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[1] 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;

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

- 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;
- 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[2] 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

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[2] 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.

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 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.).[3]

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[3] 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

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[4] 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.
- 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.

Black Engineers. NOBCChE: The National Organization for the Professional Advancement of Black Chemists and Chemical Engineers. IEEE: Institute of Electrical and Electronics Engineers. AMS: American Mathematical Society. ASCE:,American Society of Civil Engineers,

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

- 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,[5] 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 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.

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[5] 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)

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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"*The First Thing To Go Is the Pizza and Cookies: A Study of the Post-graduation status of NSF ERC Education Programs*" (2002). Anne E. Donnelly & Sally Gerrish. http://erc-assoc.org/topics/policies_studies/Grad%20Ctrs%20Educ%20Progs%20-%20Donnelly.doc

"*Post-graduation Status of NSF ERCs: Report of a Survey of Graduated ERCs*" (2010). James E. Williams, Jr. & Courtland S. Lewis (SciTech Communications). http://erc-assoc.org/topics/policies_studies/Grad%20ERC%20Report-Final.pdf

APPENDIX 4.7
SUSTAINABILITY EXAMPLES

4.7.1.1 ***Center*:** ERC for Extreme Ultraviolet Science and Technology (ERC EUV), a graduated ERC (2003–2013)

Lead Institution: Colorado State University
Center Director: Prof. Jorge Rocca, Department of Electrical and Computer Engineering
Name of Program: 3+2 Degree Program partnership with Historically Black Colleges and Universities

Type of Program: Undergraduate Education partnership with minority-serving institution

Program Synopsis: The EUV ERC has capitalized on a strategy that was used to increase the diversity of students in its undergraduate programs in order to create a sustainable program that will increase the number of students from underrepresented minority (URM) groups enrolled in engineering degree programs. A long-standing partner with the Center, Morehouse College which is a Historically Black Colleges (HBCU) college, and one of the EUV ERC's core Universities, Colorado State University in Fort Collins, are close to finalizing an agreement that would allow Morehouse students to receive a liberal arts degree at their home institution and, an engineering degree at CSU. In the future, this agreement will include the other core Universities, the University of Colorado at Boulder and the University of California in Berkeley, as well as other HBCUs such as Spelman.

Contact person/website: http://www.morehouse.edu/academics/physics/

Dates of Operation/Timeframe: The initiative should begin in the mid-life of the Center to provide adequate time for curriculum review and paperwork.

Background: The most successful strategy the EUV ERC employed to increase diversity was through long-standing partnerships with organizations that served underrepresented minority groups. In particular, the Center has built a relationship with Morehouse College through shared research and education goals. It is through these common interests that the idea for deepening and formalizing the partnership though a 3+2 degree program came about. In the 10 years of the Center, 33 students at Morehouse College have been involved in EUV-related research and 13 have done REU projects at UC Berkeley, LBNL, CSU or CU Boulder. Morehouse College is a liberal arts college and does not offer an engineering program to its students. For students who are interested in attaining a prestigious Morehouse degree AND an engineering degree, Morehouse has developed a number of partnerships with Universities across the country so that once a Morehouse student finishes the requirements for a science degree (physics, chemistry etc.) they are able to pursue an engineering degree at another University. The Morehouse degree usually takes 3 years and through a careful equivalency analysis of the courses a student has taken, the engineering degree usually takes an additional 2 years, thus this program is often referred to as a 3+2 Degree or Dual Degree Program.

Methodology: 3+2 or Dual Degree Programs require motivation, persistence and usually an individual who is responsible and dedicated to the process. Such understandings between institutions of higher learning are not easily come by especially between liberal arts colleges and universities where similar courses exist but the philosophy of education may differ. The first step in the process is to establish the equivalencies between the home institution (Morehouse college) and the second institution (CSU) to insure that courses can be recognized by both institutions and that the basic graduation requirements are met. Once the second institution can determine the background of a potential 3+2 student, a curriculum can be developed for a 2 year completion of an engineering degree. The Office of the Registrar, the Engineering School (Department) and the Undergraduate Dean all need to be involved in the process. A Memo of Understanding (MOU) needs to be created so that both institutions are aware of the parameters that are involved for the success of the student. Finally, support structures for potential students need to be identified so that the transition is smooth.

Impact/benefits: The program is important because it provides a clear pathway for students from URM groups who have been involved in the Center to continue their studies within the Center without compromising their current status at their home institution. In short, it simply provides more opportunities for interested students. The Center is particularly interested in creating this program in Colorado because the state currently has a very low percentage of African Americans that hasn't changed in 20 years (4%). By providing one pathway for students, the hope is that other students who are just beginning their college careers will view Colorado as a feasible option.

Evaluation/Assessment: Personal interviews will be used for assessment and feedback

Sustainability: Adoption of this program by the colleges and universities involved will provide sustainability

Tips: Not available

4.7.1.2 ***Center***: ERC for Extreme Ultraviolet Science and Technology (ERC EUV), a graduated ERC (2003–2013)

Lead Institution: Colorado State University
Center Director: Prof. Jorge Rocca, Department of Electrical and Computer Engineering
Name of Program: Inquiry-based, Hands-on activities in Optics, Waves and Light

Type of Program: K-12 Education Outreach

Program Synopsis: Many of the educational activities for K-12 audiences (students and teachers) that were developed by the EUV ERC on the subjects of optics, waves and light (OWL) have been adopted by numerous other educational organizations that were partners with Center and, will enable future generations to partake of these activities long after the EUV ERC has graduated.

Contact person/website: http://sciencediscovery.colorado.edu/

Dates of Operation/Timeframe: The dates and timing of Education Outreach programs for K-12 audiences can vary depending on the needs of the audience.

Background: In an effort to increase the impact of its K-12 education outreach activities, the EUV ERC partnered with other educational organizations very early in its history. The nature of these partnerships varied depending on the type of education organization. In some partnerships, materials were developed jointly and dissemination of the activities occurred through both the Center and the partner organization. In some partnerships, the flow of materials/activities was from the Center to the organization and the organization adopted the materials to be disseminated according to its own time schedule.

Methodology: Partnerships with other education organizations were initiated by the Education Outreach Director of the EUV ERC. The organizations that were targeted were those that were local to the regions that each of the Center core Institutions served. Through one-on-one meetings, the needs of the partnership organizations and the EUV ERC were discussed. These meetings sometimes resulted in incredibly creative and fruitful collaborations that culminated in new activities and ideas. In other cases, the meetings resulted in the simple adoption of EUV ERC OWL activities.

Impact/benefits: The sustainability of Education Outreach Programs is important for the continuity and longevity of the OWL activities that were developed at the EUV ERC. One of the drawbacks about educational programs in general is that they are offered for a limited duration based on funding and then they are gone. This troublesome outcome delivers an even bigger blow since programs take a little while to become integrated; while few clientele would be impacted if a program was discontinued in 1-3 years, because numbers and popularity increase with time, when a 10-year program ends, it adversely affects the most number of people it has ever effected. The incorporation of OWL activities into other Education Organization not only insures that these activities will impact a greater number of K-12 audiences it also provides a sense of permanency to STEM programs that can change depending on funding.

Evaluation/Assessment: Surveys are used for assessment and feedback to make improvements.

Sustainability: Once OWL-related activities are adopted by Education Organizations, the sustainability is dependent on the funding for that organization as well as by choices made by directors of that organization to run the programs. Annual check-ins by the Education Outreach Director of the graduated Center can ensure the continued offerings of the programs.

Tips: It is important to make sure that activities connect back to the mention of the NSF and ERC programs. In addition, because the goal of outreach activities is to increase interest in STEM careers, the inclusion of career material is advised.

4.7.1.3 ***Center***: The Gordon Center for Subsurface Sensing and Imaging (CenSSIS), a graduated ERC (2000–2010)

Lead Institution: Northeastern University
Center Director: Dr. Michael Silevitch, Department of Electrical and Computer Engineering
Name of Programs: Young Scholars (YS), STEM Field Trip Series, Research Experiences for Teachers (RET)

Type of Program: Precollege education and outreach

Program Synopsis: Educational outreach efforts associated with The Gordon Center for Subsurface Sensing and Imaging were led by Precollege Director Claire Duggan, former Associate Director for CESAME (The Center for the Enhancement of Science and Mathematics Education) and current Director for Programs for The Center for STEM Education at Northeastern University (NU) (www.stem.neu.edu). Several programs were developed and/or refined during the active NSF award period for Gordon CenSSIS. These include the STEM Field Trip Series and The Summer Science Program, in addition to the required Young Scholars and RET programs. Following CenSSIS' graduation, each program is now institutionalized at the university, supported through a variety of funding sources and strategies.

Northeastern University Young Scholars Program (NUYSP)

The NUYSP was established in 1989 in collaboration with an NSF Industry-University Cooperative Research Center and was supported by NSF directly through the YSP initiative for several years. During that time period the program reached approximately 150 students. The NUYSP program was re-established in 2004 through support from the Noyce Foundation. Since that time, 208 high school students have spent six weeks at Northeastern University conducting research, primarily in collaboration with faculty in the College of Engineering. Efforts are made to maintain contact with program alumni both directly and through supporting social medial sites such as LinkedIn and Facebook. There are over 150 members of the NUYSP Facebook page that interact and support each other in addition to maintaining contact with university faculty and staff. The most recent survey of participants had 135 respondents, 133 of which reported majoring in a STEM discipline. Of the 133 in STEM disciplines, 57 reported majoring in Engineering.

The model developed at NU has been refined to become a comprehensive learning experience for program participants and staff. YSP offers future scientists and engineers a unique opportunity for hands-on experience while still in high school. It also provides faculty and graduate students across the campus with the opportunity to mentor the next generation of STEM professionals. The program is open to greater Boston area applicants who have completed their sophomore or junior year in high school. All students are provided a stipend for the program's duration. What separates NU from other universities is also what separates the YSP from other enrichment programs for high school students: experience-based learning. NU combines classroom studies with experiential learning to allow the practical applications to come alive. The YSP program allows students to apply their base knowledge in the areas of science, technology, math and engineering in a way that deepens their understanding, and prepares them for careers in these fields.

The program continues to maintain a balance between academic and social components, providing students an opportunity to build relationships with university students and faculty in addition to fellow participants. Our objective is to create and support a STEM community well beyond the six-week summer experience.

Recruitment, Selection, and Demographics

Students are selected through both their application and recommendations. Application materials are distributed by Boston area high school STEM teacher networks and guidance counselors, and are available on our web site (www.stem.neu.edu). These networks are expanded and maintained through various STEM Education programs and professional development courses. The Center maintains teacher databases, which are updated as new teachers recommend students and participate in a professional development course, or in an affiliated program, such as the Research Experiences for Teachers program.

The selection committee comprises staff from NU's Center for STEM Education and the College of Engineering. Student applications, which consist of short essay questions, an official high school transcript, and two letters of recommendation (with at least one from a science, technology, engineering, or math teacher), are reviewed and rated by at least three staff members. Essay responses help provide insight into the students interests, personality and motivations in STEM.

Each year approximately 24 students participate in this program. Students come from a variety of cities and towns in the Greater Boston area. The program does not discriminate or give preference on the basis of gender, race or ethnicity. The goal is to maintain a balance between male and female participants and to recruit and publicize most heavily in school districts where resources are limited. Preference is given to first generation college students.

Program Components

Laboratory research experience: Students are awarded a weekly stipend while spending approximately **25 hours per week** in research laboratories. Students are assigned in teams to laboratories, many affiliated with our research centers.

Career/research exploration: Students participate in a weekly seminar series spanning a wide range of topics. Presentations made in 2013 included an introduction to several of our large research centers, including the Gordon Center for Subsurface Sensing and Imaging, ALERT (Department of Homeland Security Center of Excellence) and the Center for High Rate Nanomanufacturing. Other presentations given during the students' homeroom session included introductions to the various disciplines of Engineering, including Biomedical, Chemical, Civil, Electrical and Computer, and Mechanical and Industrial Engineering. During the summer of 2013, we introduced a series of seminars focused on ***Innovation,*** providing students the opportunity to hear first-hand from NU student entrepreneurs.

Education and career counseling: A general overview of engineering education for undergraduate students is presented by the Dean's Office of the College of Engineering and the Department of Cooperative Education, and acquaints students with the nuts and bolts of careers for scientists and engineers. Students are also provided beneficial information about searching for and applying to colleges from the NU Admissions Office in addition to learning about careers pathways from representatives from our COOP program. Students also work on a college essay from the Common Application throughout the summer, receiving feedback from staff and their peers. By the end of the program each student has one completed essay he or she can use during their college application process.

Field excursions: A variety of corporate and government site visits are conducted so students can see and speak with scientists and engineers in action.

Experience college life: YSP participants become acquainted with college life, work directly with undergraduate and graduate students, and have access to university recreational and educational facilities.

Online Resources: Students are required to maintain an electronic journal and laboratory notebook. Additionally, a closed web site is used to provide program updates to the students. This secure web site is used to provide both program and supporting information for STEM careers, along with information on the college application process, upcoming STEM competitions and available scholarships. The site also paves the way for future electronic networking and support of program alumni.

Contact person/website: Claire Duggan c.duggan@neu.edu and/or stem@neu.edu www.stem.neu.edu

Dates of Operation/Timeframe: The NUYSP program runs for six weeks each summer and is supported through callback sessions and on-line mentoring and support during the academic year.

Background: The Northeastern University Young Scholars Program (YSP) was launched in 1989 in response to a growing national shortage of qualified U.S. citizens moving into STEM careers. The YSP model provides rising high school juniors and seniors with a paid research experience alongside faculty in College of Arts and Sciences and College of Engineering laboratories, coupled with career awareness seminars, college application counseling, and field trips to local corporations and government organizations. The first generation of this program ran from 1989-1997. In 2004, it was reestablished with funding from the Noyce Foundation, and has continued to be offered each summer.

Methodology: The NUYSP and RET programs are coordinated by an organizational unit, The Center for STEM, that supports educational outreach of our research centers in addition to individual efforts of STEM faculty.

Impact/benefits: Northeastern University began to support K-12 educational efforts over twenty years ago with the early research efforts of the ERC Director, Michael Silevitch. Dr. Silevitch 's vision to build and support an education pathway for students interested in STEM led to the establishment of two educational centers in addition to the development of many successful STEM program efforts. Initiatives such as the NUYSP and RET are now institutionalized at the university. They provide an early introduction for students interested in STEM in addition to providing university students the opportunity to communicate their knowledge of science and engineering. The programs have had a multiplier effect, with program alumni now in faculty and professional positions deeply committed to supporting the STEM pipeline.

Evaluation/Assessment: The evaluation of both the RET and YSP projects was originally overseen by SageFox Consulting Group. Data collection was and continues to be conducted by program staff.

Evaluation efforts are centered on the collection of both summative and formative data. The first serves to determine the extent to which the programs are meeting their stated goals while the second serves to provide feedback as to how the programs might be improved. Our evaluation efforts continue meeting these two evaluation objectives; however future evaluations of both the RET and YSP programs will place greater emphasis on evaluating the learning environment in the laboratory.

Assessment Methods:

Participant surveys: Online surveys are conducted at the end of the summer, and as a follow-up at the end of the academic year after each program experience. These surveys are utilized to primarily assess participant's experience in each of these programs.

Mentor surveys: Online surveys are conducted at the beginning and end of each program to assess the mentor's experience, perception of outcomes, and understand the efficacy of program support.

Lab team observations: Laboratory visits are conducted to examine the lab dynamics and subsequent participant outcomes for both the YSP and RET programs.

Interviews and focus groups: Post program and end of academic year interviews are conducted with participants to supplement and clarify survey data.

Tracking of program activities: Throughout the year, schedules of events are defined and monitored. These events include recruitment activities, orientation for each program, supporting professional development courses and supporting program activities.

Sustainability: Educational outreach efforts of The Center for STEM, the educational implementation arm of Gordon CenSSIS is supported by institutional funding, foundation and corporate support, private donors in addition to supplements from federal sources.

Tips:

- Plan for sustainability of your educational programs in concert with planning for sustainability of the Center itself.
- Broaden participation of faculty and students across the college in the delivery of educational outreach components.
- Provide pathways for undergraduates to assume leadership roles in educational outreach.
- Identify and support faculty interested in pursuing complementary education initiatives such as ITEST, S-STEM, STEP, and RET sites.
- Maintain contact with partner schools and community organizations by providing information on STEM opportunities of interest.
- Market your educational outreach efforts through university and local media.
- Provide opportunities for your industrial partners to engage directly with K-12 program participants.

4.7.1.4 ***Center*****:** The Gordon Center for Subsurface Sensing and Imaging (CenSSIS), a graduated ERC (2000–2010)

Lead Institution: Northeastern University

Center Director: Dr. Michael Silevitch, Department of Electrical and Computer Engineering

Name of Programs: Summer Science Program(NUSSP)

Type of Program: Precollege outreach

Program Synopsis: Northeastern University prides itself on interdisciplinary research, urban engagement, and the integration of classroom learning with real-world experience. The Center for STEM Education has launched a number of initiatives (www.stem.neu.edu) focused on enhancing achievement of urban students in collaboration with Gordon CenSSIS, including STEP UP, the Young Scholars, the STEM field trip series and the Research Experience for Teachers Program. Additional Northeastern initiatives focus on enhancing diversity in research-based fields (GEM, NUPRIME, LSAMP). Northeastern is committed to supporting our urban community.

Who

Our summer program effort for middle school students began in 2006 and has provided an opportunity to explore STEM as participants in a unique multi week summer program for over 325 middle school students to date from the Boston area. This proposal seeks to expand our current two-week summer model to three weeks, with additional follow-up opportunities for program alumni. Participants will continue to be drawn from the from greater Boston area utilizing the expertise and talents of staff, faculty, and students from NU and the greater Boston community.

What

The Northeastern University Summer STEM Program (NUSSP) is designed to be a free academic program open to students entering the 6th, 7th and 8th grades. The program emphasizes increasing students' mathematics, science, engineering and design skills, introducing them to college life, and stimulating their interest in associated fields as a potential career path.

Each day, students attend classes that include problem solving, study, research, writing and communication skills incorporated with biology, chemistry, physics, design concepts, and field excursions. Classes are taught by licensed classroom teachers and university faculty and staff.

The program is built on a guiding THEME: Designing our future - today! Students are introduced to a Core Problem and subsequently engage in lessons and activities to develop skills and understanding to address collaboratively the challenge proposed. They produce a culminating project, a future city that is presented to parents, faculty and staff at the end of the summer experience.

Where

The program takes place on the Northeastern University main campus in addition to offering several field trip experiences for participants.

When

The program runs for two weeks during the month of July and will be further supported with several callback sessions during the school year.

The mission of the NUSSP is to enable youth entering grades 6, 7, and 8 to develop and achieve their full potential through support of social, recreational and STEM-based educational lessons and activities. The program is guided by current recommendations for effective out of school time programming and has embraced “A Trilogy for Student Success” to guide our core program components.

Our Core principles are to:
• Encourage education in Science, Technology, Engineering and Mathematics (STEM)
• Encourage and motivate youth to pursue STEM careers
• Foster teamwork, leadership and citizenship

Goals of the NUSSP:
• To educate students in the areas of science, technology, engineering, and mathematics (STEM)
• To engage students in the practical aspects of STEM.
• To introduce students to college life
• To inspire students to pursue careers in the fields of science, technology, engineering, and mathematics (STEM)
• To provide mentoring and support for participants and their families beyond the summer experience

Strategies:
• Teach hands-on, minds-on STEM activities.
• Incorporate activities that nurture and develop 21st century skills such as; communication skills (written, oral, etc…)
• Integrate field excursions to expose students to real-world STEM applications.
• Incorporate project based learning experiences that integrate content and process skills developed throughout the summer program.
• Present opportunities for students to interact with engineers, scientist, researchers, and other professionals

The NUSSP embraces research that suggests there are several key factors necessary for students to succeed in STEM subjects and careers. They are *Engagement, Capacity and Continuity.* The two week experience is built on the theme, “Young Inventors: Designing our Future. It allows participants to explore various STEM disciplines in an integrated, applicable way. Students begin by identifying the importance of STEM inventions throughout history. As they relate this to their daily lives, they begin to explore the design process. By applying this knowledge, they build and construct their own models to solve real-life problems in NU labs. Based on feedback from campers and ideas from other camp, this year we will take the emphasis off a culminating bridge design project and add a “utopian city” project, allowing students to work collaboratively to apply concepts learned throughout the summer program to a creative project, with models of each lesson added to a board representing a city of the future. Through integrating engineering into the various STEM activities we hope to provide students with a better understanding of engineering, and the design process and engineering professions in addition to the skills and attributes that makes a successful engineer. Students will learn how they might become a contributing member of society as the producer rather than the consumer of the STEM inventions of the future.

Tips: Not available