



Large Research Center Education and Outreach: Lessons from 5 years of Distributed Collaborative Design, Development and Implementation

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Large-Scale Geographically-Distributed Research Center Education, Outreach, and Training: Lessons from 5 years of Collaborative Design, Development and Implementation

Abstract

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) completes its tenth year of operation in September 2014. The NEES Center consists of a network of 14 large-scale experimental laboratories that collaborate and share resources in support of research to inform civil engineering practice and reduce losses from future earthquakes. Since the development of the center in 2003, the education, outreach and training (EOT) program has grown from a federation of local outreach activities to an integrated network of “specialists” working together to obtain significant impact towards defined education goals. The leadership of the NEES EOT program has learned from the experience and wisdom of various Engineering Research Centers to establish a focused program to promote a highly talented next-generation research workforce through formal education programs and to increase awareness of earthquake engineering advances through informal learning experiences, webinars for technology transfer, and strong media coverage. The collaboration of EOT specialists, with graduate students, undergraduates and teachers to develop and implement learning experiences has proven to be a highly impactful approach for achieving educational goals of these participants as well as the learners they engage in various learning experiences. This paper describes the critical principles governing the design of an effective education and outreach program by a multi-site, geographically-distributed research center. These lessons will provide a framework for others interested in designing education and outreach programs at future large-scale research centers.

Introduction

Education, outreach, and training (EOT) programs are important to fulfilling the broader impact aims of large-scale research centers. These programs have the potential of attracting the next generation of researchers to the field, increasing interest of K-12 students in pursuing careers in science, technology, engineering and mathematics (STEM) fields, linking other researchers and practitioners (industry) to innovative research, and informing the public of research results and their impact on society. The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), an NSF-funded network of 14 large-scale experimental laboratories connected by a robust cyberinfrastructure, completes its tenth year of operation in September 2014. Its mission is to reduce the impact of earthquakes and tsunamis on society through research, innovation, engineering, and education. Since the launch of NEES in 2003 the EOT program has grown from a federation of outreach activities run independently at the experimental laboratories to an integrated network of “specialists” working together to obtain significant impact towards defined education and outreach goals.

Large-scale research centers face the challenge of integrating the EOT operation into the general framework of the research enterprise rather than running an ancillary EOT project to fulfill a contractual agreement specified by the funding agency. One model is to concentrate education programs on the research potential of the graduate students and post-doctoral scholars working at the facility. This model emphasizes the production of new knowledge related to the ongoing

research conducted at the sites. As illustrated in Figure 1, the graduate students and postdoctoral students work at a particular site with the specific goal of collaborating on research with their mentor and Principal Investigator on an NSF grant. In this model the sites do not necessarily interact to support a broader educational agenda for these young researchers. The apprenticing graduate students and postdocs are given access to resources specific to their research goals, and provided training focused on their work at the site. Their mentors are primarily responsible for the professional development of the young researchers. In contrast to typical ERCs, the NEES network does provide additional research resources through the centralized NEES Center operations. The NEES Center hosts an annual research conference for sharing results and supports researchers with a cyber-infrastructure that provides access to simulation resources, collaboration tools, and centralized data storage and archived data sets. While a valid EOT model, this focus on research proficiency misses a number of opportunities as it does not acknowledge that graduate students will require mentoring and teaching skills in addition to research proficiency in their future careers. This model also misses the opportunity to engage undergraduate students, who are eager to explore opportunities to inform their decisions about their future workplace or graduate school.

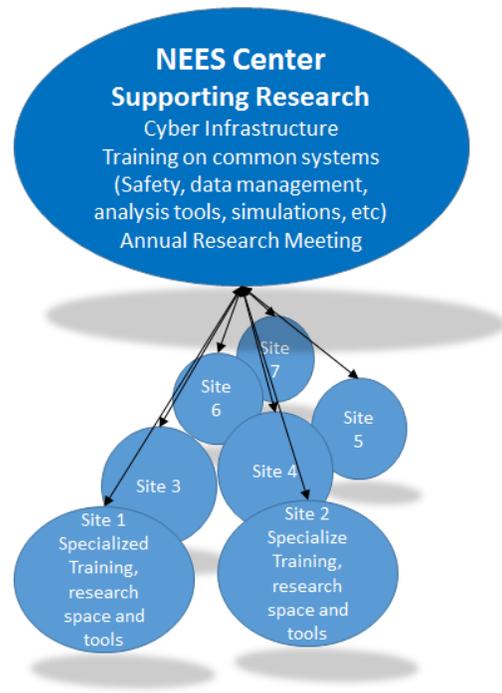


Figure 1: Model of education and outreach focused on training and developing graduate student and post-doctoral researchers.

The K-16 educational community is keen for materials that engage students in the latest thinking about science and engineering. Evolution of education standards, like the Next Generation Science Standards (NGSS)¹, establishes the need for engineering-related content in K-12 education^{2, 3}. With its focus on application of science and the explicit inclusion of engineering design, the NGSS has provided a timely opportunity to develop engineering-based K-12 materials centered on earthquake and tsunami engineering. Previous science standards, with their emphasis on inquiry and validation of scientific concepts fit well in the realm of earth sciences, but not earthquake engineering. Centers such as the Incorporated Research Institutions for Seismology (IRIS) were very successful in developing low-cost seismographs⁴, visualizations of wave propagation⁵, access to real-time seismological data⁶, classroom posters, and post-earthquake educational summaries (Teachable Moments⁷) that complement science standards and thus could be readily adopted into K-12 curriculum⁸. The NGSS has opened the door for similar developments in engineering fields. These observations represent some of the issues and opportunities a center could consider in the design of their education program.

The leadership of the NEES Education, Outreach, and Training program has learned several lessons from the experience and wisdom of established Engineering Research Centers (ERC). These are to focus the program so as to promote a highly talented next-generation research workforce through formal education programs and to develop a range of informal learning

experiences for outreach to the public. NEES EOT specialists collaborate with graduate students, undergraduates and teachers to develop and implement learning experiences to achieve multiple goals. These learning experiences have proven to be highly impactful approaches for supporting educational goals of a wide range of participants.

This paper explores the opportunities and issues associated with developing, managing and implementing an EOT program for a large-scale geographically distributed center focused on STEM research. The specific decisions regarding priorities and implementation are a function of the mission of the center, funding, and organization. Therefore, the paper begins with a short overview of possible organizational structures of a center and how the NEES center is organized. Next we define the scope of education, outreach and training experiences along with examples of possible experiences. Then, we describe the rationale and guiding principles used to inform the selection of our programs. The last section identifies some basic lessons learned and recommendations for future large scale centers.

Models for Organization of Large Centers and EOT Programs

Large scale research centers engage an interdisciplinary workforce collaborating across multiple institutions to accelerate the creation of transformational engineering systems. Achieving this mission requires generating new knowledge; developing and testing technology; and disseminating the ideas, results, theories, and innovations. Education and outreach are also critical components of the center mission because they help sustain the research enterprise by developing the workforce needed to lead the current and future research. Outreach is critical to ensuring that the center discoveries become innovations that are adopted and applied in industry. Further, outreach is critical to the public's acceptance of the importance of supporting inquiry in the Center's area of focus. Ultimately a Center's EOT program becomes part of a business model that extends the life of the center beyond its funding period. These features of an effective EOT program are some of the central attributes the National Science Foundation has defined in its guidelines for Engineering Research Centers (ERC). Therefore, research centers need to establish and manage an operational infrastructure that simultaneously realizes these features. NEES shares a similar vision as the previously-funded ERCs for earthquake engineering; however, an important difference is that NEES research is not funded by the NEES Center, therefore the relationship between research principal investigators and the managing organization are different than the typical ERC. This section summarizes some typical management structures of ERCs and compares them to the NEES Center to highlight the similarities and potential differences in the managing a large center. The goal is to illustrate the opportunities and challenges associated with running these centers.

Centers provide an organized collaboration and oversight of research in an effort to strategically achieve high impact results. Clearly, the central mission of a research center is to build new knowledge that transfers to high impact applications in science and engineering. Centers foster an environment where collaboration is encouraged through establishing a shared vision and process among various stakeholders. Effective leadership can stimulate the co-production of new ideas, development of experimental methods, implementation of programs, and sharing of resources, giving rise to rapid exchange of new results among researchers and the application of those results by industry, government, educational institutions, and policy makers. For example, the National Science Foundation funds ERCs in disciplines like biotechnology, bioengineering education, earthquake engineering, microelectronic systems (nanotechnology), advanced

manufacturing and energy/infrastructure⁹. The NSF vision for these centers is to accelerate the advancement of the science/engineering and education needed to produce transformational engineered systems in the global economy¹⁰.

A typical ERC leadership and organizational structure is illustrated in Figure 2. The labels are associated with the NEES nomenclature. This hierarchical model assumes the headquarters for the ERC is housed at the lead institution. The model illustrates a centralized authority structure for strategic decision making performed by the director supported by the deputy director who manages daily operation of the center. The director is advised internally by a strategic council (who may share the responsibility of decision making) and externally by a governance board of outside experts. Typically the remaining structure consists of specialized thrusts dedicated to meeting the specific objectives of the center. Research is accomplished by principal investigators at various institutions (academic and industrial) receiving funding from the lead institution to pursue a specific intellectual goal. Again, NEES does not follow this typical ERC funding model because all research is funded directly through NSF. Critical to achieving the center goals is establishing and sustaining collaboration among the different thrusts and participating institutions. The lead institution will often take on additional responsibility to support the education, outreach and dissemination of ideas, for example organizing an annual conference. The research thrusts generally have the equipment infrastructure to conduct experiments at each participating institution, or make it available to other thrusts and PIs as part of the collaboration.

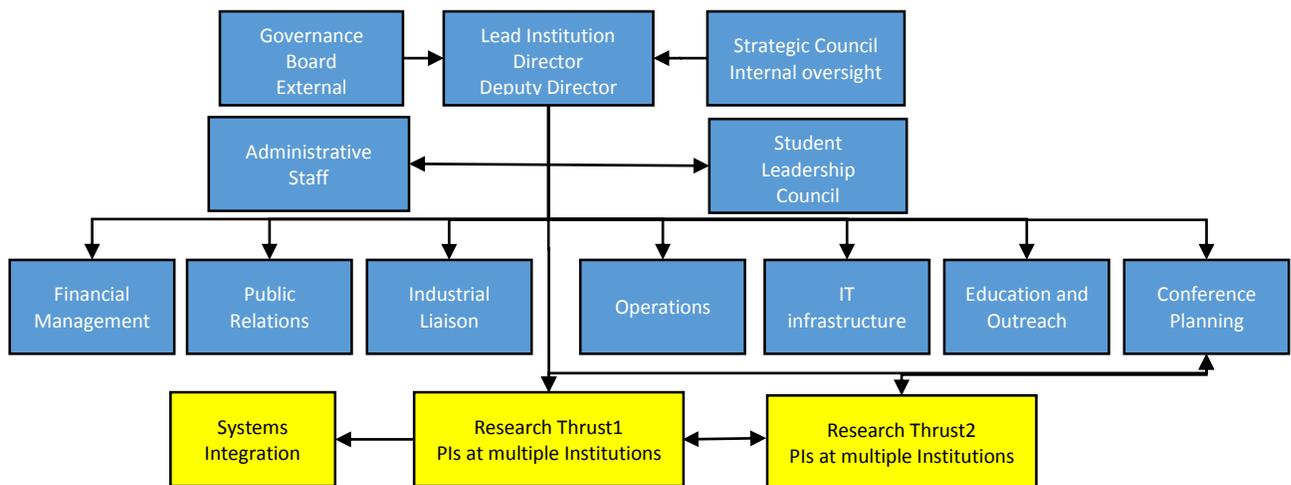


Figure 2: Potential Organizational Chart for an Engineering Research Center (ERC)

The Network for Earthquake Engineering Simulation uses another center model for managing the operations of a network of earthquake and tsunami simulation research sites. Details are explained later. Like typical ERCs the NEES Center mission is dedicated to research, workforce development, and technology transfer of its research findings and innovations. NEES operations are managed by a lead institution, Purdue University, under the name of NEEScomm. The unique feature of NEES research is the need for very large-scale testing equipment that would be too costly to replicate at multiple institutions. Examples are shake tables, a tsunami wave basin, and geotechnical centrifuges. Therefore, NEES’s organizational structure provides direct oversight of the test facilities that in turn support the research of independent researchers who are

scheduled to use the facilities. The center does not have authority or responsibility for selection or oversight of the various research grants. Figure 3 illustrates the lines of responsibility for oversight of the various research grants. The additional layer of operations and oversight between the researchers and the center's leadership (NEEScomm operations) does not exist in the traditional ERC. This layer of operations could introduce challenges for providing added service to the researcher's education and outreach plans. The point is the center's leadership has limited oversight or influence on how the researchers conduct their educational programs. What can be accomplished centrally is the development of larger network-wide programs that complement the researchers' educational programs and missions. For example the center can coordinate a Research Experience for Undergraduates, which is discussed later.

The organizational structure of NEES and ERCs are similar with respect to managing the operations of a large research enterprise. The major difference between them is that ERCs are potentially more influential over the research agenda, whereas NEES has no influence over the research focus, only over when, where, and how the research will be conducted and the structure for gathering, storing and analyzing large amounts of data associated with the complex experiments conducted at each of the sites.

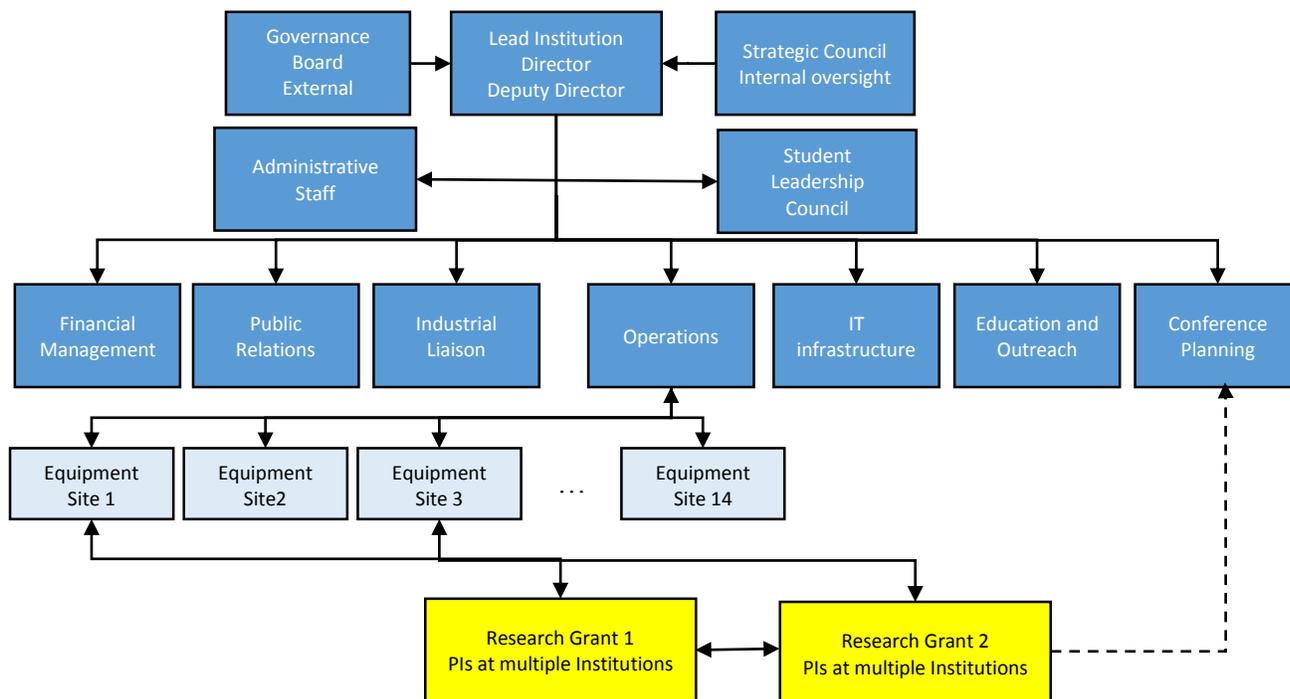


Figure 3: NEES organizational structure

EOT Program Goals

Critical to the success of a large research enterprise like an ERC or NEES is definition of the education, outreach and training goals and maximizing their impact. EOT programs can impact the use of research results, recruitment and development of quality workforce talent, and acceptance by the public of the research as a viable societal pursuit. One challenge is to define a clear set of priorities that align with the mission and vision of a center. Over the past ten years NEES was managed by two institutions, NEESinc for the first five years and NEEScomm for the

second five years. NEESinc prioritized its EOT efforts on developing a quality research experience for undergraduates (REU) program to develop undergraduate talent and a strong communication program to promote the successes of the research supported by the equipment sights. In addition NEESinc focused on promotion of the NEES accomplishments through media releases and hosting of an annual meeting. The outreach programs for the first 5 years consisted of activities developed and implemented by each of the sites and only focused on concepts associated with that site. In the second five years, NEEScomm expanded the mission and goals to achieve a larger set of outcomes. One of the first lessons learned in communicating the design of the EOT program was to have a clear definition of the meaning of each component of EOT and the potential outcomes, metrics and activities that could possibly be used to achieve these outcomes with high impact.

Education, outreach and training programs are not always well differentiated and the words are often used interchangeably. Therefore, the desired outcomes and evaluation methods can become ambiguous for collaborators in a center, the oversight committees and the ultimate stakeholders. What was needed is a clear framework for defining these terms and identification of what activities would be the most strategic to pursue. The NEES EOT strategic plan built on the definitions provided in an earlier plan¹¹ to help differentiate these terms and goals. Table 1 provides a short summary of the terms and possible learning experiences NEES defined to guide its design of effective programs that have outcomes with high impact.

As part of its strategic plan, the NEEScomm EOT team designed several additional operational goals to maximize the potential impact of the activities. The first operational goal was to gather, develop, and coordinate quality learning experiences to be used at research sites, schools, and public venues. Gathering materials was accomplished by inventorying materials from NEESinc's previous earthquake engineering ERC, and various digital libraries with K-12 lesson plans. One strategy was to refine these existing resources to meet new learning goals and make them available on NEESacademy, an educational portal on the NEES website, which is discussed later. The second goal was to foster a coordinated EOT program and an engaged NEES EOT Community. The rationale was that duplicating the EOT program across the multiple experimental laboratories maximized the potential for identifying innovative approaches to EOT challenges. The NEEScomm EOT team identified each NEESR project (NSF-funded research projects with independent PIs that are scheduled at NEES research sites) as a potential collaborator. NEESR projects have a broader impact component, many of which have produced educational activities and curricula. Providing the centralized infrastructure and support to help PIs disseminate these resources potentially amplifies their impact. Also, coordinating NEESR proposals and the EOT resources throughout the Network could also amplify each proposal's potential for broadening impact.

Table 1: NEES EOT Goals and Activities as Presented in EOT Strategic Plan ¹⁴

Thrust	Goals, Outcomes and Metrics	Stakeholders and Activities
<p>Education - increase the literacy and potential of learners to engage in inquiry activities that emphasize high-level thinking, problem solving, and collaboration. These efforts are critical to workforce development in secondary and postsecondary learning experiences.</p>	<p>Goal: Increase and train (educate) the research workforce involved in earthquake engineering and science.</p> <p>Outcomes: increased the number of undergraduate students entering STEM careers, particularly earthquake engineering. Increase the knowledge, skills and attitudes of engineering students in K-16 learners.</p> <p>Potential Metrics</p> <ul style="list-style-type: none"> • High quality research reports by undergraduate researchers • High application rate of undergraduate in various programs • High affirmation of learning on self-report surveys by participants in programs • Pre/post scores on concept questions 	<p>Undergraduate Students</p> <ul style="list-style-type: none"> • Research Experience for Undergraduates • Online Learning modules for formal undergraduate and graduate content (e.g. structures, statics, dynamics) • Ambassador Programs <p>K-12</p> <ul style="list-style-type: none"> • In-class challenge-based activities • After school programs • Summer Camps • Teacher Professional Development Workshops • Research Experience for Teachers
<p>Outreach - increase participants' awareness of, and interest in, earthquake engineering and the science associated with the research and development work conducted by NEES.</p>	<p>Goals: Increase awareness of earthquake engineering and science and the value added by NEES</p> <p>Outcomes:</p> <ul style="list-style-type: none"> • K-12/Public – increase knowledge of basic physical/natural sciences related to earthquakes and tsunamis. Increase awareness of NEES research and its impact on society. • Practitioners - increased participation of practitioners in NEES research through engagement in webinars, meetings, and professional development to improve codes and application of state-of-the-art design and construction for safe civil infrastructure. <p>Potential Evaluation Metrics</p> <ul style="list-style-type: none"> • Self-reports of participant satisfaction with experience and career interests • Observational studies of users' interactions during learning experience • Evaluation objects constructed by participants during the learning experience • Pre/Post quiz targeting factual recall, conceptual explanations and career interests 	<p>K-12 and public</p> <ul style="list-style-type: none"> • Field Trips • Open house • Museum exhibits • In-class demonstrations and lectures <p>Practitioners</p> <ul style="list-style-type: none"> • Research to Practice Webinars (live and archived) <p>Public</p> <ul style="list-style-type: none"> • Science/Engineering Discovery events • Media events
<p>Training - increase learners' ability to use tools, resources, and data associated with NEES facilities and cyberinfrastructure (e.g. NEES.org and the NEESacademy).</p>	<p>Goal – Increase and train the research workforce involved in earthquake engineering and science</p> <p>Outcomes: increased participation of researchers and practitioners in NEES through engagement in webinars, meetings, and professional development to support development of improved codes and application of state-of-the-art design and construction for safe civil infrastructure.</p> <p>Potential Evaluation metrics</p> <ul style="list-style-type: none"> • Post quiz on key facts and processes associated with the learning experience • Self-reports on learning, and satisfaction toward achieving goals. 	<p>Researchers (PI and Graduate Students)</p> <ul style="list-style-type: none"> • Webinars • Face-to-face workshops • Online Training Modules

Overview of NEES Education, Outreach, and Training Framework

NEES comprises 14 large-scale test facilities at universities around the United States, connected by a sophisticated cyberinfrastructure¹² to support research focused on better understanding challenges and innovations for designing earthquake-resistant communities. Each test facility includes a full-time or part-time person or team that supports an education, outreach and training mission. With respect to EOT, the test facilities focused primarily on *outreach* objectives including supporting 1) transfer of NEES research outcomes to the profession, 2) generating interest in STEM careers, 3) teaching students about earthquake and tsunami engineering, and 4) promoting public awareness of NEES and its accomplishments. Only about 20% of researchers are native to the universities where the test facilities are housed; the other 80% are from universities, labs, government agencies, or companies from elsewhere in the U.S. or other countries. Therefore, the other primary focus was *training* researchers on site-based equipment, instrumentation, safety procedures, software, and data management and archiving is an important function. Much of the training is done by operations and information technology staff, but some is done by the EOT staff. As will be discussed later, the Center has taken advantage of the cyberinfrastructure and its embedded course management system to increase the efficiency of the training component of its mission. The test facilities participated in a geographically-distributed REU program managed by the Center by hosting undergraduate students at the test facility and running enrichment programs for the participants.

The center headquarters, NEEScomm, supports a small dedicated education, outreach, and training (EOT) staff consisting of a director of EOT, a technology specialist, an EOT assistant, and two part-time faculty co-leaders. The function of this headquarters team is to ensure a cohesive program, facilitate a network-wide vision, provide technical support, monitor progress and assessment, and report to the funding agency. The 14 EOT coordinators at experimental equipment sites are dotted-line reports to the EOT director. An EOT Project Advisory Committee provides advice and review of EOT activities to both the EOT co-leaders and the EOT Director. In addition, the Center Communications Specialist works closely with the EOT staff at headquarters and at the 14 sites to interface with news agencies, develop promotional materials, and support the public outreach mission of the Center.

Center priorities are developed annually and reviewed quarterly based on both the requirements of the National Science Foundation cooperative agreement and five strategic aims laid out in the Center strategic plan¹³. The five strategic aims address community building, research support, knowledge transfer, workforce development, and raising public awareness. A companion EOT Strategic Plan “identifies goals and outcomes to assist the NEES Community in identifying critical directions associated with EOT responsibilities, and to help set priorities for resource allocation necessary to achieve the aims of the larger NEES Strategic Plan.”¹⁴ The EOT strategic plan provides concise definitions of “education”, “outreach”, and “training” Described in Table 1. In addition, it outlines guiding values and principles and legacy programs as well as a timeline for program implementation and metrics for measuring success.

NEES EOT Programs and Activities

Over the ten years of operation of NEES, several critical principles have emerged in governing an effective education program within a multi-site, geographically-distributed research center. Many learning experiences have been institutionalized to achieve desired programmatic and

learning outcomes outlined earlier. Each requires valuable resources of time to develop and implement, and funds to produce, assess impact, and disseminate materials to others. NEES priorities were established toward high-value projects that supported workforce development, knowledge transfer and public outreach. The NEES EOT team at NEEScomm collaborated with the NEES test facilities to co-develop and implement learning experiences. These learning experiences were either local to the sites or at National venues with high potential for visibility. To maximize the impact of the EOT budget the EOT community worked together to identify the best activities for each of the equipment sites and identified activities that could be shared by all members of the NEES community. This collaboration to co-develop, implement and assess as a community has led to several major high-impact programs for NEES EOT. The high impact programs are as follows.

NEESacademy

NEESacademy¹⁵ is a portal within the NEEShub cyberinfrastructure that provides an interactive online destination for education, outreach, and training. NEESacademy is designed to disseminate information and provide effective learning experiences for various stakeholders. This virtual institution includes an embedded learning management system, online courses^{16, 17} and training materials, utilities for creating virtual interactions such as online poster sessions, and a repository for exemplar curriculum and professional development activities and programs.

NEES REU program

NEES Research Experiences for Undergraduates (REU) program¹⁸ is a dynamic 10-week summer research program for upper division undergraduate students interested in civil, electrical, or computer engineering, and other fields related to seismic risk mitigation. The program hosts between 20 and 30 students at five to eight different sites each summer. Students spend the summer working with graduate students and mentors on state-of-the-art research projects as well as developing themselves as professionals, including their networking skills, presentation skills, communication skills, and global sense of the profession. REU participants are introduced to graduate programs in earthquake engineering at several universities and immersed in some of the aspects of applying to graduate school, such as writing a statement of purpose. Since 2006, NEES has hosted 209 students, of which 63% have earned advanced degrees in STEM and 11% have earned PhDs. A longitudinal study indicated that 85% of participants were positively influenced in their educational and career goals. The NEES REU program is an important contribution to developing the next generation of engineers.

Formal Education Materials

The EOT strategic plan¹⁴ makes a distinction between “education” and “outreach.” Educational activities are defined as “inquiry activities that emphasize high-level thinking, problem solving, and collaboration.”¹⁴ Whereas outreach activities “increase participants’ awareness of, and interest in, earthquake engineering and the science associated with the research and development work conducted by NEES.”¹⁴ Educational activities by their nature require a longer engagement of the participants than outreach activities as well as detailed lesson plans and training materials for those delivering the content. Educational activities can target a number of stakeholders including K-12, higher education, and working professionals,

and are central to developing the next generation workforce capable of succeeding in a STEM discipline such as earthquake engineering.

NEES testing facilities and research as well the cyberinfrastructure have supported both K-12 and undergraduate learning modules. A team of EOT specialists is developing a curriculum that uses educational shake tables for teaching fundamentals of earthquake engineering design¹⁹. Three of the testing sites have developed curricular modules to allow students to engage in remote laboratory experiences using research-grade equipment. The first involves remote real-time video monitoring, tele-control, and execution of experiments using the geotechnical centrifuge facility^{20,21}. The second involves remote control of a shaker on a research structure located in the California desert and the collection and analysis of time history data²². NEES research projects have developed educational modules and made them available on NEESacademy to fulfill their broader impacts goals. For example, a module aimed at 5th to 9th grade students demonstrates the behavior of piles in improved and unimproved clays²³. Another research project developed a full online course on wood design with virtual laboratories aimed at undergraduate and graduate students, and practicing professionals^{16, 17}. These curriculum and learning materials illustrate the potential of earthquake engineering as a context for learning and demonstrate how research can be integrated with and used to support formal education.

Informal Education

Informal settings such as museums offer excellent venues for communicating social, cultural and scientific information, correcting misconceptions, and transforming attitudes and cognitive skills toward STEM concepts. Learning is voluntary and self-directed and can occur in the relaxed atmosphere of a family outing or school field trip. Three museum exhibits, which will serve millions of visitors, are a keystone in the plan to raise public awareness of NEES resources and research, as well as earthquake and tsunami mitigation. The first exhibit, *When the Earth Shakes*, an 800-square-foot traveling exhibition for science museums on innovations in earthquake engineering, grew out of a NEES research project and a partnership with the Sciencenter in Ithaca, New York. The exhibition consists of eight exhibits that used a shake table, a tsunami wave tank, a *Make Your Own Earthquake*²⁴ jumping platform, videos, and interactive computer displays to explore concepts of seismology, earthquake and tsunami resistant design, and the impacts of NEES research. The interactive touch screen shown in Figure 4 allows visitors to explore how NEES research at the 14 experimental sites is addressing earthquake and tsunami engineering questions. Two smaller permanent *Make Your Own Earthquake* exhibits have been installed at a children's museum in Nevada and a natural history museum in California.



Figure 4: Touch screen for traveling museum exhibition

Outreach Activities

The NEES headquarters and experimental sites have the responsibility to provide outreach opportunities for its various stakeholders. These activities engage families, K-12, and higher education learners to increase their awareness and interest in the STEM areas; practitioners to inform them of new developments through NEES research; and the general public to inform them of research advances, showcase research capabilities and provide a public service for information. The types of programs that site EOT personnel use to fulfill this outreach commitment depend on the research mission of the site, characteristics of the research equipment, available resources, existing outreach programs at the host university, and partnerships with the local community. Typical activities include tours and open houses, visits to K-12 schools, meetings with local chapters of engineering societies, seminars/webinars, conferences, hosting film crews for television specials or news segments, and participation in STEM related fairs and outreach events. Three programs with large impact are described here.

The large-scale tsunami wave basin at Oregon State University (OSU) is ideal for EOT activities. The simulated waves are visually interesting and can be generated on demand at little cost to the site. Consequently, this site hosts close to 5,000 visitors per year in tours and

other educational activities. The site developed the *Tsunami Structure Challenge* to engage both K-12 and university students in building and testing structures in the large-scale tsunami basin to investigate concepts of tsunami hazard mitigation. To engage visitors when the tsunami wave basin is unavailable because of ongoing research, the site designed and built a 16-ft long mini-wave tank (Figure 5) and developed a companion design activity using Legos²⁵. The tsunami exhibit in the traveling museum exhibition was modeled on this mini-wave flume and its design challenge.

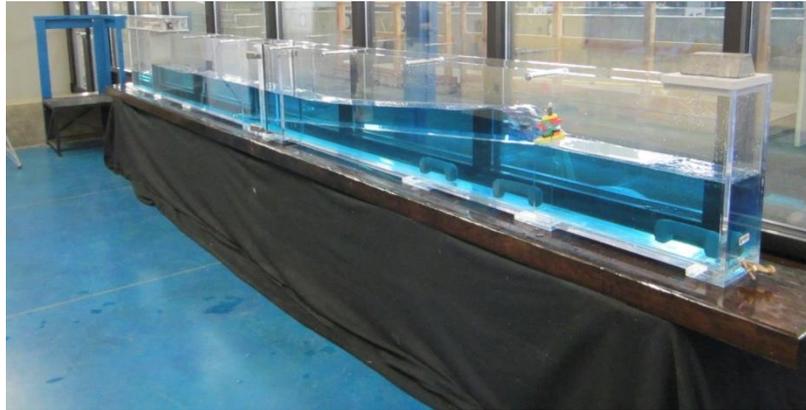


Figure 5: The 16-ft long mini wave-flume generates small tsunamis. It can be used in the lab or transported to other venues.

Because of the success of the mini wave-flume at OSU, NEES built two others for use in EOT around the country. One is housed at Howard University for use at several large-scale outreach events in Washington DC each year. In partnership with a faculty member at Howard, NEES developed an ambassador program that trains Howard students about tsunami hazard mitigation and how to effectively use the mini wave-flume in outreach activities. This ambassador program has the dual goals of expanding the available personnel to deliver EOT and engaging a large number of underrepresented students in earthquake engineering. A study of the ambassadors revealed that the program has the added benefits of positively impacting student goals, attitudes, leadership skill and engineering self-efficacy²⁶.

Practitioners are eager to implement the findings from NEES research to create better earthquake resistant designs and resilient communities. Practitioners are invited to the annual meeting but often cannot take the time off work to attend. Journal articles and online research databases²⁷ are another source of technology transfer. A mechanism that has been particularly effective in attracting practitioners is the *Research to Practice Webinar* series. Each webinar is delivered by a team of researchers and at least one practitioner who provides insight on the application and impact of the research outcomes. Webinars are 90 minutes long, including the question and answer period, and are recorded and archived on NEESacademy. Typically, multiple people in an office watch the webinar together in a conference room. A partner professional society, the Earthquake Engineering Research Institute, offers continuing education credits for a small fee. Attendance for any webinar is between 150 and 500 people. This is a great model for technology transfer because it is low cost, and requires minimal organization.

Lessons, Challenges and Recommendations

Over the past five years NEEScomm EOT staff has worked with the NEES test facilities to develop a cohesive education and outreach program. The primary focus of the test facilities is on producing quality experimental results for the NEESR researchers using their facilities. Their priorities for EOT focus primarily on training the research talent at their facilities to be safe and productive during their time at the facility. Therefore, they put a strong emphasis on helping the graduate students, post-doctoral researchers and REU students working at their labs. The operations staff has had the talent and means to meet the objectives for training these learners at their site. The facilities also recognized their responsibility to support outreach to K-12 learners and practitioners. However, not all test facilities had the staff, or expertise, to develop, implement and assess these kinds of programs. For these sites the benefit of being part of a collaborative network with the central support of NEEScomm became important components for successful EOT programs. The headquarters EOT staff have explored multiple methods to support the test facilities in participating in a network-wide EOT program. Compiled below are the top ten lessons-learned related to the design and implementation of the program over the past several years. These lessons include several of the key actions we anticipated in the strategic plan and articulate several additional considerations identified through the implementation and refinement of the EOT program.

1. Establish a clear set of objectives and priorities for both the center mission and the affiliated partners.
2. Define clear measurable metrics to demonstrate impact for the center's objectives and the affiliated partners.
3. Articulate a plan of action for achieving the objectives with a strong rationale to demonstrate impact.
4. Build a community of EOT personnel at each key institution who trust each other, work well together and are vested in achieving the desired outcomes.
5. Identify incentives for the EOT personnel to participate in the program.
6. Provide multiple opportunities for EOT personnel to collaborate together to share materials and best practices, identify opportunities for collaboration and articulate clear actions (for example, annual face-to-face meeting for at least half a day and monthly teleconference meetings).
7. Establish a centralized organizational structure that
 - a. emphasizes priorities and objectives,
 - b. fosters collaboration,
 - c. provides common assessments,
 - d. monitors progress toward goals,
 - e. provides support staff for development of materials.
8. Create incentives for the community to collaborate and contribute their products to the larger community (e.g. funding, support staff, dissemination of work).
9. Create common evaluation instruments, and train staff on evaluation strategies.
10. Leverage external partners to broaden impact and support implementation of program.

In addition to the common lessons-learned, we faced several challenges that led to some critical features of our program. Therefore, some of the larger challenges are summarized below along

with solutions we used and offer as recommendations to future designers of an EOT program for a large research center.

Challenge 1: *Establishing a clear set of priorities, stakeholders and quantifiable evidence for impact of the EOT program relative to the center's strategic aims.* In the first year NEES defined a set of Strategic Aims to better articulate the specific priorities of its mission. The EOT program had multiple opportunities to support each of these aims; however, priorities needed to be defined. Therefore, one of the initial steps was to rewrite the proposed EOT program into a new detailed EOT strategic plan that articulated key objectives and goals in terms of the center's strategic plan. As part of this effort, a new logic model was generated to expand the initial evaluation plan into a more comprehensive plan for measuring impact of the project. Therefore, one recommendation is to have a well articulate EOT strategic plan that provides a clear and comprehensive logic model illustrating translation of objectives into measures of impact. Impact should measure both the quantity of participants reached by various activities and the quality of activities in terms of the level of what participants learned.

Challenge 2: *Monitor and track progress toward targeted outcomes.* Another challenge for the center is developing a meaningful measure of impact and a reliable reporting method to facilitate tracking of a test facility's progress. The EOT representatives at the test facilities do not have a background in educational research or assessment. Therefore, they have little experience generating evaluation measures. In addition, many of the EOT representatives also had responsibilities for supporting the research projects at the center. These responsibilities were in direct conflict for their EOT efforts. Consequently, initially the primary data for reporting on EOT programs was limited to the number of participants, and the sites needed additional support to evaluate their programs with respect to quality. They also needed additional support in creating an EOT plan focused on goals and assessment. Therefore, an Annual Planning Document template was developed to help structure the planning process for the EOT representatives. This process greatly reduced the ambiguity of what the test facilities developed. In addition, it provided an excellent basis for discussion with the education and assessment expertise at the central office. Therefore, a recommendation is to have a formal process for articulating specific plans of action at each test facility. The process should require clear articulation of objectives, assessment instruments, budget, and instructional methods planned. In addition, it should include project management information associated with target audience and dates of major milestones. The prescribed template will make the process more accessible to responsible EOT representatives and provide an excellent tool for tracking progress over a specific period of time.

Challenge 3: *Identify personnel to implement and evaluate learning activities.* A successful EOT program will target a large audience, have meaningful learning experiences and will involve the assessment and redesign. Time and personnel are required to implement a cohesive plan well. An EOT representative at each test facility may not have time to implement all of the learning experiences. Often, the time commitment associated with EOT is sporadic, making it difficult to justify a full or part-time person. One recommendation is to use undergraduate or

graduate students to support various outreach activities identified in Table 1. One method is to establish an Ambassador program²⁶ that provides hourly jobs to undergraduate or graduate students. Depending on the level of involvement and expertise, these jobs could be potential recruiting methods to encourage students to pursue graduate school in a STEM discipline. Other options are to connect with student chapters of professional societies, which often conduct outreach activities as part of their mission. One challenge is that the students will need training. However, if the program becomes large enough and retains students for a long time, then these students can be mentors for new recruits.

Challenge 4: *Maintain and engage a collaborate community focused on shared objectives.* One of the most powerful outcomes of the NEES EOT program is the collaboration between the EOT representatives between the sites. After their initial meeting at an annual workshop, they came to find they were not alone in their efforts and learned many new ideas. These workshops became a strong catalyst for generating conversations about possible new directions. This energy to engage in the EOT program will wane without specific actions and regular meetings. Therefore, a recommendation for establishing a collaborative community is to have regular meetings with the goal of identifying specific action items. Action items could involve trying out other's materials, identifying new ideas to discuss at future meetings, developing new materials to be shared with others, or collaborating on journal or conference papers.

Challenge 5: *Leverage educational programs linked to research grants affiliated with the center.* Large impact could be obtained through coordinated educational programs for all the research grants associated with the 14 sites. As discussed earlier and referenced in Figure 3, the Center EOT management had indirect access to the researchers writing proposals to use the NEES facilities. Webinars on planning education programs were connected with the request for proposals. However, few research volunteered their time to participate in these sessions. Researchers felt that there were few incentives to collaborate in an educational program that may not directly impact the outcomes of the research. New models should be explored to identify a method to promote educational missions and provide incentives for individual researchers to participate in larger Network-wide educational programs.

Conclusion

An ambitious EOT program is worth striving for when it is designed with a realistic balance between measurable objectives and available resources (time, budget and personnel). The complexity is high for running any large-scale research effort because of the interrelationship of multiple disciplines, institutions, and stakeholders. Also, balancing financial resources and competing priorities of objectives can be difficult. This paper described some of the key features of the NEES EOT program and compared the NEES organization with the ERC to illustrate the similarities between these models. This was done to emphasize that the lessons learned could potentially be generalized for any large-scale research effort like an ERC.

The lessons and challenges described in this paper are not exhaustive, but bring to light some of the common challenges associated with running an EOT program for a large research center,

particularly one that is geographically dispersed. Further, many of these recommendations are becoming known because of the increased focus on education and outreach as an important outcome of a research project. A common challenge for the efforts has been the lack of concrete evaluation plans using logic models and effective assessments that target learning outcomes. Demonstrating broader impact of an effective EOT program will involve the lessons learned and recommendations summarized in this paper.

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