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Evaluating the Impact of Enrichment and Professional Development Activities on REU Students

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Abstract

Research Experience for Undergraduates (REU) programs have been credited for attracting and retaining students in science and engineering who otherwise may not have considered disciplines in science and engineering as their career choices. In addition to core research activities, REU programs generally provide multiple enrichment and professional development activities for participants. While the nature and the number of professional development activities vary from one REU program to another, the most common activities include ethics and safety training, research and industry seminars, GRE workshops, writing workshops, graduate school application preparation, and industry visits. Furthermore, some of these professional development activities are also conducted in large group settings with students from other research programs beyond the REU cohort. The rationale behind combining REU students with other researchers is to create a community of learners and provide them with an opportunity to build/extend their professional network. Although professional development activities are an integral part of the REU sites, there is often very limited coverage of such activities in the existing literature on REU projects. This paper presents the impact of professional development activities on the experience of REU participants in a manufacturing REU site at a major research university in the southwestern United States. For this study, data was collected from participants by an external evaluator by using both qualitative and quantitative methods. This paper presents and describes the cumulative data from three REU cohorts. The analysis and results of the data are disaggregated by the student academic level (sophomore, junior, senior), gender, ethnicity, the type of their home institutions (research or teaching institution), and desired career paths in the future (graduate school or industry). The paper also provides a detailed discussion and implications of these findings.

Introduction

Advancements in manufacturing technologies and cyber-physical systems have enabled manufacturing companies to offer their customers a higher degree of mass customization in product design and development [1]. In today's globalized marketplace, customers not only want a variety of products but also demand for shorter lead times. Further, customer choices keep on changing with time as newer options are made available through multiple markets [2]. As a result, the companies are under pressure to reduce the entire conceive, design, and realization phases of a product life cycle to meet the changing customer expectations [3]. This can be achieved through cyber-physical systems in the manufacturing space that enables factories to access the workspace remotely and achieve the necessary efficiency and effectiveness in their operations [4]. Similarly, industry 4.0 and logistic 4.0 in the supply chain are additional enabling technologies that are being adopted to achieve the mass customization [5].

It is important to note that the introduction of automation does not mean replacing the workforce. However, it requires an upgradation or a change in the skill sets of future workforces [6]. Prior research has pointed out a gap in the current manufacturing industry for skilled workforce to fully exploit the availability of newer manufacturing technologies [7][8]. Researchers argue that the current academic curricula do not adequately address the rapid change in manufacturing technologies [9] [10]. That said, in order to bridge the gap in the desired skills-set, institutes of higher learning are updating their curricula accordingly. Likewise, many companies enroll their employees in continuing education for up-skilling [5] or tie-up with academic institutions to develop appropriate curriculum as per requirement [3] [11]. One of the ways in which academic institutions contribute towards reducing this gap, is by providing an opportunity for undergraduate students to get involved in research [12] [13]. Such research experiences and experiential learning opportunities via different programs, create engagement opportunities for students and also allow for their professional development [14]. The National Science Foundation (NSF)-funded Research Experience for Undergraduates (REU) programs have been very successful in providing such research opportunities for students, especially those from minority student population groups [15].

Prior researchers have noted the benefits of REU in improving the research competencies of undergraduate students [4] [12]. However, it has also been suggested that students are sometimes confused as to whether they should continue in academia or get some experience in the industry before deciding about graduate school [16] [17]. To that end, REU sites provide a great platform for students to understand what graduate school and research look like, opportunities thereafter, and how to prepare for them. The objective of this paper is to evaluate the impact of different professional development activities in a REU program on overall student experiences and outcomes. More specifically, this paper presents a case study of cybermanufacturing REU program at Texas A&M University in which the participants attend multiple professional development activities that range from lab safety training, Title IX training, industry seminar, industry visit, GRE workshop, writing center workshop, presentation and communication skills workshop, Aggies Invent, and graduate school application process, to navigating a successful professional research in academia. The paper presents the results from survey of prior three REU cohorts at Texas A&M University and lessons learned for future REU programs.

The remainder of the paper is organized as follows. In section 2, it provides a brief background on the Texas A&M University's REU Site in cybermanufacturing. Section 3 discusses the recruiting process used to select the REU participants including a summary of the last three cohorts. In section 4, we discuss the sample student projects for 2021 cohort. In section 5, the paper provides a cumulative summary of findings related to impact of REU program on student's professional development for the last three cohorts. Lastly, section 6 concludes the paper by summarizing the key findings.

REU Site in Cybermanufacturing

The cybermanufacturing REU site at TAMU was started in 2018 and has completed its third cohort in 2021. As with many REUs across the United States, cybermanufacturing REU site was canceled in the summer of 2020. It is a program funded by the NSF, which includes 10-week long research experience with an objective to encourage undergraduate students in STEM fields to take up careers in the field of advanced manufacturing. Each year, a cohort of 10 or more students are selected from the universities across the United States. The objective is to broaden the diversity of the participations by recruiting majority of the students from female and/or underrepresented student population groups, and also majority from outside of Texas A&M.

Financially these students are paid a weekly stipend of 500 USD (for 10 weeks) along with free on-campus housing and travel expenses also up to $500. The participants are given an opportunity to work in any domain related to advanced manufacturing by pairing them up with a faculty mentor. The role of the mentor is to guide students through the research process including topic selection, research methodology, and reporting. Faculty mentors hold weekly meetings to monitor progress and provide support wherever required. Apart from the different research projects, there are other activities that focus towards participants' professional development and overall academic experience. Such activities include, but are not limited to, manufacturing plant visits, industry and faculty seminars on advanced manufacturing, attending a research conference, Aggies Invent, lab safety training, GRE workshops to prepare for graduate school admissions, scientific writing, and presentation skills at a summer research symposium. One of the highlights of all the professional development activities is the Aggies Invent competition, wherein participants are given 48 hours to come up with an innovative solution and present a simple prototype to an existing industry or social problem. Lastly, students present their final results at a university wide summer research symposium, which is attended by multiple REUs and other undergraduate research programs offered at Texas A&M University. All of these activities are designed towards achieving the following three main objectives of the REU site:

a) Foster research interests amongst undergraduate students and encourage them to pursue graduate education in advanced manufacturing
b) Promote careers in the field of manufacturing and automated industries

Student Recruiting

This project uses nsfetap.org portal to collect applications. The REU program was advertised on various academic professional society forums like Institute of Industrial and Systems Engineers (IISE), American Society of Mechanical Engineers (ASME), Society of Manufacturing Engineers (SME), and American Society for Engineering Education (ASEE) to attract applications of students from across the United States. In order to improve the diversity of the participants, the PI team also reached out to multiple minority serving institutions through Texas A&M LSAMP alliance.

Summary statistic of past 3 REU programs

The REU program was offered in the summers of 2018, 2019, and 2021. Figure 1 shows the applicants' statistics for all three cohorts combined. The goal was to select at least 50% of women and/or underrepresented or minority students. The prior three cohort data (Figure 3) shows that the REU program was able to achieve its diversity goals. Similarly, 80% of the students selected were outside of Texas A&M University. However, in the first two cohorts, there were higher number local students from Texas A&M University because of the last-minute cancellation by the out-of-state students.

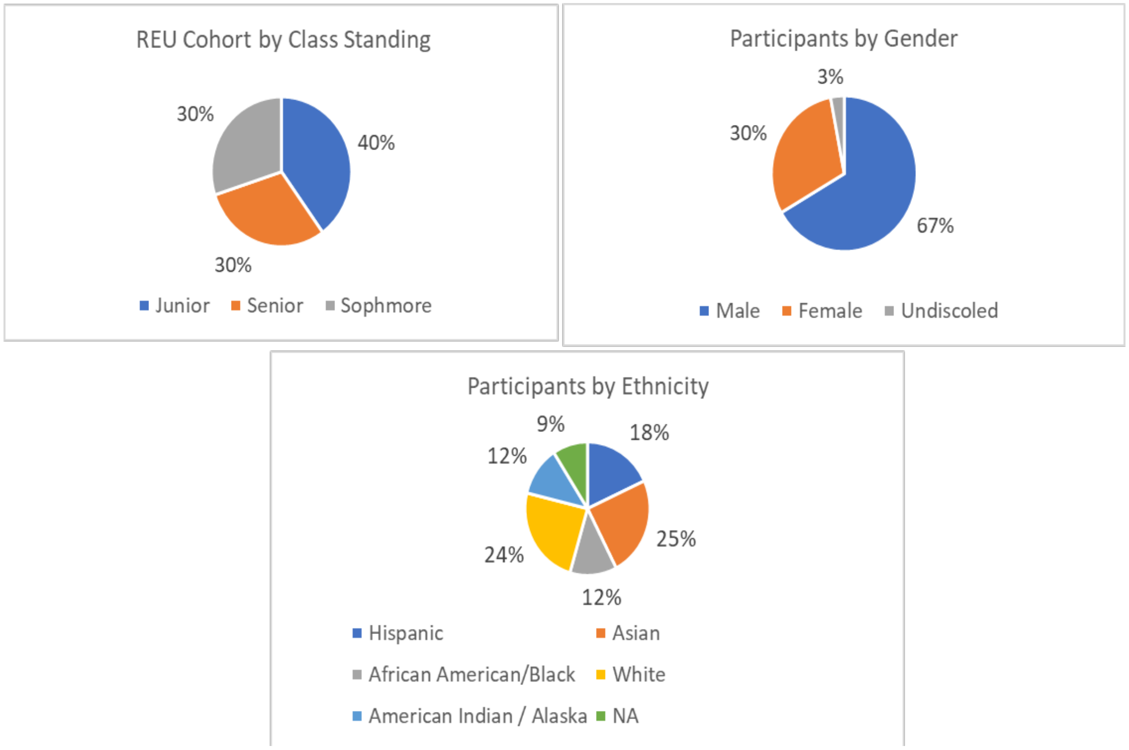


Figure 1: Summary statistics of participants from 2018-2021

Student selection process

The participant selection process involved two steps. The first step was to check whether the students meet the required criteria for consideration. Next, in the second stage, the merit of their application was assessed based on more holistic reviews by the PI team considering such things as personal essays and interest in cybermanufacturing related research. The initial shortlist was made based on the following criteria: a) a STEM field major. b) Cumulative GPA of 3.0 or more (out of 4.0) c) U.S. citizenship or permanent resident, and d) at least one semester remaining after the REU program. These shortlisted candidates were then reviewed by the PI team. Various metrics such as prior research experience, academic performance, understanding of engineering principles, challenging coursework experience in manufacturing or programming languages, diversity, recommendations, and personal essays were used in evaluation of the candidates. For the 2021 cohort, 39 applications were received from which 13 participants were selected. These students were contacted individually to get confirmation on their participation and check their availability during the summer. Figure 2 shows home institutions of the 13 students who were selected in 2021.

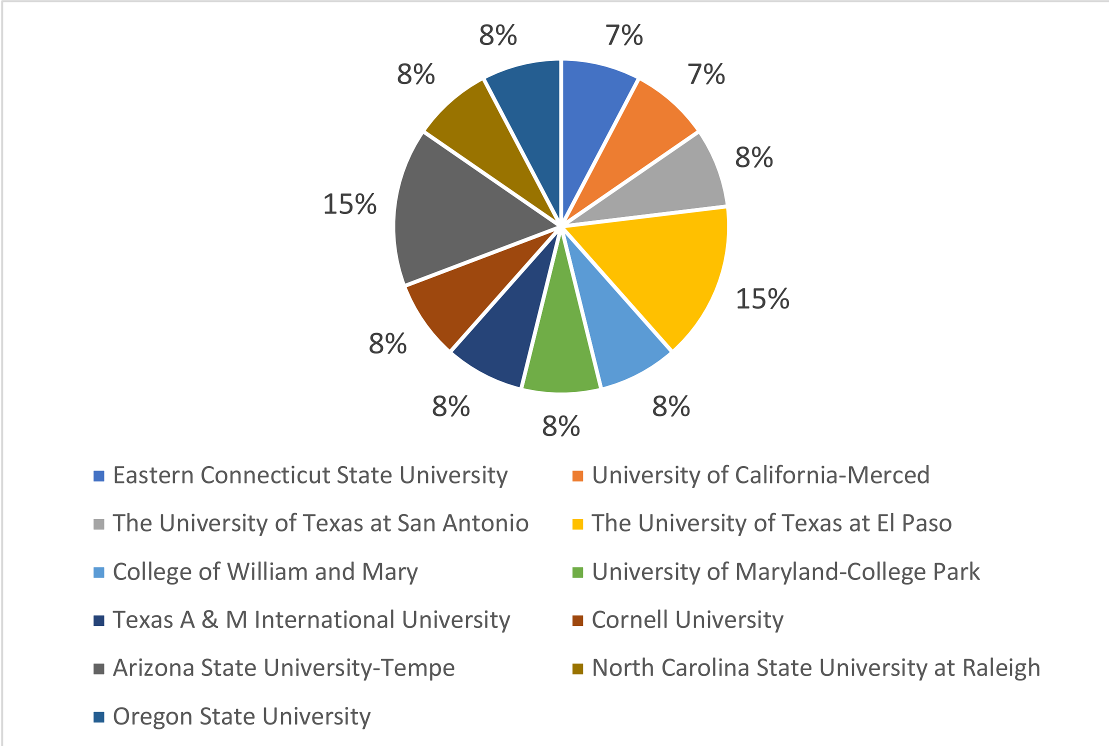


Figure 2: 2021 Cohort participants by their primary institutions

Student Projects

As per the student's background and their research interests, they were individually paired with a faculty and a graduate student mentor from that domain. The deliverables and scope of their REU project were decided based on mutual understanding between the faculty and their REU student. For summer 2021 cohort, 15 faculty mentors from three engineering departments (namely, Industrial and Systems Engineering, Mechanical Engineering, and Engineering Technology & Industrial Distribution) advised 13 students. In other words, some of the REU participants in 2021 were jointly mentored by more than one faculty member.

Following is a brief outline of the different projects worked on by the students in 2021.

1. *Binder Jetting Additive Manufacturing of Ceramics: Improvement of Part Quality*
   This study investigated possible improvements that can be made in the quality of ceramic parts using binder jetting additive manufacturing techniques with a particular focus on flexural strength and density. The student tested out how the final samples might be affected by different compaction and layer thicknesses to discover improvements in the final parts.

2. *Industry 4.0*
   The project focused on building a Internet of Things (IoT) based network on a mechanical system and analyze the data collected to determine specific trends in machine behavior

3. *Environmental Factor Predictions and Power Forecasting for Wind Turbines*

The study analyzed historical data to examine trends in wind patterns around wind farms so the energy producers have enough information to buy and sell power without resorting to exorbitant prices at the last moment. Current prediction techniques used by wind farms were also analyzed to test their accuracy and suggest improvements

4. *Voxel Bio-Printing*
The projected involved creating hardware and software module for a computed axial lithography (CAL) 3D printer to study radial carbon nanotube alignment in viscous resin

5. *Identifying Cyber intrusions through human-robot interaction metrics*
The goal was to assess cyber intrusions by focusing on monitoring human-robot interaction metrics. Human data such as eye-tracking, brain imaging, physiological responses, and external sensor data from the camera were combined to detect cyber intrusion manifestation.

6. *Preliminary Understanding of Li-Ion Battery Charging and Discharging Dynamic Behavior by Stethoscopy*
The project focused on monitoring the movement of ions in a battery by using a frequency sensor and 3D surface reconstruction via stereoscopic imaging.

7. *Flexible electronics manufacturing by aerosol printing*
The goal of the project was to optimize the method of material transfer and make the aerosol printing process less expensive. To achieve this, the group explored a method of printing layers of polyimide (insulator) with a layer of processed silver nanoink (conductive material).

8. *Fabrication of Nanocomposite membranes for water filtration*
Wastewater treatment by membrane filtration was the main focus of this project. The group designed and fabricated membranes to filter water, both to understand how these membranes work and create better ones.

9. *An Open Source Toolbox for Determining Constitutive Material Parameters*
Constitutive Laws and approximation methods were used to estimate the properties of materials in the plastic region

10. *Comparison of damage in shape-memory polymer due to milling and laser cutting*
The student compared different manufacturing processes in shape-memory polymers by taking samples and carefully cutting them.

11. *Predicting the Mechanical Properties of Carbon Fiber Reinforced Polymers from Scanning Electron Microscope Images with Machine Learning*
The goal of the project was to predict the mechanical properties of composite materials with SEM images.

12. *Machine Learning of Metals in Additive Manufacturing Process*
The project analyzed data from X-ray and thermal imaging of different metals going through the laser additive manufacturing process. Based on these and different labelling, an attempt was made to predict what will happen to subsequent materials subjected to the same process

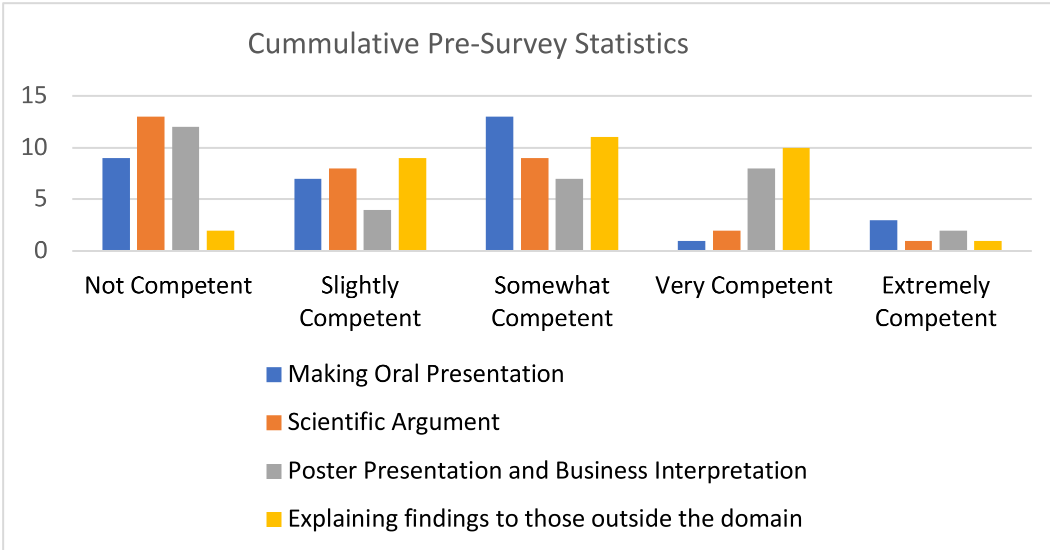
13. *Sensor fusion and analysis for smart manufacturing*
    Different tasks in manufacturing equipment produce different sensor readings. By capturing real-time data from the equipment, one can analyze it to determine what the equipment is currently doing. One can also look for signs that the equipment is behaving abnormally and stop it to reduce wasted time and materials.

Program Evaluation and Impact

Evaluation of the REU program was conducted by an external evaluator to assess the level of efficiency of the program and fulfillment of its goals. Pre- and a post-REU surveys were conducted to assess gain in research skills of participants with respect to12 metrics that included: formulate research plan, conduct background research, perform data validation, define scientific arguments, apply theory, prepare and present research poster, formulate hypothesis, develop research questions, analyze experimental results, understand publication process, understand cybermanufacturing projects, and understand project outside research area. A Likert scale of 1-5 was used, with 1 being the “not competent” and 5 being the “extremely competent”. Moturu et al [4] and Nepal et al. [5] reported the academic benefits of the REU research activities as reported in the pre- and post-REU surveys of participants in 2018 and 2019. This paper focuses primarily on impact of professional development activities on the student’s overall experience and outcomes.

The pre- and post-REU survey collected quantitative and qualitative responses ranging from the expectations of students from the REU site to their learnings and feedback for individual components of the program. The data collection and analysis presented in this paper represent all 33 participants from the three cohorts of students who participated in the REU program in 2018, 2019, and 2021. The external evaluator’s report provided to the PIs described that overall, the students had a positive experience with a net gain in research and professional competencies in all three years. Students found the industrial visits and professional development seminars to be extremely beneficial in helping them make a career decision and bridge the gap between academia and industry. They even acknowledged the mentorship received from faculty advisors and graduate students strengthened their understanding of various concepts and approach towards problem solving. “Aggies Invent” was a standout program for the 2018 and 2019 cohort, because it provided them with a culminating experience in which they could apply their theoretical knowledge and practical skills for solving a real-world problem. Unfortunately, the 2021 cohort could not participate as the competition was no longer scheduled because of the uncertainties surrounding COVID-19 pandemic. That said, a few of the 2021 REU students did participate in a cyber-security / cyber-manufacturing hackathon contest hosted by New York University’s Tandon School of Engineering.

Figure 3 shows the pre and post statistics of professional skills (like making oral presentations, presenting a scientific argument to defend one's rationale, presenting entire project and research in a succinct manner, and developing a business sense towards the same, and the ability to transfer scientific knowledge and concepts to those outside the specific domain.



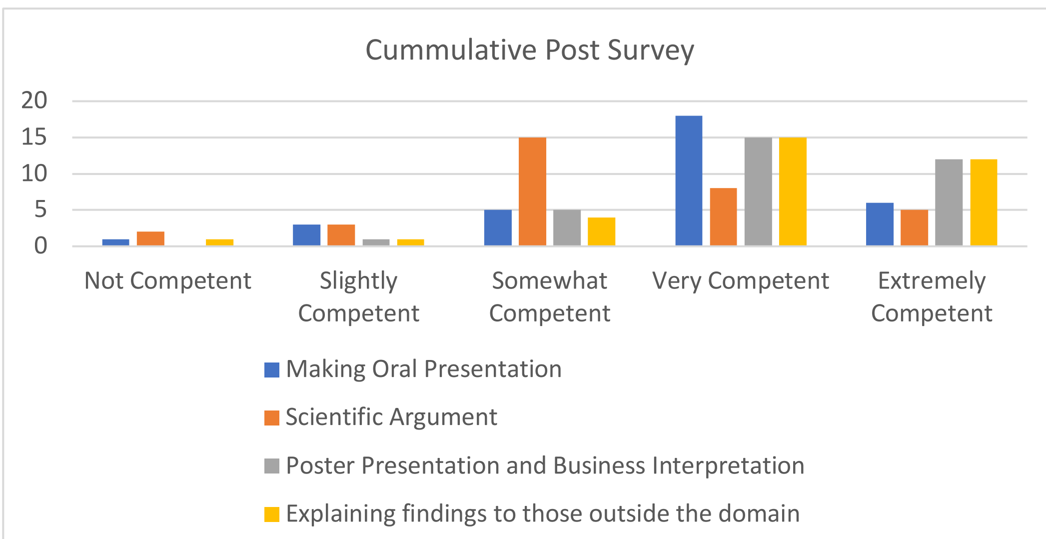


Figure 3: Average competency score before and after the REU experience

Figure 4 shows the extent to which the REU program made the students feel prepared to pursue a professional career in Cybermanufacturing. The overall positive response was the outcome of different industrial visits, relevant career related seminars and other professional development aids provided as mentioned previously.

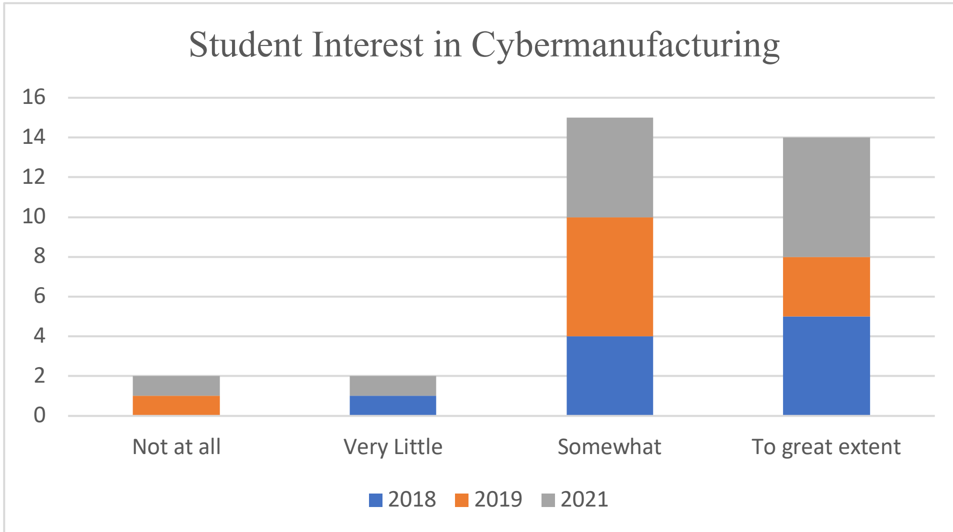


Figure 4: Participants interest towards career in Cyber-manufacturing

Conclusions

Today, customers have more options for any product because of the globalization. Further, customers also demand more varieties and relatively shorter lead times. To achieve this demand, the manufacturing industry is moving away from mass production to mass customization. Fortunately, the advanced manufacturing and computing technologies have enabled the manufacturing companies to achieve these demands. However, along with the technology, it is essential that there is a skilled workforce in place. To that end, the goal of the cybermanufacturing REU site at Texas A&M University was to stimulate the interest of second- and third-year undergraduate STEM students into careers in manufacturing. The REU program has completed its three cohorts so far by providing summer research experience to 33 undergraduate students (majority of whom were from outside of state of Texas, and also represented a diverse gender and ethnic backgrounds).

This paper focused on the professional development aspect of the NSF funded REU program in cyber manufacturing. The 10-week long research experience program in summer included several professional development activities such as research & industry seminars, technical or scientific writing workshop, presentation skills, GRE workshops, plant visit, safety training, and Aggies Invent. The results of the surveys conducted before and after the REU program did not only show an improvement in their research skills but also improved their professional competencies in making oral presentations, scientific arguments, and having an entrepreneurial mindset. Activities such as industry visits and seminars, poster presentation and real-world situational based competition like "Aggies Invent", made the students feel more confident towards pursuing a career in industry. Lastly, the students agreed that the REU program improved their depth of understanding in manufacturing, interpersonal skills and encouraged them to find solutions to problems from a business perspective.

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