege Education programs and the General Outreach to involve precollege students in the ERC activities that it supports. Accordingly, in the 2015 ERC solicitation it was required that ERCs assess, evaluate, and track the impacts of educational and outreach programs on program participants; requirements in this area will be specified in each class' solicitation. Having an assessment and evaluation plan in place not only ensures that the center meets NSF requirements, but it is also key in determining which education programs are helping the center meets its mission and which should be modified or terminated. It is the best way to gather data that can direct the development of effective programs, and goes beyond the use of anecdotal information about program satisfaction towards a more data-driven approach for assessment and evaluation of impact.

As a starting point, it is important to define assessment and evaluation, because although often used interchangeably, the two terms define different processes. Contemporary definitions vary as a function of the context in which the assessment or evaluation occurs and in terms of the assessed content. In general, *evaluation* refers to a summative judgment of worth, merit, and value at the end of a project, while *assessment* is more formative (occurring as the project progresses) and guides improvement over time. Specific to the ERCs, assessment should guide continuous improvement of the ERC's University and Precollege Education programs and the General Outreach activities involving precollege students, while measuring the programs' impacts over time. NSF ERC Program-level evaluations of educational impact are carried out by the ERC Program.

Program evaluation and assessment are not just the evaluator's or assessment officer's responsibility. Education Directors also must understand the process, design, and content of program assessment and evaluation and how to present the results effectively to inform all involved. Additionally, the center's full Leadership Team should be included in assessment and evaluation efforts. Regular communication of efforts and results is recommended.

ERC impacts are most often related to college and career trajectories in engineering and related fields. ERCs contribute to both industry and academia via their precollege and university student alumni. Assessment is an important way to demonstrate this impact. In the sections that follow and in the appendix to this section, general guidelines, key features, processes, procedures, and examples are presented to guide ERC personnel in developing and implementing assessment and evaluation plans.

The structure of Gen-3 ERC education programs should inform this process—i.e., University Education (undergraduate and graduate), Precollege Education (RET and Young Scholar programs), and General Outreach designed to engage precollege students in the ERC's research area to stimulate interest in engineering careers. In addition, the University Education programs are designed so that the ERC graduates acquire skill sets needed to be effective in industry and creative and innovative in both academe and industry. This structure is often difficult for faculty to understand and the assessment/evaluation officer can be especially helpful in working with the ERC's Education Director in designing and assessing the impacts of this new approach.

4.6.2 General Guidelines

In order to develop an effective Assessment and Evaluation Plan, all stakeholders should be involved at the earliest stages of program development, including representatives from each partner institution. This will include Education Directors, assessment officers, program coordinators, and program evaluators. To ensure that all possess a clear understanding of the assessment purpose and planning process, the following steps are suggested:

- Assessment personnel and the related assessment plan should demonstrate an understanding of NSF requirements, including quantifiable outputs and the educational impact of study components.
- Assessment planning should co-occur with overall center programmatic planning and should be in place on the first day of center operation.
- Desired outcomes, perceptions, and expectations of the University and Precollege Education programs and the General Outreach to involve precollege students in the ERC activities, must be determined.
- Appropriate methodology and assessment tools must be selected for each activity.
- Timelines for each assessment component are a must.
- The center program Evaluation/Assessment Officer should be someone who is trained in qualitative (e.g., interview) and quantitative methodologies (survey design, psychometrics), and corresponding statistical and narrative analysis. Evaluators can be external or internal and each center must decide whether to have an external evaluator based upon discrete ERC needs. This person must understand the goals of the ERC program and the center in order to develop an appropriate design and instrumentation. Be mindful that many professionals trained in this field are accustomed to measuring learning outcomes, which is not a goal of ERC education programs, per se. Thus, precollege and university level programs will have different outcome goals that should be carefully determined using the ERC Program's performance assessment criteria and the center's own programs' goals.
- All projects must meet the Institutional Review Board (IRB) approval for not only the lead university, but also for the partnering universities and industry. Furthermore, it is a requirement that IRB approval be obtained before conducting any publishable research with human subjects.

One of the most challenging parts of the assessment process is determining appropriate expected outcomes. It is often the case that faculty tend to set unrealistic expectations and over-promise results. A common example is to list changes in state-wide standardized test scores as a result of a center program. Given the large number of variables that impact test scores, it is not reasonable to assume that a small-budget (in comparison to the total education budget that impacts test scores) intervention will have an impact on state-wide standardized test scores. It is therefore important that the assessment director work closely with research faculty to ensure that expected outcomes match the time, duration, and budget of the intervention.

Appendix section 4.6.1 provides several examples of program-wide education assessment and evaluation at different ERCs.

4.6.3 Assessment Design

There are multiple levels of information that can help guide the ERC education programs' development. Front-end evaluation is a useful tool, similar to market research. An example case where this would be useful is in the development of course materials that the ERC plans for adoption by a wide audience. Front-end evaluation would involve surveying the potential users (faculty) of the new materials about what topics they would like to see covered. Also, surveying potential students about what their existing level of knowledge about a topic is would uncover misconceptions that the developers could address. Incorporating end users into the design process results in better materials and facilitates adoption.

Many times, valuable information can be gleaned from informal quick studies with small numbers of participants. For example, prior to making a website or on-line unit public, it is always helpful to have small numbers of the intended audience beta test the site or materials. Problems with navigation and function can be easily corrected before "going public." Also, quick, short surveys can help guide programming. For example, finding out how current students learned about the center can help recruiters identify useful recruiting avenues that should be continued, as well as identify less productive methods that should be abandoned.

Formal assessment will also be appropriate in many cases. Pre- and post-assessment of knowledge and skills utilizing objective instrumentation is an accepted way to measure student learning outcomes. Instrumentation typically includes items testing for specific content knowledge, and over time and with due diligence, instrumentation can be revised and modified to enhance validity and reliability (Drummond & Jones, 2010).

Both quantitative (e.g., scales, rankings, etc.) and qualitative (e.g., focus groups, interviews) methods are useful. Quantitative designs can fail to capture the richness of phenomenological experiences best offered up through personal narrative, so supplementing quantitative measures with qualitative methods can produce a more complete description of outcomes. Guided discussion can bring about descriptive data useful to the assessment process (Vacc & Juhnke, 1997). These mixed-method designs, when properly done, result in rich quantitative and qualitative data which are mutually supportive, thus enhancing design internal consistency and validity and increasing results generalizability (Hanson, Creswell, Plano Clark, Petska, & Creswell, 2005).

At a minimum, mixed-method assessment designs should include clearly articulated goals and student's gaining skill sets. The essential goals are to determine whether the (i) mission statement is being properly addressed and (ii) students are gaining the desired skill sets. Content-specific instrumentation measuring teaching (i.e., educational activities) and learning (i.e., skill sets) is useful. Complementary case-by-case interviews or focus groups are also helpful.

There are useful frameworks to help organize the assessment and evaluation plan. One example is the Kellogg Logic model, which provides stakeholders with a visual template that connects activities to expected outcomes.[13]

4.6.4 Suggested Instrumentation

Instrumentation construction can often feel like a daunting task; however, the primary necessity for proper construction is time. Gen-3 ERCs are funded under cooperative agreements with an initial time line of five years and renewals can extend that to 10 years. Support is provided in annual increments. The first renewal review is during the third year, where NSF expects that the assessment program has been set up and is functioning effectively to guide practice. Three years is more than adequate to initialize and "study" instrumentation developed specifically for use within ERC education programs. Other requirements for instrumentation development include a good understanding of student learners, their backgrounds, and prior knowledge base, as well as the desired learning outcomes.

Table 1 provides suggested measures for assessing major education programs. Besides quantitative methods (e.g., survey), qualitative methods such as in-depth interviews are also useful to identify students' learning processes, outcomes and concerns. Initially, it is often a good idea to conduct a qualitative assessment due to the small sample size of most education programs.

Table 1. University and Precollege Assessment

Program	Example	Selected Measures
Undergraduate Program (NSF requirement)	• Academic-year Undergraduates Survey • Summer Research Experiences for Undergraduates (REU) Survey	• Career Path • Concept Inventory (e.g. Hestenes, Wells, & Swackhamer, 1992) • Research ability • Attitudes (Hilpert, J., Stump, G., Husman, J., & Kim, W., 2008). • Self-efficacy (Bandura, 2006)

13 http://www.wkkf.org/resource-directory/resource/2006/02/wk-kellogg-foundation-logic-model-development-guide

Program	Example	Selected Measures
		• Professional development (Rubric for evaluation of presentation, self-assessment of key professional skills) • Creativity • Descriptive metrics: publications, presentations, attending graduate school/ industry
Graduate student skill-sets defined by each center (NSF Requirement)	• Entry survey • Exit survey • Employee assessment	• Longitudinal tracking on the progress of graduate students' skill-sets defined by your center (e.g., creativity, innovation, analytical skills, problem solving, leadership, motivation, communication skills) before starting and after graduating from graduate school. • Employee assessment on students' skill-sets at workplace. • Quantitative metrics: participations of professional training, publications, internship, and awards. • Engineering Global Preparedness (EGPI: Ragusa 2010, 2011) • Engineering Creativity and Propensity for Innovation (ECPII; Ragusa, 2011) • Course/program specific concept inventories
Precollege programs (NSF requirement)	• Young scholar program (YSP) survey • Research experience for teachers (RET) survey • Precollege partnerships • Portfolio assessment	• YSP: pre-and post-measurements on engineering knowledge, interest, research ability, attitudes, and future plan. Quantifiable metrics: publications, presentations, and persistence of interesting in studying in STEM. • RET: pre-and post-measurements on teaching efficacy , professional development, and engineering knowledge. • Quantitative metrics: impact of classroom curriculum development or research publications. • For students of RET Teachers: o Science literacy- specifically, science vocabulary, reading comprehension, science writing; (Ragusa, 2012) o Motivation for Science Questionnaire (Ragusa, 2012)
General outreach (NSF Requirement)	• Summer camps • Lab tours • Field trip • Community outreach	• Summer camps: pre and post measurement on engineering knowledge, interest in learning specific activity, self-efficacy in STEM, attitudes, & career/major preference. • Other outreach: post-measurement on interest in learning more, basic knowledge, and participant's feedback on overall programs.

Instrument sharing among ERCs is strongly encouraged. Granted, measurements will discretely vary according to ERC scientific and research orientation; nonetheless, assessment officers can talk among themselves to determine instrument-sharing advisability. The American Psychological Association recommends the following protocol for instrument sharing:[14]

1) Contact the instrument author to discuss instrument sharing.
2) Be mindful of copyright issues and obtain written permission from the instrument author prior to using the instrument.

As mentioned, instrumentation is generally discrete to each ERC research/scientific agenda. Thus, issues of fair use of copyrighted material must be considered. In short and when engaged in instrument sharing, the borrowing ERC, in collaboration with the instrument author, should discuss the likelihood of—or need for—instrument adaptation and discern the necessity for and ensuing transformative nature of those adaptations. A full explanation of fair use practices with copyrighted materials may be found at www.copyright.gov.

14 http://www.apa.org/science/programs/testing/find-tests.aspx?item=4

Overall, survey instruments should be carefully designed by the following steps:

1) Determine the evaluation goals or purpose of assessment;
2) Gather and study existing assessment reports from NSF (e.g., REU program, RET program, and YS program);
3) Use published (validated and reliable) scales from the fields of education, engineering education, sociology and psychology for specific measures you are interested in; and
4) Finalize the survey by pre-testing on a small pilot set of representative students.

Structured interviews are one methodology for discovery in the assessment process, particularly when the interview questions are predicated on a specific taxonomy for learning or criteria for assessment (Vacc and Juhnke, 1997). Case studies, phenomenological interviewing, or focus groups can be used for structured interviews. Once again, guiding questions derive from a good understanding of (i) student learning, (ii) learning outcomes or skill sets, and (iii) and mission statement concepts. To be effective, the person guiding interviews must be professionally qualified for individual interviewing and managing group dynamics.

Appendix section 4.6.2.1 gives an example of the development of an education program assessment instrument by an ERC.

4.6.5 Data Collection and Management

Creating a systematic and organized method of tracking all the education information and data through websites or other web tools (for example, Google Docs, or Survey Monkey[15]) across university partners is crucial. Data collection and management plans should be developed as part of the ERC proposal process.

Documenting photos, videos, and other form of evidence for each program is beneficial for writing the annual reports and renewal proposals. Cloud computing can be used to share photos across partner universities, if permitted by the institutions, although photo release forms and signed forms should always be stored with photos.

With quantitative designs, SAS, Mplus, SPSS, or Microsoft Excel can be utilized to analyze pre-/post-data. In raw form, these data should be housed in a locked office, on a password-protected desktop of the Assessment Officer. Once analyzed and ideally, aggregated, data should be (i) transferred to the ERC reporting database, (ii) reported at the annual conference, and (iii) reported in the engineering education literature.

Qualitative data such as interviews or focus groups' narratives can be audio-taped and, when possible, should be video-taped for data collection. Software also exists for analyzing and presenting qualitative data, (for example: http://provalisresearch.com/products/qualitative-data-analysis-software/). All data must be stored according to IRB requirements and retained for the time period required by each university.

4.6.6 Using Assessment Data

Assessment is intended not only to measure impacts on students and teaching efficacy but also to gauge programmatic effectiveness. Modifying and improving programs is best done through systematic data collection, management, and analysis.

NSF requires center reporting on an annual basis, and this includes Assessment and Evaluation activities and results. Assessment results may be used by the Site Visit Team to evaluate the effectiveness of the education programs. It is recommended that the center strive to exceed NSF expectations, highlighting signature programs by reporting data through graphics, tables, and longitudinal assessment; the ERC

[15] http://www.surveymonkey.com

should focus upon the broader impact of educational and outreach activities specific to these signature programs.

Besides assessing participants' gains in learning, interest, attitudes, teaching efficacy, or future career goals, it is important to evaluate each education program as a whole in order to identify the weakness and strength of program design. Program evaluation will serve the purpose of improving logistics and program design.

4.6.7 Notes

Rationale and Definitions for Assessment and Evaluation

The National Academy of Engineering has recommended both best practices and attributes for engineering education in their *Engineers for 2020* report (NAE, 2005). Additionally, the Academy defined Discipline-Based Education Research (DBER) (National Research Council, 2012). The NAE together, with the National Research Council, identified "assessment best practices," (NRC, 2011) as an important component of DBERs. In 2006, the Educational Testing Service (ETS) published three issue papers describing a Culture of Evidence—or evidence-centered design—as a methodology for systematically assessing post-secondary education effectiveness across institutions of higher education. Evidence-centered designs link institutional or programmatic vision and mission with student learning outcomes, which in turn are aligned with discipline-specific professional standards, and measured by, or exemplified through, concrete evidence (Millett, Payne, Dwyer, Stickler, & Alexiou, 2008). See section 4.6.8 below for reference citations.

Framers of the ETS papers emphasized that "at the heart" of an evidence-centered design is the issue of validity, whereby evidences measure or exemplify that which they purport to measure or exemplify. Evidence could include (a) annual data collection with valid/reliable instrumentation; (b) pre-/post-test designs using instruments with multiple forms; (c) a variety of assessment formats, including asking questions; and (d) "peer group comparisons." The goal of evidence-centered assessment is to produce valid and reliable data for decision-makers to determine higher education and programmatic effectiveness (Dwyer, Millett, & Payne, 2006; Millett et al., 2008; Millett, Stickler, Payne, & Dwyer, 2007).

Suggested Instrumentation

Resources for survey design and scale development from sociology and psychology disciplines:

Internet, Mail, and Mixed-Mode Surveys: The Tailored Design Method by Dillman, Smyth, and Christian.

Scale Development: Theory and Applications by DeVellis.

Reliability and Validity Assessment by Garmines and Zeller.

Psychometrics Theory by Nunnally and Bernstein

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4.7 GRADUATION AND SUSTAINABILITY STRATEGIES

4.7.1 What to Expect: The Big Picture

In the transition from an NSF-funded ERC to a graduated and self-sustaining ERC, the education programs undergo significant challenges and changes. Some program components are amenable to institutionalization, some gain support from their university administrations, but others depend on supplemental funding that is not likely to be continued after NSF funding ends.

As a center approaches the end of the 10-year NSF funding cycle, these concerns come into sharper focus. NSF intends that the culture of ERC education will continue in the center; but without continuing support from the university and industry, it is likely that many or most of the ERC's education programs will end. The center's Education Coordinator/Director should work with the center leadership to develop a self-sufficiency plan from the outset. This plan can include soliciting education funding from the university, foundations, and the private sector (notably industry or foundations).

When a center "graduates," or reaches its full term, NSF funding for educational activities may continue on a competitive basis for RET or REU Site awards, or other NSF education program awards. Depending on the Center Director’s commitment to education and the financial strength of the graduated center, some education programs may be cut back or ended. Areas that may be affected include the extensive involvement of undergraduates and underrepresented populations in education and research activities, RETs, as well as outreach programs. Given the importance of these areas, it is important to come up with a sustainability plan from the onset of the ERC. The continuation of a graduated center in some ERC-like form is essential to maintaining support for the associated education programs.

Preliminary data from earlier graduated centers suggest that:

- Research tends to become focused on applied, short-term projects that may not be suitable for dissertation level work.
- Undergraduate research and outreach program components (including programming for minorities and women students) decline.
- Student involvement, interdisciplinary focus, and team-based research decline.
- In most universities with graduated centers, the main lasting effect of the NSF ERC funding on education programs to date has been the development of multidisciplinary degrees, minors, and certificates that have helped shift engineering education away from the traditional disciplinary compartmentalization towards the interdisciplinary systems focus that is required to solve today's engineering challenges. As such, it is critical that courses that have been added to the curriculum by the center and any associated certificates, minors, and/or majors should be integrated in the university curriculum prior to the end of the center, thereby becoming part of the continuing programming of the university

Studies and a recent survey of graduated centers[16] have shown that successful continuation of education programming depends on several factors:

- Financial support (hard money) for a full-time person to coordinate activities, who is prepared to seek funding from grants and other sources;
- Strong institutional support , including support for the ERC education culture as well as significant cash or other direct financial assistance;
- Finding champions for the education and preparation of students, both in industry and at the university level;

[16] http://erc-assoc.org/topics/policies_studies/Grad%20ERC%20Report-Final.pdf

- Engagement of faculty motivated to continue and the existence of institutional incentives that further this motivation;
- A strong, continuing commitment on the part of center leadership to the goals of an ERC education program;
- Successful securing of funding from governmental agencies and private foundations;
- Creative ways of packaging program elements that fit the type of activities industry is able and willing to support (i.e., lab training internships, design course support, graduate fellowships); and
- A strong, evolving research program.

Attention must be paid to all these characteristics from the outset. They must be nurtured and maintained throughout the life of the center in order to provide a platform for successful implementation of the strategic plan. Appendix 4.7 presents examples of sustainability planning for education programs of graduated ERCs.

4.7.2 Strategic Planning for Graduation

Impending graduation can seem overwhelming, but actually it is a wonderful opportunity to reexamine the education mission of the ERC and to further assess the programs (i.e., what worked, what didn't work, has the culture of academic engineering been changed?, etc.). Based on this analysis, a new education vision can be established with a new mission statement, goals, objectives, organization, strategic planning, scope, range, initiatives and actions, budget, dissemination, delivery systems, and collaborations. It is important to communicate with industrial partners, education partners, and center faculty and staff to determine this new vision. It is also important to keep in mind the "products" of the education program and help create a strategic business model. This will help identify stakeholders and enable better communication about the benefits of the program for maximum leverage.

ERCs build considerable momentum in their education programs (both precollege and university) by the sixth year. They provide an educational environment for university students and K-12 access/support that is unmatched by other programs on campus. ERCs build an integrated cross-disciplinary culture in partnership with industry, where knowledge is transformed into real-world systems technology. The involvement with industry and the ability to see real-world results are strong motivators for undergraduates and even precollege students. These aspects are unique to the ERC environment and should be considered as valuable assets post-graduation. Considerable time and effort has been invested in creating programs that integrate research and education, collaboration, and a cross-disciplinary focus. The best strategy is to continue with an education vision that uses some of these programs, along with the "ERC" brand/status, and not to reinvent the wheel.

Timeline and Transition Plan Development

An important issue in strategic planning is the impact of the ERC's 10-year life cycle. Planning for center sustainability should begin in earnest no later than year 3 and, by year 5, a center should have a business plan for graduation. As funding is phased down overall in years 9 and 10 and the center graduates from NSF support, the education program's survival depends on institutional support (including cash), motivated faculty, commitment to the goals of the education program, and a strong, evolving research program. The continuation of a graduated center in some ERC-like form is essential to maintaining support for the associated education programs. As the center matures, the education budget should include increasing contributions from sources such as industry members, NSF education funding outside the ERC Program, and private foundations. Opportunities should be pursued to leverage the NSF funds using non-federal ERC funds for matching.

Key Participants

A strong relationship with the other members of the ERC's Leadership Team, and especially with the Center Director, will greatly enhance the center education program's prospects post-graduation. Organizational relationships that were created during the life of the center are key to the maintenance of most education programs, even programs that have been institutionalized. For example, partnerships with affiliated deans, department chairs, and other university leaders will affect the academic units and influence what a graduated center may anticipate in terms of its ability post-graduation to sustain delivery of classes, certificate programs, and new degree programs the ERC established. Sustained collaborations are the key to success, particularly for precollege programs. Working with local schools and universities is easier than working with partners who are farther afield. It also builds relationships with local partners that are potential sources of support and enables potential reforms in STEM education (and education writ large), it improves the diversity of the population drawn into STEM research, and it enriches the general scientific/engineering literacy. Therefore, as the center matures, it is beneficial to strategically focus precollege program support on efforts that resulted in strong local partnerships. However, the opportunity to act locally should not blind ERCs to their national and international opportunities, which reflect the technology and market scope of the industries they serve.

Industry. The value of the industry-education link to ERC success and ERC sustainability cannot be overemphasized. The link between industry and education is one of the determining factors in the success of an ERC, and the strength of this link is a crucial element in the longevity of the center. It can also provide a strong base for a successful sustainability plan, and this element should be incorporated into ERC strategic plans at an early stage of the center. Industry is involved in all aspects of the ERC education program. Industry representatives often serve as mentors to undergraduate, outreach, and/or graduate students and may serve on the students' masters or doctoral committee. Industry may sponsor undergraduate or graduate internships, or sponsor students' undergraduate or graduate degrees in whole or in part. Industry input helps shape the curriculum, develop original courses, and it influences the very nature and approach of the engineering curriculum of the future. Industry members may present lectures, course sections, or entire courses, or teach courses in partnership with ERC faculty members. Industrial representatives often serve on review panels evaluating and shaping the ERC education program. Industry interaction with ERCs may result in new employment and internship opportunities for students, and can even lead to the development of new research projects and thrusts for the ERC.

Many creative approaches have been developed to sustain the link between industry, faculty, and students in the center and to provide continued opportunities for industry mentorship of students post-graduation. At the most basic level, teams of students and faculty may continue to travel to companies for presentations, meetings, and tours. For more direct continued involvement, industry may design projects or suggest problems and provide funding for study by a team of faculty students in the graduated center. In general, industry will remain engaged if they feel working with the graduated center continues to help them hire students with the skills they need and address research critical to their marketplace success. Examples of success include:

- The Center for Biofilm Engineering (CBE) in Montana graduated in 2001. As of 2013, they are still doing well and just held a meeting with their companies—with 79 attendees.
- The Center for Power Electronics Systems (CPES) remains well funded and with increasing support from their Industry Consortium program at the level of more than $2M per year. The program alone supports about 30 graduate stipends. They are also well funded with sponsored research at a similar level.
- The University of Washington Engineered Biomaterials (UWEB) ERC continues to function after graduation, primarily as an Industry Consortium. Much of the research from the ERC has either been commercialized or is being successfully advanced with support from other grants (over $30 million).

Students. Students (undergraduate or graduate) should be involved in developing and evaluating post-graduation plans and implementing the new program. They are an important resource and will likely have a lot of energy, know what you are doing, and have good ideas for the future. Over ten years of NSF support, the center's reputation should have attracted students interested in working in an ERC culture; and future recruiting will benefit from the connections made by the center with departments, colleges, and the university during the life of the center. By demonstrating to others on campus the benefits of joint recruiting at professional meetings, specialized conferences (e.g., the Society for Advancing

Hispanics/Chicanos & Native Americans in Science [SACNAS], the American Indian Science and Engineering Society [AISES], etc.), it is likely that other units on campus will cover the associated personnel and travel costs to facilitate continuation of these joint recruitment activities post-graduation. Centers should not be shy about promoting the "ERC" brand post-graduation to help with recruiting.

The Student Leadership Council has a strong role in education in a successful ERC and should be included in this strategic planning. It is also advisable that the SLC continue post-graduation, as it is a forum for student interaction and communication with the ERC's Director.

Budget

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

Continuing education programs such a short courses for industry can be self-supporting and/or generate funds if priced properly. Surveying the center's industrial partners will help determine if this is an option for a given center. Written educational materials developed for either practitioners or students can also be sold at cost to cover the production of the materials. Be sure to market the most successful education programs to universities, industrial stakeholders, and others. The resulting positive publicity may attract volunteers and other support or help recruit students. Publicity of center programs also promotes the concept of the ERC.

4.7.3 Retaining High Value ERC Educational Features

There are several features of the ERC education programs that are highly valued by a range of stakeholders. The following are critical post-graduation:

Education Director

One center has experienced not only no decline in programming after graduation, but an expanded education program. This center, the Center for Subsurface Sensing and Imaging Systems (CenSSIS), can serve as a model for others seeking to successfully transition to self-sufficiency. A large factor contributing towards their success is the integration of the ERC's Education Program Director into the college post-graduation. Funding for the position is now provided by the Dean's Office and is an indication of the degree of institutional support for the ERC vision, a key element identified by SciTech Communications[17] as a necessary condition for the maintenance of an ERC culture post-graduation. The previously ERC-focused education efforts have been disseminated into the college-wide programs that the ERC Education Program Director now manages. In addition, the graduated ERC at this location successfully seeded an Undergraduate Fellows Program that has been expanded to the College of Engineering as a whole. Similarly, the CenSSIS REU program has gone college-wide and pre-collegiate outreach activities have also expanded. These programs operate on an expanded budget derived from a combination of NSF grants, multiple foundation grants, School of Engineering funds and other non-industry sources.

University Education & Research Programs

A significant number of participants—more than for any other key feature—identified the education of university-level students as the single most significant strength of the ERC Program. The consensus

[17] Williams, James E. & Courtland S. Lewis (2010). Post-Graduation Status of National Science Foundation Engineering Research centers: Report of a Survey of Graduated ERCs. SciTech Communications, Melbourne FL.

viewpoint was that cross-disciplinary interactions are key to the unique value of an ERC-style education, and that all characteristics of this feature, such as the interaction with industry and the leadership experience gained through involvement in the ERC's SLC, are important and valuable. These programs are important because they provide: exposure to a cross-disciplinary systems view and opportunities, teamwork, exposure to the latest developments, innovation and entrepreneurship, leadership opportunities, direct involvement with industry, and communications training and opportunities.

These characteristics may be difficult to maintain post-ERC because of funding and cultural shifts. The following strategies can help overcome these barriers and help maintain these features:

- Establish a new ERC curriculum. This can be a challenging and complex task, but it can help maintain interdisciplinary research & education areas.
- New degree programs, in particular, will require substantial long-term institutional resources and commitment from the ERC and the parent university, but these will by their very nature be sustained past the life of NSF ERC funding.
- If your ERC is a multi-university center, establish long-term memoranda of understanding so that credit can be given to students taking the course at other partner universities.
- New degree programs must be especially well coordinated with the existing academic standards and structures of the university and build on student interest and enthusiasm; as such, they will also be sustained past the sunset of NSF funding.
- Professional certificate programs, if properly planned and delivered, can help meet the demand for continuing education in the ERC's associated industry and improve the reputation of the center. ERCs that offer such programs, however, must allow for enrollments that fluctuate with swings in the economy.
- Maintain and/or build new testbeds as a source of student research, interdisciplinary, and multi-campus research and education collaborations.

An example of College-wide adoption of ERC-developed courses follows:

- The graduated but still-active Packaging Research Center (PRC) at Georgia Tech had developed two "Design, Build, Operate" courses. Both of these courses were developed and initially fully supported by the PRC for about two years. After the trial period of two years the Center asked for them to be cross-listed and included as permanent senior-level courses in the curriculum of Mechanical and Materials Science and Engineering, in addition to Electrical Engineering. It took a little over a year for these courses to be approved by the departments and all was completed before the end of NSF ERC funding. These courses are now offered regularly every year. A graduate course that was developed by Center Director Rao Tummala, "Microelectronic System Packaging," is cross-listed among the other engineering departments (EE, ME, MSE and ChE) and continues to be offered regularly. Since the cross listing and approval process were completed before the end of NSF ERC funding, these courses became permanent courses in the curricula, which makes it easier to offer them every year without much support from the PRC.

Cross-institutional Collaboration

It is a significant challenge to maintain multi-campus cohesiveness and funding; all graduated ERCs have handled this differently, with varying levels of success. Cross-institutional collaborations can be preserved by continuing to share experiences and ideas through portfolios, workshops, and other mechanisms. Partner universities can continue to share recruitment activities by, for example, recruiting for one another, or by conducting joint recruitment events at partner universities for REU sites, Research Assistant (RA) positions, etc. In particular, both cross-campus research and education initiatives can be sustained, and new opportunities developed, by continuing to encourage cross-campus student exchanges (e.g., hosting REU students, cross-campus summer research exchanges for graduate students, and collaborative recruitment of graduate students from partner institutions). An important feature of most ERCs is the SLC, which gives students a collective voice in the center's affairs and fosters leadership skills. Continuing the SLC past graduation ensures continued communication between campuses. Examples of cross-collaboration success post-graduation include the following:

- When the Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC) graduated, Emory University and its partner Georgia Tech appointed a committee to make plans for the future. The ERC has been reconfigured and renamed, but continues to move forward with financial support from both institutions
- The Pacific Earthquake Engineering Research (PEER) Center operated as an NSF-funded Center from 1997 to 2008. The Center continues today, with more activity, research participants and funding than it had as an NSF center. PEER has added more core and affiliate institutions and investigators continue to write collaborative proposals and have more than 50 sponsors.
- The Gordon-CenSSIS ERC is still in operation. They competed for and won two major center-level awards as a multi-partner collaborative. These are the ALERT Center of Excellence, funded by the Homeland Security Agency, and the PROTECT Center of Excellence, funded by the NIH's National Institute of Environmental Health Sciences. CenSSIS set up a plan on how to distribute external grants across the partner ERC universities to maintain those ties on new grants.
- The Particle Engineering Research Center (PERC) at the University of Florida is still continuing. Even though they were among the last of the single university-led ERCs, upon graduation in 2005/06 they joined hands with some of the faculty funded by PERC at other universities and have applied for joint research grants. With one of them they have established a joint NSF Industry/University Collaborative Research Center (I/UCRC).
- Following graduation the Offshore Technology Research Center (OTRC) partners (Texas A&M University and the University of Texas at Austin) successfully pursued a major 5-year cooperative agreement with the Department of the Interior, which was subsequently renewed for another 5-year period, as well as several joint industry projects.

Opportunities for Diversity

The NSF funding and direct influence of the ERC to directly impact diversity will cease after graduation, but most graduated centers have found that the commitment to diversity has been institutionalized and that other sources on campus may be leveraged to provide support. During the center's lifespan, collaborating with NSF programs such as the Louis Stokes Alliances for Minority Participation (LSAMP), one of the Alliances for Graduate Education and the Professorship (AGEP), Bridge to the Doctorate, and other programs will create a network for fostering diversity that will continue beyond Year 10. Additionally, prior to graduation the center leadership should build relationships with the Deans of the Graduate School and Undergraduate Affairs, or their equivalent, at each partner campus to encourage and assist the University leadership to pursue diversity grants. Suggestions for sustaining the diversity culture of the ERC post-graduation include:

- ERCs should make special efforts to reach certain groups (including underrepresented minority groups, veterans, and at-risk youth). In this role, the ERC seeks to improve public awareness of technology, improve the skills and knowledge of potential science and engineering students, increase the diversity of the engineering student pool, and recruit those students to the ERC itself and/or its associated institution(s). Work with industry, university upper-level administrators, and other units on campus (for example, Civic Engagement and Service Learning units) to maintain these functions.
- Seek upper-level administration, industry partner, current NSF ERC, and other university organization support to continue recruiting events at diversity conferences (AISES/SACNAS, SWE, SHPE, NSBE, NOBCChE) and technical conferences (IEEE, AMS, ASCE, etc.).[18]

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[18] AISES/SACNAS: American Indian Science and Engineering Society /Society for Advancement of Chicanos and Native Americans in Science. SWE: Society of Women Engineers. SHPE: Society of Hispanic Professional Engineers. NSBE: National Society of Black Engineers. NOBCChE: The National Organization for the Professional Advancement of Black Chemists and

Collaboration is necessary to both for research assistant stipends to recruit students and for booth/travel costs.

- Financial support for graduate students can be obtained from a wide variety of sources, including grants from NSF, private foundations, and federal and state agencies. Look to see if your university(-ies) has/have funding from or are a member of, the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc. (GEM) or have similar funding to help support new/continuing students past graduation.
- Determine which industry partners have a diversity agenda, and offer to help them with that agenda. Mutually beneficial activities may include: 1) seeking funding from industrial partners for student support on research projects of interest to them, at both the graduate and undergraduate level; and 2) helping industry recruit high-quality students for their co-op and internship opportunities.
- Work with campus administration to write new grants/initiatives to support diverse students (LSAMP; NSF Scholarships in Science, Technology, Engineering and Mathematics [S-STEM], NSF Improving Undergraduate STEM Education[19] and similar opportunities).
- Work with ERC faculty to write new grants/initiative to support diverse students, such as NSF Research Traineeship Program (NRT) in FY2014 or Partnerships for International Research and Education (PIRE) proposals.
- The emphasis on undergraduate participation in research is a special feature of the ERC Program, with an emphasis on recruiting from a diverse population (e.g., work with industry to pursue REU funding, work with your ERC faculty with aligned NSF grants to request supplemental funding for REU students, solicit university support for administration of REU programs from multiple departments within the university, write new REU site proposals around joint testbeds, etc.).
- Domestic and international collaborations are vital, since graduate students from external institutions can best be recruited by forming long-lived collaborations with the faculty and staff of those institutions.

Precollege & Community Outreach

ERC personnel agree that there is significant value for the Nation in K-12 outreach and the majority viewpoint is that this key feature should be retained. The center's educational mission includes educating the public on developments in science, engineering, and technology; retraining engineering and industrial workers in new technologies and research areas; and designing programs to reach new audiences with new engineering and technological innovations. However, these features are also possibly the single most vulnerable aspect of the ERC program post-graduation. The most vulnerable K-12 programs are those established because they were mandated, but not leveraged with existing campus resources or local community partnerships. ERCs generally do not have sufficient expertise to continue to design and deliver effective community K-12 outreach programs after graduation without such institutional partnerships.

With that said, there are sustainable options for an ERC to continue outreach to K-12 teachers and students, contribute to reforming science and math education at the precollege level, and expand the student pipeline for engineers. Suggestions for sustaining K-12 programs include:

- Conduct a needs analysis. Each ERC should determine what precollege offerings make sense in the context of its strategic plan, resources, and community relationships.

Chemical Engineers. IEEE: Institute of Electrical and Electronics Engineers. AMS: American Mathematical Society. ASCE:,American Society of Civil Engineers,

[19] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504976&org=DUE&from=home

- Define a post-center focus by working with faculty and administration to identify elements that are of benefit to them, such as broader impacts for their research grants.
- Engaged faculty can help to maintain K-12 teacher and student workshops, competitions, lab tours, and school visits. Summer camps may be supported through student participation fees, and may generate enough revenue to provide scholarships for socially or economically disadvantaged students.
- Continue to "be present" in community events to encourage community college and K-12 students to pursue careers in engineering and undergrads to continue on to grad school.
- Design Challenge Workshops may be a means to engage the K-12 community, community college students, and others with university students, faculty, and industry partners in addressing center goals.
- Submit an RET Site proposal to NSF.
- ERCs should collaborate with successful, established non-ERC K-12 programs and/or with technical education specialists with K-12 expertise. ERCs can serve as a resource for positive experiences (e.g., via the RET program), and these partners can help sustain programs post-graduation.
- The goals of precollege and community programs should be defined early and revisited often in order to develop appropriate sustainability plans. Centers have defined a wide range of goals—from transforming K-12 technical education to simply providing an enrichment component—based on their strategic plan pre- and post-graduation.

See appendix sections 4.7.1.3 and 4.7.1.4 for examples of precollege program sustainability.

Partnerships with Industry

The value of the industry/education link to ERC success and ERC sustainability cannot be overemphasized. This link is one of the determining factors in the success of an ERC, and its strength is a crucial element in the longevity of the center. It can also provide a strong base for a successful sustainability plan, and this element should be incorporated into ERC strategic plans for graduation at an early stage of the center. Industry should be involved in all aspects of the ERC education program, as noted in section 4.7.2 above (Strategic Planning**)**.

Industry is also keen on maintaining relationships with the center. In a study conducted in 2004 by SRI International,[20] the five factors that were rated as "very important" or "extremely important" by the highest proportion of industry representatives (between 48 and 53 percent) were:

- The continuous existence of a strong ERC "champion" in the company unit;
- Management support of the ERC within the company;
- The closeness between the ERC's specific technical focus and theirs;
- Responsiveness of ERC faculty/researchers to their needs; and
- The ERC's efforts to communicate and stay in contact with sponsors.

In addition, the hiring of a center student or graduate was the most highly valued of all types of ERC partnership benefits. Approximately 40 percent of the member representatives reported that their unit had hired at least one ERC student or graduate as a summer or regular employee. About 12 percent had hired three or more ERC students or graduates. On a wide range of performance criteria, a large majority of ERC students or graduates hired were rated "somewhat better" or "much better" than comparable non-center hires. More than half of the student or graduate hires were rated as performing "much better" than

[20] SRI (2004). The Impact on Industry of Interactions with Engineering Research Centers. (http://erc-assoc.org/sites/default/files/studies_reports/Impact%20on%20Industry%20of%20ERC%20Interactions_SRI_12-04.pdf)

comparable students in their breadth of technical knowledge (53 percent) and in their ability to work in interdisciplinary teams (55 percent). Fully 87 percent were regarded as performing better than comparable hires in their overall preparedness for working in industry.

Many creative approaches have been developed to strengthen the link between industry and students in the ERC program, to provide opportunities for industry to mentor students, and to build post-graduation sustainability plans. Suggestions on critical steps for developing sustained industry/education partnerships include:

- The ERC's Education Coordinator/Director should have a close relationship with its Industrial Liaison Officer (ILO), because the two activities overlap strongly and affect each other's results.
- Educational links to industry involve mutual learning, in which knowledge flows both ways. To help establish programs that fulfill this need and have high potential to be sustained, industrial contacts/partners for the education program should be identified as early as possible.
- Develop an interactive program with industry that brings industrial involvement at many levels.
- Engage graduate students in developing and implementing industry-education partnerships. They will bring a unique perspective for helping students to learn how industry operates and to understand industrial perspectives, so that they are prepared to contribute immediately on the job after graduation.
- Industrial internships are one of the most valuable mechanisms for industry-ERC educational interaction and are readily sustained post-graduation. They are mutually beneficial, providing vital technology transfer and educational experience for both undergraduate and graduate students while giving the industry partners a thorough look at students as potential employees.
- As the center matures, education programs should be reviewed with industry to help ensure industrially relevant education and industrial support in the later years of the ERC.
- Encourage teams of students and faculty to continue to travel to companies for presentations, meetings, and tours post-graduation. Continue to maximize student interaction with industry through poster sessions and presentations at industry meetings and workshops whenever possible.
- Industry also may continue to design projects or suggest problems for study by a team of students in the ERC, but they should be encouraged to directly fund these projects.

Delivery and Dissemination Systems

During NSF funding, the ERC should incorporate a variety of delivery and dissemination systems within its education portfolio. Graduated ERCs have found some systems to be effective mechanisms for continuing high-value education aspects post-graduation. Examples include:

- Short courses provide not only continuing education opportunities for industrial personnel but also technology transfer both to and from the center and can be supported through participant fees post-graduation.
- Seminars and workshops are among the quickest, most efficient, and most economical ways to promote industry-ERC interaction involving students and faculty. They can be video-recorded for future access.
- Some ERCs record courses and/or industry presentations for later viewing by students (including industrial personnel) at remote locations.
- ERCs have pioneered the development and use of many innovative educational technologies. Their impetus has included: the need to deliver nearly identical information to scattered locations (various affiliated universities and industry sites) on diverse schedules; larger class sizes; and a growing scarcity of faculty. Find a vehicle, such as website, online video, course module, or book that works for your particular center partners.

- Computer-based instruction—distributed through CDs, Dropbox files, and/or web access—offers convenient access to educational modules, workshop presentations, conference presentations, educational games, and other materials.
- Government and industry are developing standards for web-based learning systems,, but these standards remain immature and this may impact the longevity of such resources.
- New ERC-initiated web-based authoring and delivery systems are under development that should influence standards and ultimately improve the development and delivery of educational materials on the web.

Other Opportunities

We recognize that ERCs play a facilitative role in helping faculty think about commercial applications of their research. Therefore, involvement in an ERC facilitates "role transitions" for faculty members. Some ERCs facilitate these transitions better than others, and there are a number of best practices involving faculty role transitions. For example, several universities have internal entrepreneurship mentoring. Often, volunteer consultants are available in areas such as law, management, venture capital, and serial entrepreneurship. In many cases, the consultants are alumni of the ERC or university, and they coach academics on how to participate in the commercialization of their research discoveries. These consultants are also a source of referrals for finding capital and managerial talent. Other universities offer a great deal of support to potential faculty entrepreneurs in advancing their technology in a way that allows the faculty researcher to remain an academic researcher instead of trying to become a CEO. These models can be replicated in other places where the level of support is available from state, city, industry, and university sources. One interesting best practice involved creating a position titled "Industry Professorship." The ERC's ILO is a central figure in creating an innovation-friendly environment.

4.7.4 Sustainability Summary

Past studies and a recent survey of graduated centers (SciTech Communications, 2010) have shown that successful continuation of education programming depends on several factors. Attention must be paid to all these characteristics from the outset. They must be nurtured and maintained throughout the life of the center, to provide a platform for successful implementation of the strategic plan. Critical factors for successfully sustaining ERC education programs post-graduation include:

- A full-time (hard money) person to coordinate activities, who is prepared to seek funding from grants and other sources;
- Strong institutional support, including support for the ERC education culture as well as significant cash or other direct financial assistance (space, dedicated personnel, new department or unit, etc.);
- Champions of the education and preparation of students, both in industry and at the university level;
- Faculty and students motivated to continue and institutional incentives that further this motivation;
- A strong, continuing commitment on the part of center leadership to the goals of an ERC education program;
- Creative ways of packaging program elements that fit the type of activities that industry is able and willing to support (i.e., lab training internships, design course support, graduate fellowships);
- A strong, evolving research program;
- Successful securing of alternate funding for education programs, including other NSF and federal agencies, state, industry, foundation, university and community support;
- Research that is able to evolve to remain on the cutting edge;

- Dedicated/paid personnel in place to develop, coordinate and run the programs but also willing to seek funding from grants and other sources;
- Degree programs (minor, major, certificates) and courses that were established during the NSF-funded years;
- Effective transition strategy that builds on and enhances the center's strengths;
- Broad involvement of faculty, staff, industrial partners and university administration in transition planning;
- Institutional factors (e.g., degree of university commitment, whether the center is a prized asset, and whether policies are supportive of cross-disciplinary research and education);
- Active industrial support and continuation of industrial membership and Industrial Advisory Board guidance;
- Industry becoming involved in the cost of student training (i.e., funding a training laboratory, supporting short courses that are also used for industry, student fellowships, research assistantships, design course support, and awards);
- Effective implementation of a realistic transition strategy that builds on and enhances the center's strengths; and
- Quality of leadership of the ERC's management team and the education program directors.

4.7.5 Bibliography: Graduating ERCs and Education Program Sustainability

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4.8 CHAPTER SUMMARY: STRATEGIES AND LESSONS LEARNED

There are several key features of a successful ERC Education Program. The program must be recognized as a critical part of the organization, and this should be reflected in the center organizational chart and budget. Personnel with the appropriate credentials and background must be recruited, and must also be considered part of the center Leadership Team and included in all leadership activities. There are prescribed components of every ERC (e.g. REU, RET, Young Scholars for Gen-3) but centers are encouraged to develop and to adapt these to meet their institutional requirements. Given the 10-year life span of a center under NSF funding, education programs should be dynamic. It is to be expected that NSF's education priorities may shift as new opportunities become available during the lifetime of the center. Centers must be both flexible enough to meet new challenges, and also proactive in identifying new opportunities to make an impact.

ERC students need to go beyond the traditional engineering training by having opportunities for leadership and professional development (for example in innovation, creativity, and global awareness). Center faculty must buy into this and support student's time in these value-added activities outside of lab/research time.

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

4.8.1 Engineering Education Program Planning and Direction

- Funding for education should be consistent with its high priority among NSF ERC program goals. The explicit financial support of the Center Director is crucial.
- In planning an education program, the center must align its vision and goals with the center's strategic plan and objectives.
- The choice of an Education Coordinator/Director will determine the success of the education program. The University Education leader may be part-time but the Precollege leader should be full time. Someone who is interested in mentoring students and working with REU students must be a member of this team. The positions should be viewed as professional, with appropriate flexibility, autonomy, and status.
- An Education Advisory Committee should be established to give center faculty a mechanism to provide input into center education programs and to provide support for them.
- Adequate ERC core funding must be provided to the education program. A collection of supplemental grants alone does not make a coherent program, as not all funding opportunities will fit in the education strategic plan and only those that do fit should be pursued.
- It is prudent to develop an education program in phases that are implemented over several years, beginning with programs for graduate and undergraduate students in the center's home institution(s).
- Strategic planning for education must consider the impact of the 10-year ERC life cycle. As a center "graduates" from NSF support, the Education Program's continuation depends on institutional support (including cash), motivated faculty, commitment to the goals of the education program, and a strong, evolving research program.
- As the center matures, the education budget should include increasing contributions from sources such as industry members, NSF supplemental funding, and private foundations. Opportunities should be pursued to leverage the NSF funds using non-federal ERC funds for matching.

- A strong relationship with the personnel of the NSF ERC Program leadership, and especially with the center's Program Director, will greatly enhance a center's education program.

4.8.2 Students

- ERC faculty and staff should cooperate with the department and college in recruiting graduate students as broadly as possible (such as at professional meetings, by word of mouth with colleagues, and via the internet).
- Financial support for graduate students can be obtained from a wide variety of sources, including grants from NSF, industry, private foundations, and federal and state agencies.
- Outreach to graduate students at institutions that are not part of an ERC can best be obtained by forming collaborations with the faculty and staff of those institutions. Both domestic and international collaborations are vital.
- An important required feature of ERCs is the Student Leadership Council, which gives students a collective voice in the center's affairs and fosters leadership skills.
- Developing a feeling of “centerness” among students at geographically-distributed locations requires planning, regular opportunities to interact, and faculty support for time to do this.
- It is crucial to provide multiple and frequent avenues for students to interact with center industrial partners.
- Opportunities should be provided for students to gain an understanding of engineering in the global context.
- Centers have a mandate to provide students with specific training/experiences designed to help them become the creative innovators and technology leaders of the future.

4.8.3 Curriculum Development

- Establishing a new ERC curriculum is a challenging and complex task, involving coordinating many faculty members in an interdisciplinary research area.
- New degree programs, in particular, require substantial long-term institutional resources and commitment from all ERC partner universities.
- Inserting ERC-developed materials (modules, lectures, etc.) into existing courses is easier than developing new courses and over time can have greater impact.
- Find a vehicle, such as web delivery or a book, for wider distribution of course materials.
- A new minor degree program must be especially well coordinated with the existing academic standards and structures of the university. The key to successful development is to build on student interest and enthusiasm.
- Involve students (undergraduate and/or graduate) in evaluating plans and implementing the new program.

4.8.4 REU Lessons Learned

- Use multiple methods to recruit diverse students into your programs.
- Be highly inclusive—leverage resources at your university (e.g., other REUs, honors programs, etc.), and at partner universities.
- Create strong two-way relationships with your industry membership.

- Search for ways to create community—find a way to showcase undergraduate research results.
- Mentoring is important, so explicitly train your mentors.
- Assessment and evaluation are absolutely critical, and it is strongly advised that you consider partnering with professional A&E teams (internal or external) to develop this. You need to establish the research questions from the onset and ensure that the instruments and analyses you have chosen will allow you to answer your research questions (this includes getting human subjects clearance so that you can publish your results).
- Key point to keep in mind: REU's must be U.S. citizens or Permanent Residents (green card holders).

4.8.5 Precollege Programs

- Precollege engagement requires professional leadership and substantial resources in order to be effective.
- The precollege program should be included as a key component of the center and the Precollege Director should be included as part of the center Leadership Team.
- Center Directors should schedule regular times to meet with precollege personnel and promote inclusion of the precollege program in center activities.
- In order to promote and sustain a more diverse engineering workforce, the center should strive to create an inclusive and supportive work environment for precollege teachers and students.
- Sustained collaboration is the key to success in this part of the ERC's mission. By working directly with schools, other ERCs, academic institutions, and companies in collaborative partnerships, ERCs can propagate their successes through first-hand human contact, which is the most effective channel for transferring educational know-how or technology.
- Don't overlook campus outreach and recruiting professionals who often have budgets and staff, as well as expertise in community college recruiting.
- ERCs' collaborations with K-12 teachers and students are an important contribution to reforming science and math education at the precollege level and expanding the students' pathways for engineering. Each ERC should determine what precollege offerings make sense in the context of its strategic plan, resources, and community relationships.

4.8.6 Sustainability

Studies and a recent survey of graduated centers have shown that successful continuation of education programming depends on several factors. Attention must be paid to all these characteristics from the outset. They must be nurtured and maintained throughout the life of the center to provide a platform for successful implementation of the strategic plan. Critical factors for successfully sustaining education programs post-graduation include:

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- A strong, continuing commitment on the part of center leadership to the goals of an ERC education program;
- Creative ways of packaging program elements that fit the type of activities industry is able and willing to support (i.e., lab training internships, design course support, graduate fellowships);
- A strong, evolving research program;
- Successful securing of alternate funding for education programs, including other NSF and federal agencies, state, industry, foundation, university and community support;
- Research that is able to evolve to remain on the cutting edge;
- Dedicated and paid personnel in place to develop, coordinate, and run the programs but also willing to seek funding from grants and other sources;
- Degree programs (minor, major, certificates) and courses that were established during the NSF-funded years;
- An effective transition strategy that builds on and enhances the center's strengths;
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- Effective implementation of a realistic transition strategy that builds on and enhances the center's strengths.