A Comparative Analysis on the Engineer of 2020 - A Holistic REU Program

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Introduction

Since the beginning of the millennium, the conceptual Engineer of 2020 established the motivation for early 21st Century engineering curricula [1]. While it has created some improvement in educational programs, its impact is far more reaching in areas beyond its original objective, such as Research Experiences for Undergraduates (REUs). This REU program improves the traditional REU procedures by incorporating methods that produce the desired traits of the Engineer of 2020.

The Future Renewable Electric Energy Delivery and Management (FREEDM) Systems Center and PowerAmerica Institute created a cooperative Education and Workforce Program with joint staff, programs, facilities, and equipment. FREEDM focuses their research in power electronics, power systems, electric vehicles, smart grid, and renewable energy technologies. PowerAmerica is a U.S. Manufacturing Institute focusing on wide bandgap semiconductors. Through the Center and Institute collaboration, the immersive REU Program enhances the experience working with emerging technologies. This ten-week REU Program exposes students in research as they develop their professional, technical, and research skills. In addition, the purpose of this National Science Foundation (NSF) funded program is to interest students to attend graduate school after degree completion. REU participants are matched with a Primary Investigator (PI) and Graduate Mentor as well as a project based on students' interests.

To produce Engineers of 2020, this REU Program integrated aspirations of the National Society of Engineers from the early 2000s. The select stated objectives were to "produce engineers with technical competence and a broader array of professional skills," improve "retention of students and broader participation of women and [underrepresented] minorities" (URM), enable smooth transitions between community colleges and four-year universities, and "introduce interdisciplinary learning in the undergraduate environment" [2]. The year 2020 is no longer a distant target; therefore, this paper assesses our REU outcomes versus the skills, abilities, and characteristics of the ideal Engineer of 2020.

Specifically, this study compares the goals of the REU program and the Engineer of 2020 based on technical competence, professional skills, retention rate, participation of women and minorities, transition between community colleges and four-year universities, and interdisciplinary learning. Each area is then discussed and identified as either being part of the REU program or existing curricula.

Program Differences from Traditional Research Experiences for Undergraduates

The globalized economy has resulted in the movement of advanced manufacturing to many developing countries. Although largely beneficial to consumers and the economy, this flight of domestic advancement manufacturing from the US workforce impairs the competitiveness of the United States in next generation manufacturing, such as wide band gap-based power electronic devices. Due to a skills gap, it has been reported that 5% of the jobs in manufacturing, approximately 600,000 positions, cannot be filled [3]. This REU program addresses this by exposing participants to emerging topics in next generation advanced manufacturing, specifically the utilization of wide band gap devices in power electronics. The adoption of this technology within the areas of power systems, data centers, consumer electronics, electric vehicles, and defense are of critical economic and national security importance.

In comparison to conventional REU program structures, this REU has the added benefits of weekly technical sessions followed by related labs, professional skills sessions, graduate school and funding discussions, and tours of local facilities with renewable energy grid integration and wide band gap technologies. Incorporating these dedicated learning environments to the existing faculty and graduate student pairing, research process, and weekly REU meetings enabled group bonding, improved presentation skills, preparation for future careers, and learning outside the classroom that was directly associated to their research. These skills were then displayed in online electronic portfolios (e-portfolios) that could be added to LinkedIn accounts to display new talents and research developments. The overall activities are similar to other REUs invested in developing Engineers of 2020 [4]. Keystone activities are described in the following subsections.

Technical Sessions and Labs

With students of all levels and backgrounds joining the REU program, the technical sessions achieved a base level of knowledge across the REU participants. This was accomplished through seven modules that were presented over the course of 7 weeks, as shown in Table I. Modules I, II, III, IV, and V consisted of two separate sessions. The first session detailed theory, and the second required participants to perform a lab test pertaining to the theories previously presented. Through these modules, participants were exposed to the fundamentals of electrical engineering, computer aided engineering design, and the emerging field of wide band gap semiconductors.

The objectives of Modules I, II, and III provided participants with an adequate background in electrical engineering prior to the Wide Band Gap Devices Module (IV). Modules V, VI and VII provided further instruction on applied electrical engineering with a focus on prototyping and real-world applications. Due to the prevalent theme of this REU program being the adoption of wide band gap devices in power electronics, the technical assessment component of the survey was performed strictly on the topics of Module IV.

Professional Skills

After being matched with mentors and a project, each REU participant was required to write a literature review. This review was submitted to their mentors and the REU Education and Workforce Team for constructive feedback on technical competency and writing clarity. The participants continued their technical writing by submitting a report on the research completed at the end of the summer. These requirements taught participants the primary processes of research by learning how to understand the literature and effectively communicate research findings. After learning proper poster formatting and presentation skills, the final reports were transferred to poster presentations that were viewed by the REU symposium attendees.

TABLE I: TECHNICAL SESSION MODULES

Module	Objectives
I. Programming	Two workshops focused on programming using MATLAB® and Arduino microcontrollers. The MATLAB® section emphasized basic programming commands and data structures. Similar to a real world application, the Arduino section integrated those programming concepts for use within an embedded system.
II. Fundamentals of Electrical Engineering	The fundamental concepts and laws pertaining to electrical engineering were presented in this module. The lab portion instructed participants in constructing a Resistive-Capacitive (RC) circuit and measuring its time constant.
III. Background of Power Systems and Electronics	This module served as a precursor to the subsequent wide band gap course and provided participants with an overview of power electronics circuits.
IV. Wide Band Gap Devices	The wide band gap course further detailed power electronics circuits and their uses. It emphasized the important implications wide band gap devices will have on the future of power electronics. This full day course incorporated a lab section in which participants constructed two power converters with one being driven by a wide band gap device. The two converters performance characteristics were then evaluated and analyzed [5].
V. Analog Electronics and Filters	This last hardware intensive module focused on system level electronics. Emphasis was given to systems that incorporated many of the previously mentioned components and laws. These systems included amplifiers, filters, and logic devices. The lab portion included the designing and testing of electronic integrators and differentiators.
VI. Printed Circuit Board Design and SolidWorks®	Participants were given a tutorial on SolidWorks® and EasyEDA (printed circuit board design software). Information and guides were provided on how to fabricate the drawn parts and drafted boards.
VII. Electric Vehicles	An overview of electric vehicles, their history, future trends, and environmental impact was presented. This module followed the context of the content presented in the preceding modules.

Other skills discussed were directed towards graduate school and, more generally, future careers. The objective of these exercises was to bolster interest in applying to graduate school as well as increase confidence in the participants' application materials and interview skills.

E-Portfolio

During the program, each student created an electronic portfolio (e-portfolio) using the platform, Portfolium. Portfolium has a similar format to social media sites, and this created familiarity for the students. When using Portfolium, students built posts by uploading an artifact, selecting a category, writing a description, listing skills, tagging teammates, and creating a hashtag. Each student in the REU Program created ten posts during the ten-week program. They documented research deliverables, professional and technical sessions, field trips, conferences, or any experience that helped them grow professionally.

The purposes of e-portfolios were for developmental (learning/reflection), showcase (professional/career), assessment (summative), and institutional (academic) purposes [6]. The REU Program focused on the developmental and showcase uses. For developmental purposes, their e-portfolios promoted transferable skills, lifelong learning, and reflective thinking [7]. As one student shared,

> "The Portfolium reflections that I completed were very useful in monitoring my research and learning progress. Particularly during my training with Typhoon HIL, I was able to document specific stages in my skills development with the software. Also, other tours and visits helped me connect those experiences to research and learning objectives."

Additionally, students learned how to create a marketable LinkedIn page; therefore, with a showcase purpose, students were able to support their LinkedIn skills with specific skills listed. Another student stated,

> "I feel that the Portfolium reflections that I completed as an REU were a great way to expose and market myself to the engineering industry."

The program plans to continue to use Portfolium as a marketable tool and to develop stronger transferable skills for participants.

Assessment Methods

Participants were assessed through a variety of direct and indirect methods. Technical skills gained from the lecture series were measured through successful completion of the correlating lab. Mentors evaluated participants' performance in research tasks by observations. The final poster presentations were given feedback by the audience who attended the REU symposium. Participants were critiqued on the effectiveness of visual aids and communication skills through an optional questionnaire submitted online by the audience.

All REU participants were asked to complete pre- and post- surveys that included demographics, university and major information, technical skills, confidence levels, and personal evaluations as established in references [8] and [9]. These surveys created a better understanding of the impact of the REU in multiple realms, including interest in graduate school and the confidence in the development of technical and presentation skills of the participants.

Program Outcomes

The total number of participants in the REU program was 12. All participants submitted responses to the pre- and post- program surveys. Five (5) of the participants were women or from URM, and 4 were from a local community college. The participants consisted of 4 seniors, 5 juniors, and 3 sophomores. The fields of electrical engineering, computer engineering, mechanical engineering, aerospace engineering, and civil engineering were represented among the cohort.

Based on their survey responses, 100% of the students' goals for the experience were met through the program as a transformative experience for students in professional, technical, and personal areas. The most common expectations, chosen by more than 80% of the participants in the pre-survey, were

- Collect and/or analyze data or information to answer a research question,
- Understand how my work contributes to the "bigger picture" of research in the field,
- Go on research-related field trip(s) (to other labs, etc.),
- Attend student conference(s) that include(s) students from other colleges,
- Prepare/present a poster presentation describing my research and results,
- Prepare a final written research report describing my research and results, and
- Deliver an oral presentation describing my research and results.

As all REU programs, the fundamental motivation is to recruit and encourage participants to continue research and post-baccalaureate studies. Based on responses to the surveys, this program was successful in that regard. In the pre-survey, 67% and 25% were interested in Master's and Doctoral degrees, respectively. While Master's degree interest increased slightly (75%), the number of participants interested in Doctoral degrees doubled to 50%.

Efforts to Increase Diversity in Various Career Paths

An unforeseen result of the professional skills sessions was that the participants desired conversations to cover tools that are useful in both academia and industry, such as networking, interviews, and resume design. In response to recommending this REU program to others, one participant commented,

> "Even if you're not planning to do research or grad school, the program gives marketable skills for use in the workplace or in classes..."

Therefore, these participants gained skills that are transferable to any chosen career path.

As 58% of the REU participants were either female, minorities, and/or from community college, it is important to discuss their potential careers. Since there was only one woman in the program, she has been added to the URM for the discussion. They were more likely to be interested in graduate school before the program. All the URM and woman were interested in either a Master's or PhD in both the pre- and post- surveys. Figure 1 depicts participant interest in post baccalaureate studies with community college participants and URM and woman highlighted separately. Participants could choose any and all degree paths since the traditional Master's to PhD path and direct to PhD routes are possible. It is important to note that half the students from community colleges were also URM. It can be seen that the community college participants and URM and woman bolster the increased interest in the pursuit of Doctoral degrees in the post-survey.

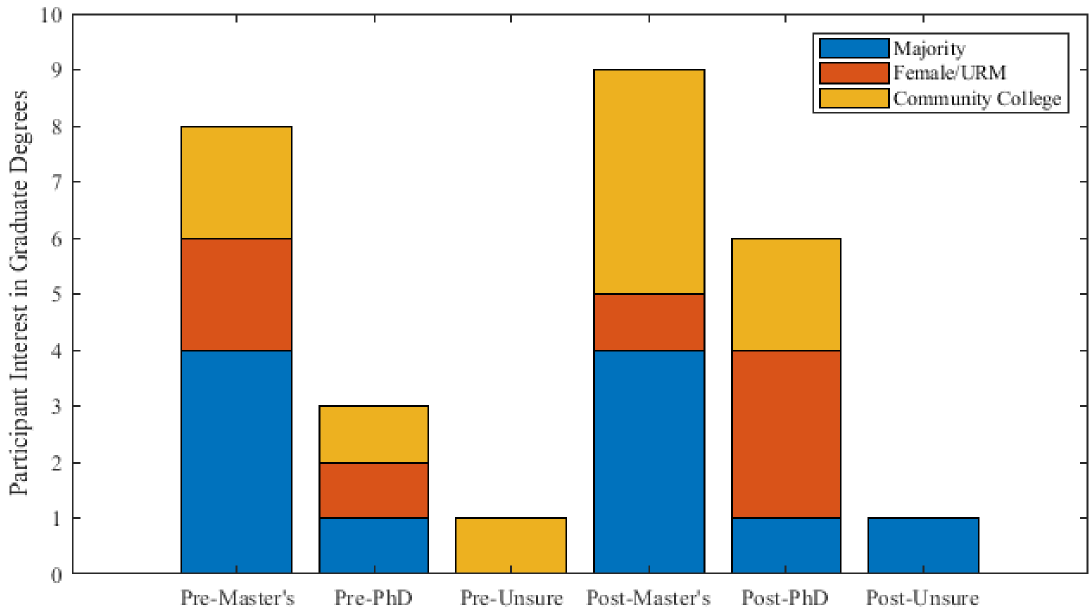

Fig. 1. Interest in graduate studies in pre- and post- surveys.

Diversity extends not only to gender and ethnicity; it includes diversity of thought and path to commencement. This program aimed to incorporate community college students in the applicant pool by recruiting at local community colleges. The firsthand experience exposes them to opportunities that they may not have at a community college. However, it is notable that a majority of the community college students were already interested in graduate studies prior to the REU program as shown in Fig. 1. It is easy to conclude that they were wanting experience in research since these participants chose "interested in understanding the research process in your field" when asked in the pre-survey what benefits they expected to gain in the program.

Comparison to the Engineer of 2020

With the information discussed in the Program Outcomes Section, a comparison between participants in the REU program and the ideal Engineer of 2020 can be made. Of the recommendations made by the National Academy of Engineers in references [1] and [2], the four that best correlate to the expectations that revolve around students will be used. Each subsection discusses the individual expectations and if they are already part of the participants' curricula or introduced via the REU program.

Technical Competence and a Broader Array of Professional Skills

Since there was a broad spectrum of technical knowledge due to their respective years of study, technical competence is a difficult measurement. With the previously mentioned technical lectures and labs and participants' abilities to complete their respective projects, it is reasonable to assess a strong baseline level of technical skill. In completing their degrees at their respective universities, technical competence will be fulfilled. This is in agreement with the Engineer of 2020 ideals.

The pre- and post- technical competence assessments, which focused on wide band gap devices (Module IV), showed positive results. The post-assessment showed an increase in correct responses in seven out of nine total questions. A 30% or more improvement was observed in three of these questions. No variation was observed in the remaining two out of nine questions. Overall, the average score for the technical competence improved from 67.2% to 73.9% between the pre- and post-assessments respectively.

A crucial professional skill is communication, written or oral. Students self-reported on a five-point Likert-scale that after the REU Program, communication (M=4.08) as a strength and that the REU Program helped to develop their oral (M=4.25) and written (M=4.5) presentation skills. Participants' first exposure to communication in the program was writing a literature review. After a session on how to read literature and some basic guidelines on writing research papers, these were reviewed by the graduate mentors and the REU Education and Workforce Team. It was seen that there was room for improvement in technical writing which was discussed in more detail in a professional skills session later in the summer. Much stronger technical writing is reported at the end of the program as seen on the participants' posters for the symposium. Other similar areas of improvement in communication were found in resumes and cover letters after another session. Graduate school applications were discussed, but writing samples were not collected.

Other professional skills, including professional attire, interviews, conference etiquette, and writing professional emails, were covered in the sessions as well. Overall, there is a disconnect in the Engineer of 2020 and the engineering curricula in the professional skill set. In the post-survey, however, the free response sections show the appreciation for learning these skills prior to completing their degrees and moving on to the next phase, graduate studies or otherwise. Select responses are given:

> "The meetings were useful for learning about the soft skills of undergraduate school such as resume building, applying for graduate school, and getting funding for graduate school."
>
> "Not only did we learn valuable professional skills, but these sessions served as a way to debrief about research progress."
>
> "The variety of career development and research skills resources i[s] unparalleled."

This detachment causes several disadvantages for students applying for graduate school or industry jobs. Students may struggle receiving interviews or may interview only to be unprepared for the process. This may cause technically competent students to have difficulty attaining future goals.

Retention of Students and Broader Participation of Women and [Underrepresented] Minorities

The outlook for retention within this group of participants is strong. Both surveys indicated a high likelihood of completing the current engineering degree or any engineering degree with a nearly constant 4.83 and 4.92 mean, respectively, on a five-point Likert-scale. Therefore, the engineering curricula is producing high retention rates in this small population, and the REU program reinforced participants' interests in engineering. As students who attend REU programs tend to be more confident in graduating, this group is not representative of the general engineering student population.

Our REU program had a relatively strong representation overall for women, URM, and community college students; however, in this area, a major weakness was only having one woman in the program. We are working to correct this by advertising to women in engineering societies, such as the Society of Women Engineers (SWE) and Women in Engineering (WIE), for future years of this program. In this directive, this REU program could do better. The lack of women in the applicant pool is the biggest barrier to this objective.

Transitions Between Community Colleges and Four-Year Universities

Beyond the scope of this work is the ability to transfer credits between institutions which can be daunting. Key to the participants from community college is the advantage of gaining technical and hardware skills prior to transitioning to a university. On a five-point Likert-scale, community college students demonstrated growth in relationship development (M=4.75), identifying different ways to solve problems (M=4.5), creating a step-by-step plan to solve a problem (M=4.5), and written presentation skills (M=4.5). These skills should help these participants gain confidence in being at the same level as their university-only counterparts. It is questionable if these skills are developed in community college coursework. However, this program enabled these participants to make any adjustments deemed necessary for transition. In this regard, an REU program is useful in this transitioning process.

Interdisciplinary Learning in the Undergraduate Environment

Five (5) fields of engineering were represented by the participants. Contrary to our small female applicant pool, this depicts overall student interest in interdisciplinary topics. This is ideal in comparison to the Engineer of 2020. There are two potential reasons for this representation: (i) faculty are promoting this idea in coursework that engaged these students in interdisciplinary thought or (ii) students are searching for other means of gaining interdisciplinary projects as courses are not delving into this topic. Which it is cannot be determined through the research methods used for this paper.

Potential Improvements for the Program

Looking beyond 2020, engineering students will encounter new challenges as they integrate into a more globalized economy. These challenges are illustrated in the many globalized engineering projects, such as the construction of modern passenger aircraft. In such projects, engineering teams span borders and encompass a variety of different countries and cultures. In order to better adjust to such a workplace, there will be increasing demand on future engineers to have fluency in multiple languages and awareness of other cultures [10]. While it is beyond the scope of REU programs to teach new languages, more effort can be made to discuss the impacts of working in a global setting.

To better mentor students, we hope to provide formal training according to the university's best mentoring practices. This includes clear expectations through a contractual agreement between the mentor and the student, providing a realistic research site, selecting appropriate graduate mentors, meeting on a natural playing field, and facilitating the research experience. Additionally, tools will be used from the National Research Mentoring Network. Mentorship is critical as faculty mentors assume responsibility for scaffolding the knowledge creation process rather than act as 'knowledge conduits' [11].

Conclusions

Sixty-seven percent (67%) of the students from the program will graduate in 2020 or later; hence, the reason this comparison is so pertinent. While all engineering students gain technical competency in the classroom, deficiencies remain in most curricula when compared to the Engineer of 2020. Targeted efforts, like the proposed REU program, are required to remove these shortcomings in students' profiles. The presented program structure may serve as a guide for other universities to develop well-rounded engineers for the future.

References

[1] National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press, 2004.

[2] National Academy of Engineering, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. Washington, DC: The National Academies Press, 2005.

[3] Deloitte and The Manufacturing Institute, "Boiling Point? The Skills Gap in U.S. Manufacturing," *The Manufacturing Institute*, 2011. [Online]. Available: http://www.themanufacturinginstitute.org/~/media/A07730B2A798437D98501E798C2E13AA.ashx. [Accessed: 20-Oct-2018].

[4] M. West, W. Cross, S. Kellogg, and A. Boysen, "A novel REU program to develop the skills of the Engineer of 2020," in *2011 Frontiers in Education Conference (FIE)*, 2011.

[5] Dayerizadeh, A., & Carpenter, P. P. (2017, June), Board # 54 : Wide Band Gap Academy—Education and Workforce Development for the 21st Century Power Electronics and Power Systems Industries Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. https://peer.asee.org/27877.

[6] F. Alam, H. Chowdhury, A. Kootsookos, and R. Hadgraft, "Scoping e-Portfolios to Engineering and ICT Education," *Procedia Engineering*, vol. 105, pp. 852–857, Jan. 2015.

[7] N. L. Carroll, L. Markauskaite, and R. A. Calvo, "E-Portfolios for Developing Transferable Skills in a Freshman Engineering Course," *IEEE Trans. Educ.*, vol. 50, no. 4, pp. 360–366, Nov. 2007.

[8] AWE: Assessing Women and Men in Engineering, [Online]. Available: www.engr.psu.edu/awe/, [Accessed: February 2, 2019].

[9] G. Ragusa, "Preparing university students for global workforces: Comparisons between engineering and business school students," *2010 IEEE Frontiers in Education Conference (FIE)*, Washington, DC, 2010, pp. F4J-1-F4J-5. doi: 10.1109/FIE.2010.5673329

[10] S. A. Rajala, "Beyond 2020: Preparing Engineers for the Future," *Proc. IEEE*, vol. 100, no. Special Centennial Issue, pp. 1376–1383, May 2012.

[11] P. E. Doolittle and W. G. Camp, "Constructivism: The Career and Technical Education Perspective," *Journal of Career and Technical Education*, vol. 16, no. 1, Sep. 1999.