2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33748

Design and Development: NSF Engineering Research Centers Unite: Developing and Testing a Suite of Instruments to Enhance Overall Education Program Evaluation

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Design and Development: NSF Engineering Research Centers Unite: Developing and Testing a Suite of Instruments to Enhance Overall Education Program Evaluation

Abstract

National Science Foundation (NSF) funded Engineering Research Centers (ERC) must complement their technical research with various education and outreach opportunities to promote society's engineering participation and advocate collaboration between industry and academia. ERCs ought to perform an adequate evaluation of their educational and outreach programs to ensure that such beneficial goals are met. This activity is done with full autonomy, which allows each ERC to design and implement its evaluation processes and tools in total isolation. The evaluation tools used by individual ERCs are often quite similar suggesting that these isolated efforts have produced redundant resources that cannot be easily compared due to minor nuances and differences across tools. Single ERC-based evaluation also lacks the sample size to truly test the validity of any evaluation tools. Leaders, educators, and evaluators from six different ERCs are leading a collaborative effort to address the stated issues by building a suite of common evaluation instruments for use by current and future ERCs as well as other similarly structured STEM research centers. A common suite of instruments across ERCs would provide an opportunity to not only streamline ERC education evaluation, but also conduct large-scale assessment studies. This project aims to develop five major deliverables: 1) a common quantitative assessment instrument, 2) a web-based evaluation platform for the quantitative instrument, 3) a set of qualitative instruments, 4) an updated NSF ERC Best Practices Manual, and 5) supplemental resources within a new "ERC evaluator toolbox".

Introduction

NSF has been supporting the ERC program since its inception in 1985 [1]. This support has funded a total of 75 centers (18 of which are currently operating) across the US with varying research foci and missions [1]. An important feature of all ERCs is the educational programming that disseminates emerging knowledge from center activities and focuses on building a culture of inclusion. These programs vary from one center to another but must include academic year educational opportunities for post-doctoral researchers, graduate students, and undergraduate students, as well as summer opportunities for undergraduates (Research Experiences for Undergraduates; REU), K-14 teachers (Research Experiences for Teachers; RET), and high school students (Young Scholars Program; YSP). Each center is also responsible for conducting public outreach activities relating to its engineering research mission, including outreach to K-12 and community college students. The core mission of all ERC education efforts is to: 1) produce graduates who understand industrial practice and will be adaptive, creative innovators in a globally connected, innovation-driven world, and 2) augment the engineering curriculum with educational materials derived from the ERC's research [2].

NSF requires that all ERCs implement data-driven approaches to assess, evaluate, and track the impacts of their education and outreach programs to inform program development and ensure that the center meets ERC requirements [3]. Yearly findings should be reported as part of the center's annual report and site visit. Such responsibility falls on each ERC to develop and organize its own evaluation plan and protocols and is often coordinated by center education directors/leadership, in collaboration with external evaluators or evaluation teams.

The process by which each center determines how they will evaluate their educational programming is presented as an open-ended problem. Each center is given the authority to choose its own preferred evaluation techniques and tools (e.g., surveys, focus groups, interviews, or lab observations) to meet the criteria set forth by NSF. This flexibility is useful in some respects, but quite daunting when integrating novel research, education, and outreach agendas across multiple university sites. Such flexibility has led to ERCs' isolated work in designing and developing program evaluation tools, despite NSF's encouragement to collaborate across centers. Siloed ERC evaluation efforts equate to redundant evaluation efforts that make cross-ERC comparisons essentially impossible. NSF's required evaluation of program-specific outcomes across all ERCs naturally suggests a need for a set of common ERC-specific instruments that can be used by all ERCs and similarly structured large-scale STEM research centers. This project seeks to take up this challenge with a direct, conscientious effort to address this need and combat current limitations facing ERC evaluation.

The project aims to broadly impact practice within the engineer-formation system by providing a new approach to measuring the effectiveness of education and diversity programs within and across ERCs. The goal of the project is to enhance evaluation for not only individual ERCs, but make it possible to expand and compare across all ERCs. The suite of evaluation tools includes a modularized quantitative instrument, online instrument disseminate platform, set of qualitative protocols, updated NSF ERC Best Practices Manual document, and a supplemental evaluator toolbox. The development of a suite of common evaluation tools will reduce the workload for ERC external evaluators and will provide a clearer picture for each center on how to improve educational programming for a broader impact.

Background and Literature Review

Research on NSF ERCs includes NSF-driven reports and external investigations. NSF annually evaluates the overall impact of the ERC program toward its core mission by compiling aggregate baseline data reported by each ERC. These cumulative assessment reports provide current ERC statuses, numbers and types of products or innovations, influence on curriculum, degrees conferred, graduate employment, diversity of participants, the personnel conducting research, and industry participation [4]. NSF also conducts industry ratings of ERC graduates compared to non-ERC graduates on a yearly basis [5].

External task groups and reports have also frequently been solicited by NSF to study ERCs. One example is an ERC-specific survey conducted to examine undergraduate and graduate education activities across 22 active ERCs to better understand center outputs in terms of the number and nature of new and modified courses, new major and minor emphases, new certificate programs, and new degree programs [6]. ERC-required educational programs (e.g., REU, RET, and YSP) as standalone programs have also been assessed broadly [7- 9]. The reports produced by these combined sources of program evaluation have been used to inform revisions in subsequent program solicitations. For instance, reports on RET programs have revealed inconsistent engagement in research for RET participants, likely due to greater priority on curriculum development for their classrooms. Subsequent RET program expectations now mandate authentic research involvement for RETs with reinforced requirements for follow-up activities. Such reports are useful, but rare, because of the cost and limitations associated with the types of methodologies implemented.

Additional research outside of NSF-commissioned reports has further illustrated the accomplishments and challenges of assessing ERC education and diversity efforts. The relatively limited number of published studies assess various educational programs within a single ERC using a variety of methods of analysis. These studies have explored effects on graduate students [10-11]; center-level development of graduate-level curricula [12]; issues of retention and graduate recruitment of undergraduates into engineering [13-14]; skill development [12, 15]; effects of mentoring [16]; efforts to improve mentoring [17]; teacher motivation, student expectations, and teaching practice [18-19]; teacher development as scientists [20]; change in conceptions of scientific inquiry and inquiry-based instruction [21]; perceptions of youth participants and facilitators of educational outreach activities [22]; and diverse YSP participants' experiences and learning from program participation [23].

The relevant literature examining ERC educational contexts exhibits several limitations to be addressed in the current project. First, collected data for the majority of studies are self-report, other-report, and/or document analyses. Few studies engage thick, rich descriptions of artifacts or observations of ERC activities [15, 24]. Second, most studies focus on a single type of ERC participant. Notable exceptions include a study of summer research experiences for cohorted RET, REU, and YSP participants using social network analysis to examine cross-group interactions [25] and the impact of cohorting on YSP participants [26]. Third, current evaluation strategies are largely designed by each ERC using a siloed approach. Studies rarely compare or draw conclusions across ERCs. Siloing of evaluation efforts limits the potential for large-scale studies with participant samples greater than 50 because of small participant pools within a single ERC [19]. Most large-scale studies of ERCs have included participants beyond the ERC program [27], which limits the application of findings to ERC programs specifically. Finally, research examining ERC educational efforts has been criticized for focusing on outcomes that are only indirectly related to the program's core mission [10]. These limitations are not unique to ERC programs. Many government multipurpose cooperative research centers wrestle with the same difficulties of assessing and evaluating center and program outcomes and impacts, including aggregation and weighting of outcomes; deconstructing and operationalizing the meanings of performance criteria; and constructing comparison groups [28].

Engineering Education and Centers Program Clusters

This project is addressing each of the four NSF Division of Engineering Education and Centers (EEC) program clusters: 1) broadening participation in engineering, 2) centers and networks, 3) engineering education, and 4) engineering workforce development.

First, the evaluation tools developed within the project will pay special attention to collect comprehensive, valid, and reliable data on constructs including outreach engagement/participation, mentoring efficacy/impact, student sustained interest in a content area, perception of support mechanisms, and the extent to which centers exhibit diversity and a culture of inclusion. These data will help ERCs across the nation assess the performance of their educational programming in recruiting and sustaining engineering participation within the community, especially among traditionally underrepresented populations in STEM.

Second, ERCs share a common goal of developing a globally competitive workforce that can translate fundamental research into practical innovations to solve grand challenges in engineering. Education and evaluation teams across ERCs have the unique opportunity to assess the effectiveness of the different strategies employed by their ERCs. This suite of common evaluation tools not only supports existing ERCs but can serve as immediate tools for brand new ERCs and similar large-scale STEM research centers.

Third, both quantitative and qualitative research are conducted alongside the evaluation. This research provides insight into a wealth of engineering education knowledge, such as the different pathways of people enrolled in engineering programs and/or who ultimately goes on to become engineers, and the implementation and application of engineering education research findings into practice. This knowledge helps advance nationwide engineering education. Expanding research beyond the project team also promotes and encourages continual cross-ERC collaboration and research.

Last but not least, the designed evaluation process provides a feedback loop for continual improvement by increasing evaluation consistency across all ERC education and diversity programming. This feedback loop supports the growth of an inclusive and innovative engineering workforce.

Project Team

A unique opportunity for cross-ERC collaboration exists at Arizona State University (ASU) because it is the lead institution for two currently funded NSF ERCs – Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) and Center for Quantum Energy and Sustainable Solar Technologies (QESST) – as well as a partner institution for a third ERC – Nanosystems Center for Nano-Enabled Water Treatment (NEWT). The education, diversity, and evaluation leaders for these three ERCs formed The ERC Education Consortium (TEEC) in 2016 to take advantage of this shared geographical location. The goal of TEEC is to collectively leverage expertise, experiences, and resources across the three ERCs. This collaborative effort has led to the design and implementation of cross-ERC events, shared programming, and streamlined program evaluation.

The origins of this project began during the 2019 ERC Biennial Meeting in Washington, D.C. where TEEC prepared and presented a workshop titled 'Establishing a Common Set of Tools for Evaluating Educational Programs Within and Across ERCs' [22]. TEEC again reached out to all 18 existing ERCs upon the project's approval by NSF in 2020; all current existing ERCs expressed interest in collaborating and /or participating in the project. It is worth noting that a subset of ERCs are in their tenth and final year of operation but still recognize the potential value of participating. The current project is now being marketed under the name, 'Multi ERC

Instrument Inventory' or MERCII. Additional education and evaluation leaders from three ERCs–Center for Advanced Technologies for the Preservation of Biological Systems (ATP-Bio), Center for Innovative and Strategic Transformation of Alkane Resources (CISTAR), and Center for Precise Advanced Technologies and Health Systems for Underserved Populations (PATHS-UP) – have been brought into the consortium to leverage existing expertise and connections to ASU (Note: ASU's University Office of Evaluation and Educational Effectiveness serves as the external evaluation team NEWT and PATHS-UP.) TEEC now comprises education, diversity, and evaluation leaders representing six different ERCs at varying stages of existence (one at year 1, two at year 4, two at year 6, and one at year 10).

Project Design

MERCII includes five components: 1) develop a quantitative instrument that is both comprehensive and flexible enough to be used across ERC participant groups (e.g., faculty members, yearlong research assistants, and summer interns), 2) create an online platform to share and disseminate the quantitative instrument, 3) develop a complementary set of qualitative tools (e.g., interview, focus group, and observation protocols), 4) update the NSF ERC Best Practices Manual, and 5) construct a supplemental evaluator toolbox.

Quantitative Instrument

TEEC has recently completed the third revision of the MERCII survey leveraging the constantly expanding expertise of the team. Coordinated iterative cycles of reflection and action were used for instrument development [30-31]. The instrument currently has seven baseline categories that could be applied to all ERC population groups and will be used to conduct cross-ERC comparisons. Table 1 documents the baseline categories (excluding demographics): understanding of the ERC, impact on skills, culture of inclusion, mentorship experience, future plans, and program satisfaction. These six categories were extracted from the NSF ERC Best Practices Manual [3] and ERC program solicitation [32] as cross-cutting categories that NSF recommends evaluating to monitor ERC progress and impact around workforce development and culture of inclusion initiatives. Comparisons will be presented in aggregate to individual ERCs to avoid rank-ordering the ERCs.

Optional modules are also under development to expand insights and provide flexibility for individual centers. The optional quantitative modules include measurements that are not a mandatory requirement from NSF (e.g., engineering identity, engineering ethics) or apply only to a specific subset of the ERC population (e.g., RET experiences, mentorship experiences for mentors, etc.). TEEC will also make recommendations for existing measurements on other assessment topics to provide support and guidance to all ERCs to help meet their diversified evaluation requirements. All optional scales can be added to the baseline set of categories while disseminating the instrument to different populations. The instrument will be further tested with more ERCs in Summer 2021 to collect additional validity evidence and improve instrument reliability.

Table 1. *MERCII quantitative instrument baseline categories, sample questions, and items*

Category	Question or Question Stem	Sample Items
Understanding of the ERC	Rate your level of understanding for each of the following items.	The mission of the ERC
		Concepts associated with the ERC field(s) of study
Impact of Skills	Rate the degree to which participating in the ERC improved your professional/research skills in the following areas.	Networking with industry
		Taking on leadership roles
		Formulating research questions
Culture of Inclusion	Rate the degree to which the ERC exhibits diversity and a culture of inclusion. As a participant in the ERC, I feel…	My contributions are valued by other ERC members.
		I belong in the ERC.
Mentorship Experience	Rate the degree to which you received the following from your ERC mentors.	Support in conducting independent work.
		Feedback that is constructive
		Direction on my research project
Future plans	Rate how likely you are to pursue a future career in each of the following settings.	Academia (higher education)
		Government agency
		Pre-college education
Program Satisfaction	Rate to what extent you agree or disagree with the following statements.	I am satisfied with my ERC experience.
		I would recommend working with the ERC to others.

Online Platform

A sub-team of TEEC is currently creating a web-based platform as an online hub that houses materials and instruments. The MERCII platform will further provide an easy-to-use tool for all ERCs to facilitate evaluation, share data, and report impacts. An initial needs assessment has been conducted to gain a better understanding of stakeholder needs for this tool. These requirements include aspects of architecture, functionality, authentication, data management, data analysis, interface design, communication, and output. For example, the platform will be designed to allow ERCs to create an account, select scales to include or exclude, disseminate the survey to participants, and view tabulated results. Automated data analysis will provide TEEC and individual ERCs with data while freeing up additional time to focus on qualitative efforts. The scrum framework is adopted to develop the online platform to assure the requirements are being precisely matched. The next step is to map the requirements into software logic and prototype the alpha version of the platform.

This project aims to reduce the effort in implementing quantitative evaluation for ERC evaluators. One approach is to incorporate the platform into existing media already available to the community, instead of creating a brand-new website. One example is nanoHUB, which already includes an ERC Evaluator Leaders Group [33]. Another example would be the Engineering Research Centers website, which includes the ERC Best Practices Manual [3].

Qualitative Protocols

A 'one size fits all' approach to ERC evaluation will not work for every ERC. ERCs use a variety of evaluation metrics for their programs, which suggests a clear need to offer qualitative tools that complement the effort to develop the MERCII survey. The complementary qualitative pieces planned include four generic protocols for interviews, focus groups, poster session scoring, and classroom observations. The developing process of qualitative protocols is also cyclic, involving existing protocol synthesis, literature referencing, team discussion, and iterations of testing and revising. All four protocols are currently under construction with the interview and focus group protocols; interview and focus group protocols are on schedule to be ready to test during Summer 2021. The interview protocols and focus group protocols both include questions addressing all categories present in the survey. These protocols are designed to provide increased flexibility allowing for greater variation in implementation compared to the quantitative instrument. The goal is to simply provide a template to allow for some level of consistency across ERCs.

Best Practices Manual

NSF supports ERC Education and Inclusion evaluation efforts by providing recommendations for "best practices," lessons learned, and a bank of example instruments to reference based on feedback from ERC education program developers [3]. Currently available tools lack adequate testing and related validity evidence. In some instances, the provided information is only a theoretical framework making it extra difficult to reference and adopt.

TEEC has requested and received approval from NSF to update this Best Practices Manual. An independent new chapter is planned to provide guidance on the evaluation and assessment requirements and activities across multiple aspects of ERCs. The two main aspects are 1) ERC education programs and 2) diversity and culture of inclusion. The first update is to replace the outdated measure examples and add MERCII evaluation tools into the manual once extensive validity and reliability evidence has been collected. Other planned updates include adding different vetted and reputable evaluation tools from various sources, i.e., TEEC approved tools. ERCs have a different emphasis on specific evaluation categories and research interest through evaluation. Examples of such categories include identity, entrepreneurial mindset, or sense of belonging. This approach will be taken to crowdsource possible additional measures.

Evaluator Toolbox

The evaluator toolbox is an embedded resource that provides evaluators with a space to share "lessons learned" and "evaluator tips" across ERCs. The creation of this collaborative space will elicit opportunities for all ERCs to collect data that successfully captures both implementation (process) and impact (outcome) data for their educational programs. This effort is designed to excite those leading evaluation efforts within ERCs through a community of practice models that goes beyond the Best Practices Manual.

Evaluator leads in TEEC have recruited other partner ERC evaluators to form a series of ongoing monthly ERC Evaluator Group meetings. Collaboration efforts have been implemented within this group to discuss what resources and guidance evaluators want as part of a toolbox to help them in conducting a wide range of work. ERC evaluators have expressed particular need around instructions for using MERCII evaluation tools, tips for conducting quality evaluation, a place to share and request information, and examples of adequate NSF evaluation reports/presentations.

The MERCII evaluator toolbox will include operational best practices (e.g., IRB protocol development, data storage of sensitive information, and development of data tracking systems), lessons learned from current and past evaluators (e.g., when and how to distribute surveys for increased response rates), best practices in evaluation (e.g., collecting data from multiple stakeholders for confirmation and using mixed methods), and how to report findings (e.g., data visualization templates in Microsoft Excel and one-page visuals).

Summary

TEEC has established a sound foundation for the delivery of each MERCII instrument during Year 1 of the project. Quantitative and qualitative MERCII tools will be ready for testing in Summer 2021. The MERCII online platform is being prototyped with an eventual testing date sometime in late 2021. The evaluator toolbox is growing with tools intended to support ERC evaluators. A structure and directions have been established for updating the ERC Best Practices Manual. The increase in the number of participating ERCs has consequently increased the sample size for this project. This will give TEEC the ability to make comparisons within and across the greater ERC population. TEEC intended to ensure that the instruments created provide proximal data for individual ERCs to use to inform their own centers. TEEC also wants to provide aggregate insights across ERCs to provide new information into how ERCs vary in their strengths and abilities in preparing their students to become competitive in the global workforce. These data need to be useful for both goals in order to inform individual ERCs and to compare across ERCs. Some ERCs might be implementing program components that prove more effective in student learning, which could be mirrored in other ERCs. Having common instruments will further NSF's desire for collaboration across ERCs to share and learn from one another's experiences.

Acknowledgments

This work is supported by the National Science Foundation Grant EEC-2023275. Any opinions, findings, and conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We would also like to thank the leadership team, education team, and the evaluation team of all partner ERCs – ATP-Bio, CBBG, CISTAR, PATHS-UP, QESST, and NEWT – for their support and participation in knowledge sharing, data collection, and offering constructive feedback.

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