Board 115: Preparing Next Generation of Manufacturing Leaders: A Case of REU Site in Cybermanufacturing

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Abstract

Recent advancements in information, wireless sensing, data analysis, and 3-D printing technologies are transforming manufacturing into a highly customized process, with a short time to market, and a competitive cost structure to sustain businesses in a highly globalized market. Central to this emerging paradigm is cybermanufacturing which is a critical technology that combines the above-mentioned recent advances in technologies to transform manufacturing into essentially a commoditized "cloud-based service". Likewise, it has the potential to evoke creativity of the general population to design and create personalized products. To that end, one of the key enablers of this paradigm is the recruitment and training of a new class of manufacturing workforce that can (1) combine engineering product design capabilities with information technology tools to convert ideas into components and (2) transform a wide range of precursor materials into products to meet advanced functional requirements by using cyber-enabled machine tools. However, many students, particularly those at predominantly undergraduate institutions (UGI) and minority-serving institutions (MSI), have not been exposed to advanced or cyber-based manufacturing research and education. This paper presents a case study of NSF-funded summer research experience for undergraduates (REU) site in cybermanufacturing. The paper describes the student recruitment process, demographic information of the most recent cohort, sample student projects, and other enrichment activities that were organized during the 10-week summer REU program. As a part of program evaluation, the participants were surveyed before and after the REU experience. The survey questions covered a wide range of topics including their scientific research knowledge and skills, career knowledge and interest, and professional skills. Survey results from 2018 cohort shows that REU experience was not only very helpful for students in deciding the manufacturing as their career path but it also improved their research competency.

1. Introduction

Prior to industrial revolution in early 19th century, most of the products were handmade and highly customized. The industrial revolution saw the use of machines in manufacturing that has not only helped improve the productivity but also reduced cost due to large production volumes (Srinivasa and Bukkapatnam, 2014). However, in the current state of highly globalized economy and ever decreasing product life cycles, customer have more choices, therefore are seeking greater variety (highly customized products) with shorter lead times and enhanced quality. Furthermore, today’s products are much more advanced in terms of integration of hardware and software and demand ultra-high performance. Therefore, in order to meet that need, future manufacturing processes would require technologies that can make a wide range of short run, custom products with very short setup times. Likewise, a future manufacturing services sector requires the ability to anticipate and rapidly adapt to changes in needs without supply chain disruptions (Chan et al., 2018).

Cybermanufacturing (CM) is the application of Cyber-physical systems to the conventional factories where there is continuous communication between various systems on the cloud which includes the status of the machines, risks associated and necessary solutions to avoid the risks

(Lee et al., 2015; Wang and Wang, 2018; Song and Moon, 2017). This helps in increasing productivity with enhanced quality and product complexity. To that end, Iquebal et al. (2018) present a framework to monitor and control the laser origami process by using image-based sensing system. In fact, with recent advancements in information technology (e.g., wireless sensing, communications and "big data"), manufacturing processes (e.g., 3-D printing) as well as automation technologies (e.g., internet of things), the future of manufacturing could be much more customized with shorter time to market, and competitive cost structure to sustain businesses in a highly globalized market (Chan et al., 2018). Cloud computing enables massive data storage and advanced analytics. Big data and data analytics enable the users in making informed decisions based on a large pool of available data. M2M establishes the communication between multiple machines and augmented reality to establish the human interaction in the overall system (Barbosa et al., 2016).

While advancement in information technology and computational intelligence, manufacturing firms are able to achieve the goal of producing complex and highly customized products, the industry major concern is lack of skilled workforce Nagl (2018). Currently, there are several approaches are being taken by both industry and government agencies to deal with workforce skills gap in advanced manufacturing. Some of these approaches include: industry academic collaboration to provide industry centered educational programs such as certificate programs (Nepal et al., 2016), partnering with high schools to attract young students into manufacturing (Bushmaker and Franz, 2017), and providing opportunities for continuing education and other professional development opportunities. On the other hand, The National Science Foundation supports several research and educational programs that are geared towards attracting undergraduate students like *research experience for undergraduates* (Zhu et al., 2018), and high school students (*research experience for teachers*) to engineering career including manufacturing (Ataai et al., 1997).

The purpose of this paper is to present a case study of research experience for undergraduates (REU) site in cybermanufacturing at a major research University in Texas. The paper provides the overall description of the program including student recruitment, sample projects, and schedule along with findings of the program evaluation from 2018 cohort.

2. Program Background

The REU site in cybermanufacturing at Texas A&M University is funded by National Science Foundation. The key objectives of this program are: increase enthusiasm and research skills in manufacturing among students in the early stages of their undergraduate education, especially those with limited access to this research at their home institutions; increase students' knowledge of and interest in careers in manufacturing; and prepare students with professional skills to enter the STEM/knowledge workforce and/or graduate school. For three years, the program recruits a cohort of 10 students/year who work on a number of advanced manufacturing related projects for 10 weeks in the summer starting from last week of May through first week of August. Each student has to complete both research ethics and lab safety training before starting their research. All students are mentored by a professor and also a graduate student. In other words, each student has a faculty and as well as a graduate student mentor. For 2018 cohort, all faculty mentors were from College of Engineering. The mentors guide the students in selecting the research project and also throughout the progress of the research. Students participate in weekly meetings with the mentors discussing the progress of their research. In addition, they meet with the REU Site PIs as a group multiple times during the 10-week long program to update their research progress and share their experiences. The students also participate in several enrichment activities such as industry seminars, workshops, field trips to gain industry view of the research. The students give a mid-session presentation halfway through the research regarding their progress. Lastly, they participate in a college wide summer research symposium in which they present their final research. As for financial support, each student gets a stipend of $500 per week along with financial assistance for accommodation and all the enrichment activities such as GRE workshop and field trips to industry. Students are only responsible for their food expenses.

3. Student Recruiting

As mentioned in the project objectives, the goal of the CM REU program was to attract as many minority candidates as possible and also a large majority of participants from outside of Texas A&M. To that end, the program was advertised in national level professional society platforms like IISE, SME, ASEE, and ASME along with advertising on the Texas A&M websites. In addition to mass advertisement, attempts were made in reaching out few targeted minority serving institutes via personalized emails to broaden the applicant pool. Interested students could submit their application via REU site's website https://cybermanufacturing.tamu.edu/apply-now/.

3.1 Summary statistics of the 2018 applications pool

In overall, there were 63 applications received for 10 positions. Applicants were from multiple states across the United States covering wide diversity with respect to gender and ethnicity. The applicants represented both four year schools and two year junior colleges. There were number of minority serving institute represented in the pool. Figure 1 illustrates the application pool broken down by ethnicity, location, gender, and research interest.

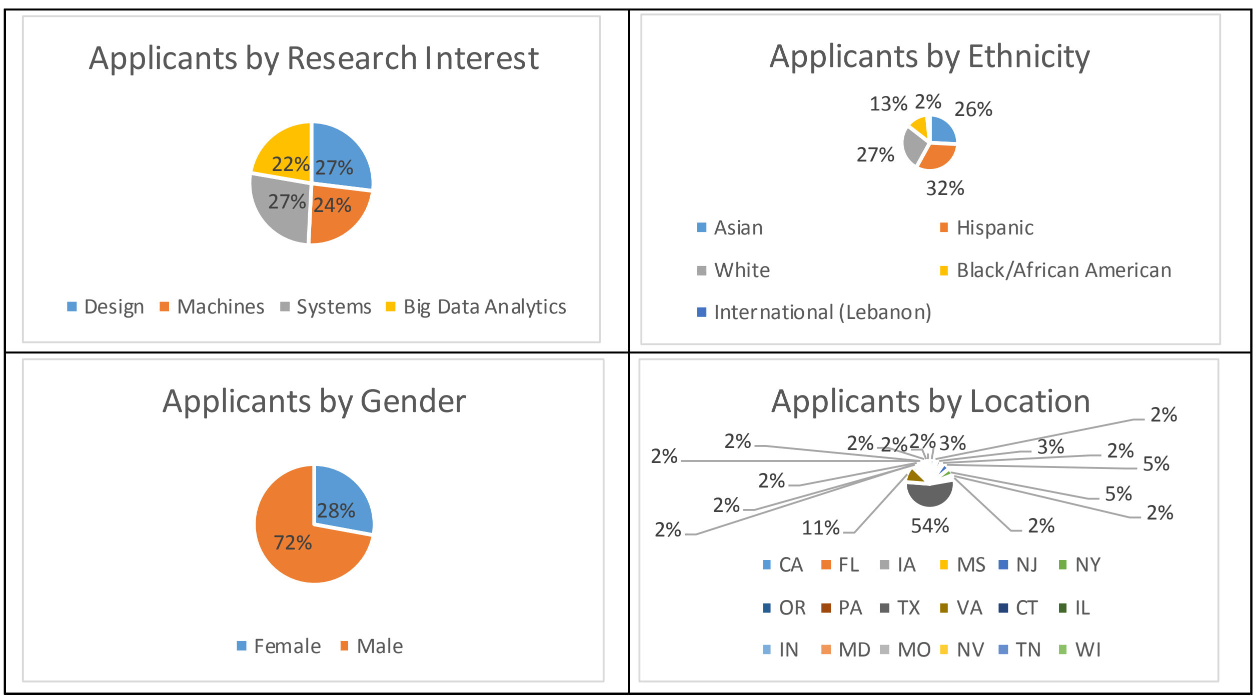

Figure 1: Number of Applicants for 2018 Cohort broken by various categories

As shown in Fig. 1, nearly half of the applicants were from outside the State of Texas. Likewise, over one third of the applicants were from underrepresented population groups mainly Hispanic and African American.

3.2 Students selection process

A multiple criteria methodology was adopted in making selection decision of the REU participants. Those criteria included: a) having a major in a STEM field. b) Cumulative GPA of 3.0 or more (out of 4.0) c) at least one semester remaining after the summer program, and d) U.S. citizenship or permanent resident. In addition, the preferred qualifications included prior research experience, programming knowledge, strong foundation of engineering principles through various math, science, and engineering courses, and personal essays. All applications were reviewed by PI team and 10 students were shortlisted for further consideration. Each shortlisted candidate was contacted individually to reconfirm their availability and interests. At the end, 10 students were selected by complying with the program's recruitment goal with respect to diversity and out of Texas A&M priorities (See Table 1).

Table 1: Selected participants for 2018 cohort

REU Student	Home Institute	State	Gender	Ethnicity	Expected Graduation	Mentor Department	CM Area
1	Texas A&M University	TX	Male	Hispanic	2020	ETID	Design & process planning
2	Lamar University	TX	Female	Asian	2019	MEEN	
3	Texas A&M University	TX	Male	Asian	2020	MEEN, ECEN	
4	California State University, Los Angeles	CA	Male	Hispanic	2020	ISEN	
5	Texas A&M University	TX	Female	Asian	2019	ISEN, ECEN	Prognostic and Process Control
6	Texas A&M University-Corpus Christi	TX	Male	Black/ African American	2020	ISEN	
7	Lone Star College/ Texas A&M University	TX	Female	White, Hispanic	2020	ISEN	
8	University of Texas at El Paso	TX	Female	Hispanic	2019	ETID	Real time enterprise wide integration & coordination
9	Bradley University	IL	Male	White	2018	ISEN	
10	Lamar University	TX	Male	White	2019	MEEN	

Figure 2 depicts the participant's representation with respect to ethnicity, location, gender, and research interest. The program's goal was to recruit at least 50% women and minority students, and over 80% from outside of TAMU, with one third from out of State of Texas. As shown in Fig. 2, the program was able to meet the diversity goal. Although, in the original offer, there were 40% students from out of State of Texas, there were few dropouts right before the program was about to begin.

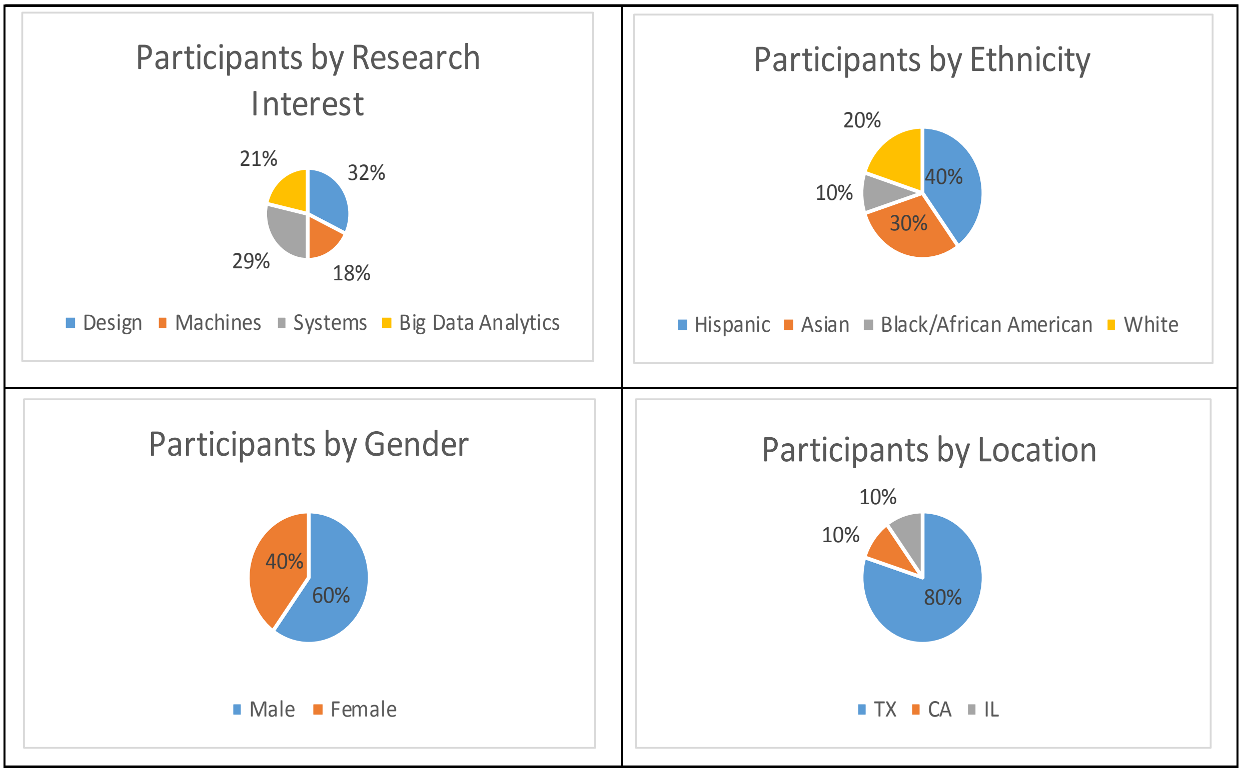

Figure 2: 2018 Cohort participants by gender, ethnicity, location, and research interest

As a result, with respect to location, there were only 20% out of state of Texas and 60% outside of Texas A&M University. However, it may be noted that the 2018 cohort represented five universities and one community college of which three were minority serving institutes. Two of the institutes were from out-of-state (IL and CA) as well. Figure 3 shows the participant percentage by universities and colleges.

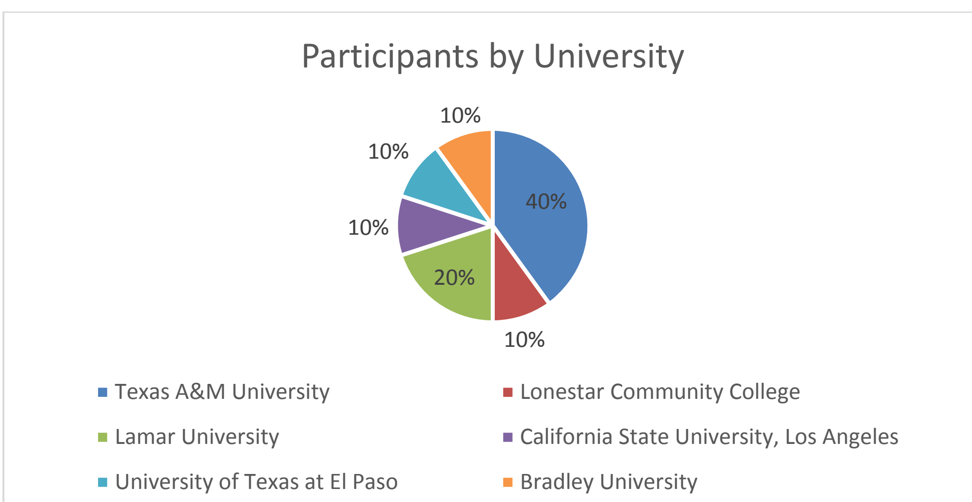

Figure 3: Student Distribution by their primary institution.

4. Student Project Description

The 2018 cohort had 10 mentors with diverse research backgrounds spanning four departments (Industrial, Mechanical, Electrical & Computer, and Engineering Technology & Industrial Distribution) at Texas A&M University. The PI team assigned each student to an appropriate mentor by matching student's strength and the mentor's research areas. Table 2 presents mentors and their affiliations along with their research areas who were involved with the 2018 cohort of REU students.

Table 2: 2018 Cohort mentors and their research areas

Mentors	Position	Department	Research Area
Mentor 1	Associate Professor	Engineering Technology and Industrial Distribution	NPI, Supply Chain Management, Optimization, Risk Analysis
Mentor 2	Professor	Industrial and Systems Engineering	Data Analytics, Smart Manufacturing
Mentor 3	Professor	Mechanical Engineering	R2R Manufacturing Systems, Autonomous Vehicles, Robotics
Mentor 4	Assistant Professor	Industrial and Systems Engineering	Advanced Manufacturing Processes, Reliability Engineering
Mentor 5	Professor	Industrial and Systems Engineering	Stochastic Systems, Computer Communications, Sensor Networks
Mentor 6	Professor	Electrical and Computer Engineering	Cyberphysical Systems, Cyber Security, Machine Learning
Mentor 7	Assistant Professor	Manufacturing and Mechanical Engineering Technology	Additive, Laser Manufacturing & Nano Composites
Mentor 8	Professor	Mechanical Engineering	Plasticity of Metals & Polymers, Thermo Mechanics
Mentor 9	Associate Professor	Industrial and Systems Engineering	Biomedical Manufacturing, Nano Manufacturing
Mentor 10	Assistant Professor	Mechanical Engineering	Nano Composites, Additive Manufacturing

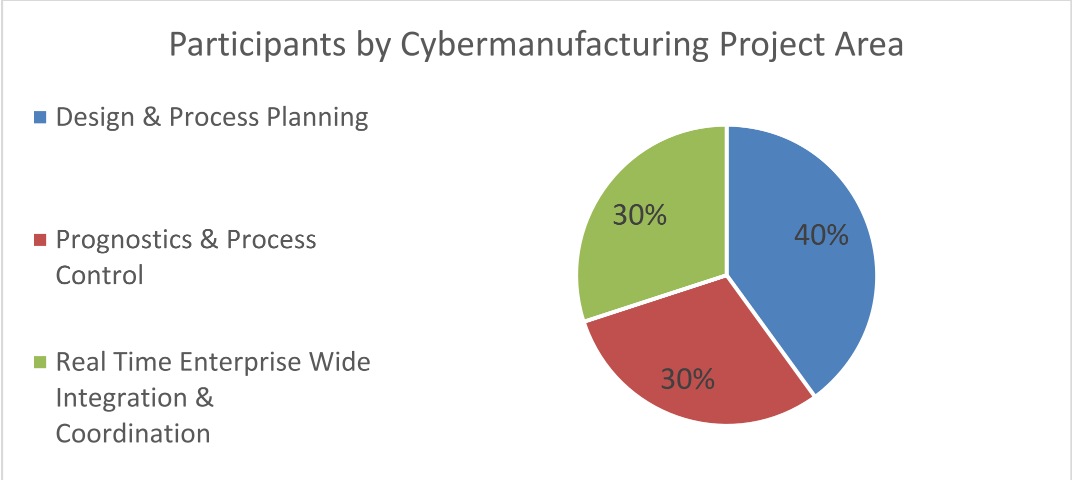

Figure 4: Student distribution in the Cybermanufacturing project areas

Figure 4 shows the student project distribution by three areas of cybermanufacturing, namely design and process planning, prognostics and process control, and real-time enterprise wide integration and co-ordination.

Following paragraphs provide a brief description projects worked by all ten REU students.

1) Web-based software tool for R2R CM Systems
   This project involved embedding advanced technologies in the conventional R2R machining operation which is widely used in paper and sheet metal industry. Student evaluated the R2R machine experimentally and recommended the placement of web guiding mechanisms in the machines to improve the quality.

2) Advanced manufacturing for kirigami structures
   This project was focused on the autonomous kirigami cybermanufacturing system (AKCS) which cuts and folds the polymeric sheets to make custom components. Student worked on a proof of concept of the tools involved in the AKCS and compared them with other machining processes and also 3D printing. The student learnt the interaction of physical modeling, process planning, and control.

3) Vat photo polymerization 3D printing
   This project dealt with the nanoscale reinforcement materials in stereo lithography resins to improve the hardness, tensile strength, impact strength, elongation and electrical conductivity of the printed products. Student produced the 3D printed product with reinforcements of nanocomposites and analyzed the quality improvement of the product. The product is tested and analyzed for performance with respect to mechanical properties, electrical properties and biomedical properties.

4) Process planning and optimization in the additive manufacturing of nickel titanium shape memory alloys
   This project was about the additive manufacturing of complex geometries with Nickel-Titanium (NiTi) alloy. Student analyzed the drawbacks of conventional manufacturing methods to produce intricate geometries of NiTi alloy and developed the selective laser melting method in additive manufacturing using design of experiments.

5) Change detection in Nano indentation setup
   This project involved the Nano indentation setup. Nano indentation setup is used to test the physical properties of a material by scratching it with a high precision needle. Student analyzed and collected the acoustic signals from the abrasion of the needle with different materials. These signals in the computer will be connected to the physical properties of the material.

6) Online data collection and closed loop control in cyber manufacturing
   This project examined the cross communication of CNC's and human beings. Student deployed contactless sensors such as speed, force, distance, sound, temperature and camera around the CNC machine to collect signals. The signals are connected to the

controller for processing and sent to the data cloud where offline managers and researchers can make effective decisions.

7) 3D printing of insulated thermosets
This project dealt with additive manufacturing of thermoset materials which are becoming popular in the aerospace industry due to their perceived cost effectiveness, time saving, and material efficiency. Student utilized newly developed ink that solidifies near instantaneously through frontal polymerization and 3D printed thermoset samples in different conditions like temperature and pressure.

8) Manufacturing of smart wearables
This project conducted an in-depth study on manufacturing of smart wearables. Student performed a state of the art review of prior research related to smart wearable design and manufacturing and provided key findings with a future research plan. The start of the art review includes the additive manufacturing and laser kirigami methods of manufacturing.

9) Optimal magnetorheological fluid for localized polishing of freedom surfaces
This project studied magnetorheological fluid that changes properties in the presence of magnetic field. This property is used for polishing of difficult to reach surfaces in the aerospace and biomedical industry. Student optimized the fluid mixture used for polishing to create optimal amount of fluid flow and desired stiffness of the fluid on the polishing surface.

10) Optimization of void placement in ecoflex for maximum fracture strength
This project investigated the application of ecoflex, a substrate material in which precut tear turns 90° when the tear collides with void in the material. This material is widely used in flexible electronics. In this project, student developed a new method to manipulate the mechanical properties of ecoflex.

5. Integration with Other Research Programs at the College of Engineering

The REU program activities were aligned with the undergraduate summer research grant(USRG) program offered by College of Engineering at Texas A&M University. This was done primarily to coordinate the enrichment activity and to provide a cohort/networking opportunity for the Cybermanufacturing REU students with other similar programs offered in the college. In addition to enrichment activities such as GRE workshop, graduate application process, and ethics & lab safety training, the college also hosted Aggies Invent and research symposium at the end of summer. Table 3 provides an overview of different activities that REU students were involved in during their 10-week research experiences at Texas A&M University. Among other events, the Aggies Invent was a unique design and manufacturing experience that the REU students participated with their peers from other summer research programs in the college. It involved a 48-hour design and manufacturing challenge in which the students were required to design, build, and test (from concept to prototype) to solve various real world industry challenges. The topics were provided by the industry. The REU students teamed with the other students from the college and worked on projects that had cybermanufacturing theme.

Table 3: Description of student activities during 10-week summer research program at TAMU

Activity	**Description**	**Week**
Welcome/ Orientation by College of Engineering and UGR, research ethics and lab safety training, research kick-off meetings	Students participated in the welcome meeting making them familiar with the program team, university along with the COE rules and research guidelines. Students also underwent training in research ethics and lab safety.	1
Work on research projects, weekly meetings with mentors	Student started working on their respective projects under the guidance of professors. They also participated in weekly meetings to discuss the progress and improvements.	2-9
Field trip to a manufacturing plant	Students went on a field trip to an air-conditioning unit manufacturing plant in Houston.	3
Student research progress meeting with PI team	Students participated in project progress presentation where they present the project status and progress. This meeting was organized by the REU PI team.	4
Faculty research seminar	REU students attended a research seminar organized by PI team in which they learned about the faculty research programs. The students also briefed the faculty about their ongoing projects.	4-6, 9
Aggies Invent	Students teamed up with other USRG participants in a team of 5 and took part in 48-hour engineering design and manufacturing challenge.	End of 4
Panel discussion on graduate school applications	This activity involved a discussion on the graduate school application process and what should the students seek in the course and the university they are applying. As students in the REU project are inclined towards research, this was a great platform for them to strengthen their graduate school application.	5
Industry seminars	The REU students attended multiple industry seminar on advanced manufacturing related topics. The seminars were organized on Texas A&M Campus in College Station. In addition, the students also participated in the 2018 NAMRC conference in College Station, TX.	5-9
Meeting for formative assessment	Students participated in a survey conducted by an external evaluator as a part of REU project plan.	6
GRE workshops	These workshops organized by USRG helped students to be familiar with the GRE exam which is crucial for graduate school applications. Various sections of GRE and preparation strategies were discussed in this workshop.	6-8
Draft research report help	Students participated in the COE activity focusing on research report writing skills.	8-9
Engineering summer research poster symposium	Students presented their research project summarized in the form of a poster and explained their projects to the audience/faculty coming to their poster in the symposium.	10
Exit interview	Students were interviewed at the end of the program to evaluate their feedback on the overall program and their research experience. This was again conducted by the external evaluator via email.	10

6. Program Evaluation

This NSF-funded REU program involved an external project evaluator who conducted two surveys: pre and post REU activities. The survey included multiple questions including the questions related to CM topics, students research experience, and overall summer research program management. The questions were designed in the form of Likert Scale (1-5). According to the survey, in overall, students had a very positive learning experience with the REU program. More specifically, the activities that the students found most beneficial were the industrial visits and industrial seminars in which they were able to interact with industry people and learn the real world aspects of manufacturing. Students also found their mentors and graduate student mentors very helpful in their research work with respect to lab work, technical writing, and publications. Students also acknowledged that the REU experience has helped to improve their knowledge in 3D printing, programming languages like python, improved their ability to perform independent learning. Overall, the survey shows that 90% of the students rated this program as very helpful to gain knowledge of a career in cybermanufacturing.

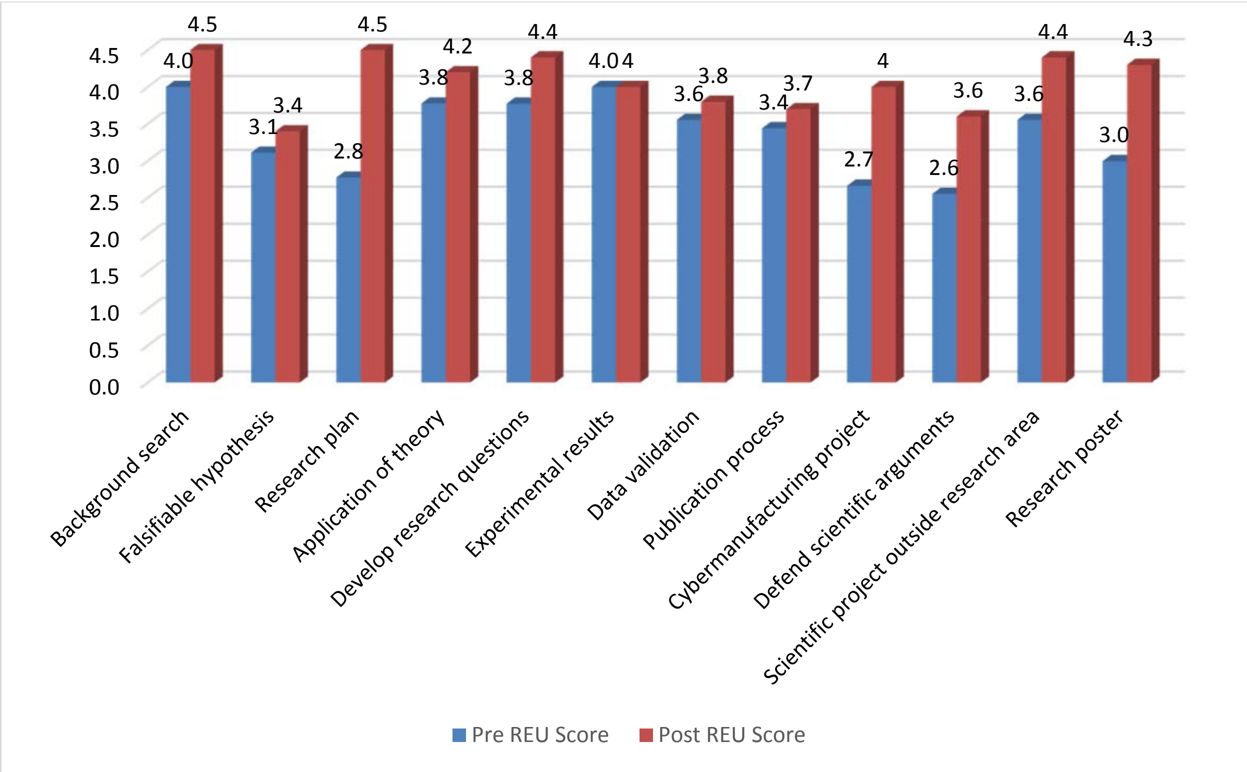

Figure 5: Average competency score before and after the REU experience

Figure 5 provides a comparison of results of pre and post REU activities. As shown in this figure, students felt they gained more confidence in all 12 aspects of research competency after the REU experience. For example, after this experience, students felt more confident in conducting a literature review for their research. Likewise, their competency level has also increased in using theoretical knowledge to guide the research project, developing realistic research questions, and judging the validity of experimental observations and theoretical calculations. Students skill in technical writing for professional publications was also improved as a result of this research experience. On the other hand, there were suggestions to have more frequent interactions with the REU students and faculty mentors. This could be because of summer season during which the faculty typically travel for conferences and other research and personal matters.

7. Summary and Implications of REU Program for Talent Development

Manufacturing technology has been going through many transformational phases in history, for example, from craftsmanship, industrial revolution, mass production, globalized manufacturing (modular design and manufacturing) and to highly customized and 3D printing. It has also seen sharp increase in integration of hardware and software including sensors in both processes and products. While advancement in information technology, wireless sensing, cloud computing, and data analytics have enabled the current manufacturing technologies to achieve highly customized products in a shorter lead-time, many research and government data show that the US manufacturing in general is facing a workforce shortage. More importantly, our research revealed that there was still a negative perception about manufacturing job (such as being dirty and low paid) among younger population in the US and Europe. In order to mitigate these challenges, many companies are partnering with universities and high schools to attract more talents in the manufacturing. The US government is also making investments in several programs focusing on STEM education, research, and training through agencies such as National Science Foundation and Department of Labor.

This paper presented a case study of an NSF supported REU program in cybermanufacturing. In particular, it presented a 2018 cohort of students who participated in 10-week long summer research experience at Texas A&M University. The students worked on individual projects in CM related topics under the guidance of their faculty and graduate student mentors. They also participated in other enrichment activities offered by USRG including GRE preparation workshop, industry visit, and industry and research seminars. The results of pre and post REU experience showed a significant improvement in student's research competency. More importantly, all students have indicated that they wanted to pursue a career and/or higher education in cybermanufacturing as a result of this experience. Although this was a very small sample to make any conclusive statement, according to the survey data, this experience was certainly instrumental in attracting as well as preparing these ten engineers and researchers to the fields of manufacturing.

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