Outcomes & Lessons Learned from a NSF-REU Site on Metrology & Non-Destructive Inspection

Abstract

The objective of this paper is to detail the outcomes and lessons learned over the past three years of the project cycle, from a National Science Foundation (NSF) Research Experiences for Undergraduates (REU) site on metrology and non-destructive inspection (NDI). Besides detailing the evolution of the major activities over the course of the project progression, the project performance in terms of meeting outcomes and the lessons learned will be elaborated on.

The goal of this REU site was to enhance the knowledge and skill level of a diverse cohort of undergraduates through empowering, hands-on and interdisciplinary research experiences in metrology and NDI technologies. This site was essentially a direct response to a recurring concern raised by regional industry partners and technical workforce recruiters about the lack of pragmatic metrology/NDI-related knowledge and skills in their incoming regional workforce. Over the past three years, a total of 30 REU students progressed through and completed the program. The major project evaluation mechanism consisted of pre- and post-program questionnaires (besides individual research project deliverables), that provided insight into student impressions of the site as well as their intent to pursue advanced study and STEM careers. These were tabulated against the goals of the REU site, and conclusions drawn on the site's progress in achieving its intended objectives. Details are also provided on the recruiting efforts undertaken and the applicant pool it generated, especially regarding the switching of the application portal from one that was managed individually by the REU site, to a common pilot application system managed at the NSF program level. Finally, the demographics and regional spread of the participants as well as their intentions for advanced-study and STEM career choices are detailed as well. Altogether, the experience, outcomes and lessons learned from this REU site operation are expected to guide the effective and efficient operation of future REU sites as well as undergraduate research projects in general.

Background & Program Details [1]

On soliciting feedback from the manufacturing and energy industry nationwide, as well as from Industrial Advisory Board members that hire Texas A&M University (TAMU) students, a recurring concern brought up over the years was that often the incoming workforce did not exhibit the necessary knowledge and skills in metrology and inspection. Metrology, the science of measurement, and inspection transcends scales, materials, and disciplines; yet, rarely are its salient aspects emphasized. This NSF-REU site titled "Interdisciplinary Research Experiences in Metrology & Non-Destructive Inspection" was a direct response to address this critical need. It had its program dates spanning May-2017 to May-2020, with the summers of 2017-2019 hosting cohorts of 10 students each, to impact a total of 30 students over 3 years.

The overarching goal of the site was to enhance the knowledge and skill-level of 30+ undergraduates through empowering interdisciplinary research experiences in both traditional/advanced metrology and (destructive and non-destructive) inspection technologies. Each year, 10 undergraduate students were hosted at TAMU, classified into 5 vertically-

integrated project (VIP) teams, each comprising of 2 REU students, undergraduate and graduate students (from TAMU), and a faculty mentor, who worked in concert on select research projects over 10 summer-weeks; each REU student pair was matched based on complementing skills and interests. Creating such collaborative teams was intended to promote both horizontal and vertical learning in an interactive environment, thus laying the pathway to mold independent researchers who are also team players. During this time, they were immersed in hands-on research experiences comprising of a transformative research project, capsulated technical sessions and complementary lab practice, field tours, research seminars, and professional development workshops; this on-site experience was supplemented with a 1-year follow-up for continued interaction, growth, and guidance for pursuing advanced study. Student deliverables included dissemination of research results, and a follow-up plan tailored to each student's career interests.

Altogether, this site is expected to help create empowered future researchers and a workforce well-rooted in metrology/inspection, and motivate them to pursue advanced STEM degrees and careers. With a focus on the energy/manufacturing sectors, the site aspirations are:

1. To excite, empower and educate 30+ undergraduate students in metrology and destructive /non-destructive inspection technologies,
2. For them to experience an immersive research-training through a transformative project,
3. To mold them as independent/collaborative researchers and effective communicators,
4. To learn to ask the right questions, formulate plans, and pragmatically interpret data, and
5. To inspire and enable them to pursue advanced study and related STEM careers.

Program Activities

As detailed in Table 1, during the pre-program phase, target institutions were contacted, applications solicited, REU student pairs selected, and projects assigned. Students used the transition months to build their project-specific competency via assigned reading, so they could hit the ground running. During the on-site period, major REU activities included a 40-hour/week hands-on research project, capsulated technical sessions/labs, seminars, and college-level professional development workshops and networking to develop soft skills. Student-pairs worked closely with their mentor and research group via individual and group meetings. Deliverables included a research plan and progress reports, public dissemination through research papers and posters/presentations, as well as a CV and realization plan tailored to each student's career objectives. Pre-/post-program assessments were conducted as per the external evaluator's directions. The on-site experience was supplemented with a 1-year follow-up, and an extended follow-up to track professional progress.

This REU site endeavor is in line with the Texas A&M University System's commitment to undergraduate education, and in particular to undergraduate research as a high-impact learning practice. To effectively facilitate undergraduate summer research, the College of Engineering has an elaborate infrastructure in place specifically for the numerous REU sites (along with TAMU undergraduates, and national/international exchange students) via the Undergraduate Summer Research Grants (USRG) program; this caters to both the student's research project as well as professional development, and culminates in a university-wide research symposium. The following are representative samples of mechanisms in place for summer students:

- Low-cost on-campus housing reserved especially for summer REU research participants,

- Streamlined student access to all student-related university resources such as IDs, Dining, eCampus, Wi-Fi, Libraries, Parking, Recreation Center, Health Center, Open Labs, etc.,
- (Free) bus transportation services within the city/campus, and bike/car-share programs,
- Disability Service Office (DSO) provides support to participants with special needs via accommodations coordination, referral, information, assistive technology services, etc.

Table 1: Annual cycle of REU site activities including pre-/post-program events and evaluation

MONTH	(ANNUAL) SCHEDULE OF REU SITE ACTIVITIES	
Dec. - Feb.	Contact target institutions. Present/distribute program details. Solicit applications.	
Mar.	Receive applications (via Mathematica). Conduct virtual interviews. Select/match REU pairs.	
Apr.	Formal acceptance. Standby list. Logistics. Introduce projects. **Project competency catchup!**	
May	Coordinate travel, housing & other amenities. Check-in formalities. Arrive @ TAMU.	
@ TAMU	Pre-program survey (by external evaluator).[#] Debriefing. Onboarding. Campus tours.	
(WEEK)	**RESEARCH PROJECT EXPERIENCE (VIP TEAMS)**	**PROFESSIONAL DEVELOPMENT (COE USRG)***
May **(Week-1)**	**Define project objectives, methodology, timeline & outcomes.** Ethics training courses.	Welcome breakfast. Orientation. General lab safety training. Welcome Bar-B-Q. Ethics.
Jun. **(Week-2)**	**Research plan due!** Overview of metrology/ inspection principles & labs. Safety courses.	*GRE workshop*: What to expect. *Seminar*: TAMU early admissions program.
Jun. **(Week-3)**	**Research questions & tasks.** Training & practice on relevant laboratory equipment.	*GRE workshop*: Maximize your study time. *Seminar*: Applying to graduate school.
Jun. **(Week-4)**	**Conduct research tasks.** Departmental & on-campus research center tours.	*GRE workshop*: Verbal. *Seminars*: Funding your education; Grad life; Selecting advisors.
Jun. **(Week-5)**	**Conduct research tasks.** Prepare progress report & (group) research presentation.	*GRE workshop*: Quantitative. *Seminar*: Making the most of your graduate degree.
Jul. **(Week-6)**	**Progress report due! Group presentation. Continue research tasks.**	*GRE workshop*: Written/Analytical. *Seminars*: Graduate school 101; Preparing a CV. BBL[%]
Jul. **(Week-7)**	**Continue research tasks.** Emphasis on correctly interpreting acquitted data.	**CV due!** Early admissions due. *Seminars*: Scientific writing; National fellowships. BBL
Jul. **(Week-8)**	**Continue research tasks.** Plan/adapt &/or invoke contingency plans to finish on time.	*Seminars*: Effective poster presentations; Writing abstracts, papers & publishing. BBL
Jul. **(Week-9)**	**Abstract due! Wrap-up research.** Prepare paper/presentation/poster. Trial presentation.	*Seminars*: Conflict Resolution; Transition from undergrad to grad school/beyond. BBL
Aug. **(Week-10)**	**Research paper due! Group presentation.** Formulate individual career plans (guided).	**Poster due/presentation! TAMU Summer Research Symposium.** Awards ceremony.
@ TAMU	Post-program survey (by external evaluator). Reflection essay. Professional networking.	
Follow-Up (1-year)	Database & mailing list setup. Scheduled periodic status updates for continued guidance on career objectives (for 1-year). Posting of opportunities. Strategies to position for success.	
Extended	Periodic contact (beyond 1-year). LinkedIn updates. Track professional career progress.	
[Fall]	Evaluator report; discussion & intervention plans. Grad student & mentor training.	

*[College of Engineering (CoE) Undergraduate Summer Research Grants (USRG) activity]-[Optional]
[Deadline] [#][Evaluation activity] [%][Brown bag lecture by Institute for Broadening Participation (IBP)]

The majority of the 10-week on-site period involved the students working on their research project. This involved the essential steps of understanding the background/motivations, conducting/refining a literature review, conducting equipment training (and general lab safety training), and diligently working to advance the project solutions. To foster scientific curiosity, the research mentors intentionally strived to spark the curiosity of these potential future STEM researchers through real-world examples and hands-on tasks; the intent was to guide their thought process and holistic discovery in a manner that imparts confidence through

metacognition. Additionally, two technical sessions (in the labs) were provided to the students, one on metrology and the other on non-destructive inspection, so they could gain an appreciation of the broad and interdisciplinary nature of these fields. These were complemented with tours of related centers/facilities on campus as well. Towards the end, the REU students were guided in creating a professional poster that detailed their research project. After being provided feedback on the oral practice presentation of their project, they formally presented them at the university-level summer research symposium for undergraduates. Further, procedures for proper project windup including the structuring and archiving of the data/samples generated was instituted. Following these checkout procedures, the REU cohort was integrated into a networking group on LinkedIn to facilitate building their peer-network, as well as for the faculty mentors to follow-up on their future plans for advanced study and pursuing STEM fields.

In addition to the research project, students had the opportunity to pursue professional development activities offered on-campus, that included preparing applications for graduate school, GRE preparation workshops, resume preparation, public presentation and interview practice, etc. Since these were coordinated separately by TAMU as part of an Undergraduate Summer Research Grant (USRG) program, it was not mandatory for the REU students; as a result, participation levels varied across years. Representative images from year-3 are shown.

Figure 1: The summer-2019 cohort of REU students (left), and along with their mentors (right)

Figure 2: The 2019 REU cohort taking part in the non-destructive evaluation lab (workshop)

Figure 3: The 2019 REU cohort taking part in the metrology lab (workshop)

Figure 4: The 2019 REU cohort taking part in the Material Characterization Facility (MCF) tour

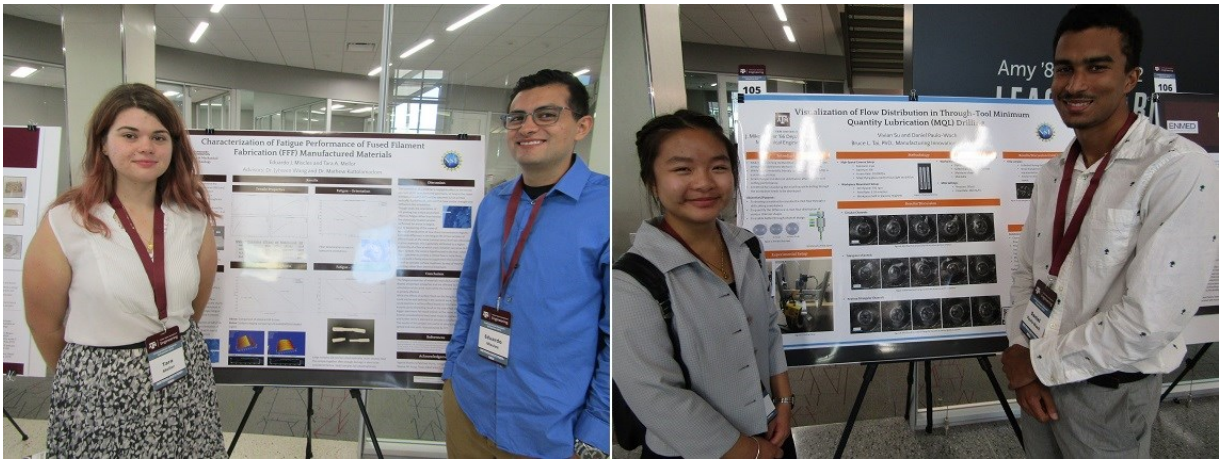

Figure 5: Two of the 2019 REU cohort student teams (pairs) presenting their final poster at the *Engineering Undergraduate Summer Research Grant (USRG) & Research Experiences for Undergraduates (REU) Research Poster Symposium,* at Texas A&M University

It should be mentioned that in addition to the REU students, a number of TAMU engineering undergraduate and graduate students within the research groups of the participant faculty groups

also got a chance to improve their technical, personnel and managerial skills by coordinating and interacting with the visiting REU students as part of their combined research project activities.

Participant Recruitment and Selection

As outlined in Table 1, target institutions were contacted and applications solicited, during the pre-program phase. Recruitment efforts leverage several channels to invite suitable applicants:

- TAMU Engineering Academic & Student Affairs (EASA)
- Professional societies
- Institution visits
- Personal contacts
- Program coordinators of undergraduate programs in external instututions

Acting on the recommendations of the external evaluator, special attention was paid to disseminating the REU opportunity to organizations besides research-intensive educational institutions (*i.e.*, 2-year colleges, liberal arts colleges, etc.). Advertising efforts took the form of directly contacting peers and reaching out to undergraduate program coordinators in numerous colleges and universities, besides the typical email blasts. During years 1-2, application materials were collected via email, in lieu of generating an online fillable form that had to have certain compliance checks. During year-3, applicants utilized the newly piloted Mathematica Policy Research web-based system for a common application process. After multiple rounds of screening, certain students were selected for brief virtual interviews. Selection criteria included *(i)* Technical background and research aptitude/potential, *(ii)* Interests in research/STEM, *(iii)* Leadership and extracurricular activities, *(iv)* The potential to be matched in a vertically-integrated team, and *(v)* Target numbers for diversity, URM, women/ veteran and limited-STEM. Following this, a faculty panel ranked the eligible applicants, and selection/deselection notifications were sent out. Once the 10 students were selected, they were matched with faculty mentors, and details regarding the logistics and expectations were sent out for a smooth transition and startup.

As mentioned earlier, program opportunity dissemination efforts predominantly took the form of directly contacting peers and reaching out to undergraduate program coordinators at specific universities; interestingly, UG program coordinators (typically, staff) proved to be most effective in disseminating and motivating students to apply. Year-1 yielded 17 applicants. With time-on-our-side for year-2, we were able to diversify/expand recruitment efforts as intended. Year-2 yielded 31 applicants; 3 of the selected came from STEM-limited colleges. For year-3, in addition to expanding efforts, we utilized Mathematica's pilot application portal, which yielded 47 applicants. 9 of 10 students selected each year were external students. Table -2 outlines these.

Table 2: Demographics of the REU student cohorts for each of the 3 years (total of 30 students)

REU Cohorts - Demographics	2017	2018	2019
Participants (#)	10	10	10
URM (#)	1	2	3
Women (#)	2	2	6
Limited-STEM Institutions (#)	1	3	1
Underrepresented Groups (URG) (%) (double counts removed)	**30%**	**70%**	**90%**

When considering the recruited cohorts from each year, the percentage of under-represented groups (which include URMs such as black, Hispanic, women, and participants from community/technical/liberal-arts colleges) vary from a low 30% to 70% and then 90% for the final year. As mentioned earlier, though the total numbers (in years 2, 3) are within target, efforts were expended to recruit equally from all the groups; note that these numbers are not double counted when calculating the %URG (under-represented groups). The home institutions of the 30 students are shown in Figure 6. The markers span the breadth of the US, and Puerto Rico.

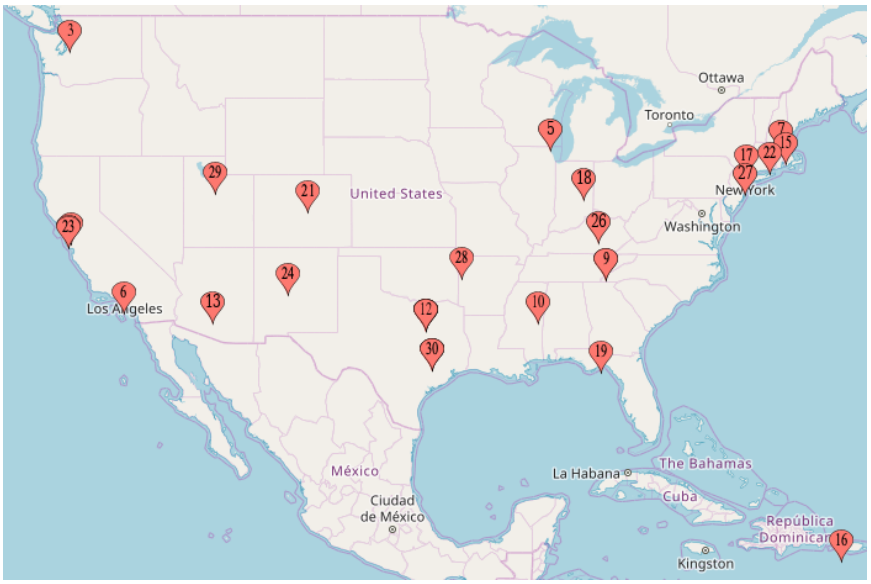

Figure 6: Home institutions of the 30 REU student participants that span the nation

Program Performance in Meeting Intended Outcomes

Following the completion of the onsite period, the pre- and post-program surveys were securely transferred to the evaluator for assessing the site performance (including program administration, program impact, etc.). Based on recommended guidelines for effective evaluation plans [2], an external evaluator conducted formative and summative evaluations of the program using the commonly used CIPP (Context, Input, Process, Product Evaluation) model [3]. The external evaluator developed pre- and post- surveys to assess whether (i) the site met its recruitment goals, (ii) monitor student gains from the program, and (iii) how the participants perceived the program administration.

For item-(i), though total target numbers (>50%) were generally met in terms of recruiting URM/women/freshmen-sophomores, the numbers fell short when recruiting from limited-STEM-research institutions (~2 community/technical or liberal-arts college students per year). It was recommended to lay out a systematic plan to reach out personal contacts at 2-year colleges across the nation to remedy this. For item-(ii), the evaluator particularly noted that the REU program helped students (positively) decide on their future career plans; either to confirm or to advance. A notable gain at the conclusion of each of the summers was that, there was no student who was undecided about their future (STEM) careers. Several participants highlighted this impact of the program on their career plans through an open-ended essay; select quotes include: “This research program has made me want to pursue graduate school more than when I came into it.” “The REU has helped solidify which career path I want to take.” “…given me

confidence in grad school…" "It has given me insight into research that I didn't have before." The last two quotes show that the REU program provided both knowledge about research, and increased the student's self-efficacy related to graduate school. The majority of students also indicated a high-level of confidence in doing standard and new technical tasks related to the project. The team-framework was viewed by students as beneficial to both their learning and the research progression. The mixture of different (vertical) researcher levels was perceived to have a positive impact on the research performance, as well as the multi-disciplinarity of the team. For item-(iii), all participants rated the aspects of the program administration at ~5.5 out of 6 (Likert scale: 6 = very satisfied). Overall, the participants responded positively on the program administration, housing (improvement from last year), new/more certainty in pursuing advanced STEM study and careers, as well as beneficial learning experiences in a team setting.

Regarding the career choices of the REU students, being at the ~2.5 yr. time-marker of the 3-year REU program, most of the 30 REU participants are still pursuing their undergraduate degrees. As for the rest who have graduated from their undergraduate programs, 5 are employed as engineers, 1 is pursuing her M.S. degree, and 2 their Ph.D degrees.

Finally, the PI has periodically reached out to the prior year REU cohort participants to reiterate the support mechanisms available, as well as to check up on how they were progressing through their degrees/careers; altogether the students still in their undergraduate programs seem to be progressing well through their degrees and are slated to graduate on time as indented. Further, a couple of students from the prior-year cohorts expressed interest in coming back for another summer as a REU student again. Also, one REU student from the year-2 cohort extended their summer research project by enrolling as a visiting student at TAMU during the following Fall semester (2018), for whom the faculty was able to secure (monetary) sponsorship (stipend and housing) from the local company that he was collaborating with for his summer REU project; this was an encouraging gesture from the partner industrial firm, which further confirms the quality/impact of his work during summer.

The research results of the students' summer projects were disseminated as posters accompanied by an oral synopsis to a university-wide audience in a professional setting, at the *Engineering Undergraduate Summer Research Grant (USRG) & Research Experiences for Undergraduates (REU) Research Poster Symposium,* at Texas A&M University. The REU students were also invited to sign up as volunteers for the collocated *ASME International Manufacturing Science & Engineering Conference (MSEC)* and *SME North American Manufacturing Research Conference (NAMRC)* at Texas A&M University in 2018, which all of them availed, thus getting exposure and free access to the technical program and presentations. Results/extensions from one these projects was presented at the *King Abdullah University of Science and Technology (KAUST)* poster competition, and other presented at the *2019 and 2020 ASME International Manufacturing Science & Engineering Conference (MSEC)* in Pennsylvania and Cincinnati, respectively. Others are being further developed for publications, with REU students as authors, or acknowledged appropriately. Altogether, the REU students have presented their work at a number of research symposiums [4-16, 22], in peer-reviewed conferences and journals [17, 18, 23-29] and some have won awards for their work as well [19-21].

Conclusions & Lessons Learned

The purpose of this paper was to detail the outcomes and lessons learned over the past three years of the project cycle, from a NSF-REU site on metrology and non-destructive inspection technologies. The intellectual merit of the site activity was to advance scientific knowledge in metrology/NDI through interdisciplinary research projects related to energy and manufacturing. The Broader Impacts of the site activity was to create empowered future researchers and a workforce well-rooted in metrology/NDI, and motivate them to pursue STEM degrees and careers. Set up to alleviate a critical need in the knowledge/skills of the incoming workforce, this site operated successfully over 3 years impacting 30 undergraduate students from across the nation. Site operations and procedures were standardized and made more efficient with each iteration of the site offering. The overall recruitment goals were met successfully with 30%, 70% and 90% recruitment of under-represented groups for years 1, 2 and 3 respectively. The program met its intended site goals as attested by the external evaluator. In general, participants who were undecided on their future plans as well as those intending to follow STEM-related degrees and/or careers affirmed their plans at the end of the REU program. The majority of the participants are still pursuing their undergraduate degrees; the rest who have graduated are either reemployed in a STEM-related career or pursuing their graduate degrees. Students from the prior cohorts have kept in touch with the PI as well as with each other via professional networking mechanisms such as LinkedIn, and the student work has been published in numerous venues. Altogether, this REU site has been deemed successful so far with the prior participants on track in their respective advanced STEM degrees or careers. The students who are currently progressing through their degrees are being tracked to ascertain their final education/career choices.

Acknowledgements

This material is based on work supported by the National Science Foundation (NSF) grant EEC-1659856. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

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