Filling the Technical Gap: The integration of technical modules in a REU Program for 2+2 Engineering Students

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Abstract

Due to the abstract nature of the field, electrical engineering students can benefit significantly from active learning to increase understanding and self-efficacy in the field. In some cases, students may lack of confidence in their abilities, which can lead them to avoiding the engineering field altogether [1]. For this reason, a Research Experience for Undergraduates (REU) program integrated weekly technical modules focused on critical skills to benefit participants, particularly individuals from a community college. The objective was to increase their technical abilities and develop their self-efficacy in engineering and research.

Due to the non-intuitive nature of many electrical engineering concepts, when students engage in hands-on hardware experiments, they increase their interest, confidence, and understanding. Therefore, technical modules were designed to incorporate the foundational knowledge and active learning approaches. The topics covered by the four one-hour technical modules included programming, electrical circuits, electric vehicles, and computer-aided design (CAD). Except for the CAD module, each module required students to participate in a pre and post-survey to assess the impact of the material. All students improved except in the electric vehicle module, which did not have an active learning format.

All topics were selected based on the high-demand skills needed for the workforce. In addition to the four technical modules, there was a half-day power electronics workshop that instructed students on the impact of wide bandgap semiconductors on future power conversion. This workshop went further by instructing students on PCB design, soldering and assembly of a Gallium Nitride based buck converter [2]. Wide bandgap technologies are an emerging and high-demand skill, therefore providing an extraordinary experience. Two-year institute participants' understanding of wide bandgap technologies increased on their post-assessment by 42% with all REUs from two and four-year institutes demonstrating 100% comprehension.

In addition to technical skill development, self-efficacy in engineering is of equal importance as it contributes to achievement and persistence in engineering majors. The community college REUs self-reported after their 2019 program participation the following: they were confident that they would be enrolled in an engineering major in the next academic year, had confidence to complete any engineering degree, were more confident as researchers and that they could persist in engineering during the current academic year. With the use of e-portfolios, students documented their learning and artifacts to demonstrate their growth and confidence in the skill.

As current policy aims to boost domestic technical and manufacturing jobs, there will be a need for a workforce with specialized skills such as those gained in this program. As shown, technical labs can be a significant intervention to assist students in transferring from a two-year institution to a four-year institution, particularly in terms of skill development and self-efficacy. Approaches such as this will increase the community college participants' retention and confidence as a researcher and an engineer to apply these skills in their future courses and

careers. The purpose of this study is to identify if there is potential impact from technical modules for community college students.

Introduction

The need for a skilled STEM workforce will be greater than any other occupation between 2012-2022 [3]. The ability to meet this demand for a highly skilled trained workforce in STEM fields is a frequently discussed problem as the nation strives to be competitive internationally. One solution to grow the STEM workforce is to recruit from diverse backgrounds, such as students from two-year institutions, also known as community colleges. These institutes serve the most diverse student populations in higher education with a higher proportion of women, older students, first generation students, veterans, working parents, low-income, and underrepresented minorities, than four-year institutions [4].

Many students who are pursuing engineering at a two-year institute are part of a 2+2 engineering program. In these programs, students attend a two-year institute for the first half of their post-secondary studies, taking foundational courses before transferring to a four-year institute. Once they transfer, students complete their upper level courses for their bachelor's degree in an engineering field. During this transfer process, there can be various challenges. In the two-year environment, students are provided the foundational courses with additional support and advising. In comparison, four-year institutes have an expectation that all students have a certain skill set as they complete their upper level coursework. After transferring, these students face a new learning environment and a heavy course load potentially causing "transfer shock" [5].

Understanding the need for a more diversified workforce in STEM and specifically engineering, a summer Research for Undergraduates (REU) Program at the FREEDM System Center at North Carolina State University (NCSU), which is a four-year institution, purposefully started recruiting from neighboring two-year institutes. As the two-year institute REU participants increased, the Education and Workforce team observed the need for more training in fundamental technical skills for these students and others. Therefore, a series of modules were created to help REU students be better prepared to succeed in the research environment. The study highlights the results obtained from the 2019 program's technical module integration and the impact on the two-year institute REU participants' technical abilities as well as self-efficacy.

Background

The REU program is a ten-week summer immersive experience at the FREEDM Center located on the NCSU campus. The FREEDM Center is an Engineering Research Center (ERC) funded by the National Science Foundation (NSF), which focuses on renewable energy and power electronic applications that are related to many different emerging technologies such as wide bandgap semiconductors, electric vehicles, and the smart grid. The purpose of an REU Program is to recruit more students into STEM graduate programs. However, the Education and Workforce team for this REU Program prepares students for both graduate school and industry. During the REU program, students conduct research and participate in various professional development sessions for forty hours per week. When conducting research, students are also paired with a Primary Investigator and graduate mentor to support them through the process. The graduate mentor relationship is a significant contributor to a student's performance. They become the REU's guide throughout the project for questions and direction as well as providing the necessary scaffolding to assist the student to be successful. This REU program also aims to provide a holistic experience with different speakers from research and industry, field trips, weekly meetings focused on research updates, professional development, and technical labs.

There is essential coursework and related experience necessary to be able to conduct research at FREEDM. Therefore, all the students from the two-year institutes were sophomores, who were also part of engineering 2+2 programs. The program was during the summer transition between their two-year and four-year institute. However, students from the two-year institutes struggled conducting research due to the lack of technical skills. To address this, the REU program began implementing technical labs to provide the necessary skills for research. These lab sessions not only provided skills to be successful in research, but also in their coursework, with the aim of decreasing the risk of transfer shock. This is defined as a drop in GPA when students transfer to a four-year institute [6].

Technical & Tinkering Self-Efficacy

Self-efficacy can be significant to a student's confidence in their skills and success in a career. Two-year students often struggle with their engineering self-efficacy as there is a lower level of skills required for their coursework compared to four-year institute students [7]. In most engineering curriculums, students have first- and second-year courses (100 and 200 level) where they work with hardware and test equipment. Typically, two-year students have less of a propensity to have a background in which they have "tinkered". Self-efficacy in their tinkering and technical skills can be a major factor in their upper level courses. Technical and tinkering self-efficacy is defined by Baker, Wood, Corkins, and Krause as [1]:

- *Technical self-efficacy*: one's confidence and belief in their competence to learn, regulate, master, and apply technical academic subject matter as it relates to success in engineering

- *Tinkering self-efficacy*: one's experience, components, and comfort with manual activities such as manipulating, assembling, disassembling, constructing, modifying, breaking, and repairing components.

Students' self-efficacy, particularly related to engineering, is significant because it relates to predicting student's career choice, academic achievement, and career perseverance. Therefore, if the student has low self-efficacy, it is more likely that the student will leave the major/field [8]. The way the curriculum is taught can also impact students' self-efficacy; well-structured collaborative experiences and hands-on activities have been shown to have positive implications for self-efficacy [9]. According to Concannon and Borrow [10], transfer students from two-year institutions have a lower self-efficacy than students who began in a four-year institution. The REU program's technical modules were designed with the goal of supporting the student's self-efficacy in their technical and tinkering abilities to be successful in their coursework as well as a tool of retention into the engineering fields.

Technical Modules and Workshop

The goal of each technical module is for students to have obtained a skill set that enables them to analyze, design and engineer projects. Not only will the students better understand the material in their courses, they will also be equipped to address problems and challenges faced in research and industry. The modules are purposefully designed to be collaborative, focused, and authentic learning experiences. Throughout the ten weeks, students participated in four one to two-hour modules and one-half day workshop. The one to two-hour modules are outlined in Table 1:

Table 1. Description of the Technical Modules

Module	Goal	Content
Electric Vehicles (EV)	• To provide context for wide bandgap (WBG) labs and electrical engineering modules. • Convey the tremendous impact electric vehicles will have on the future environment, economy and consumers.	• History of EVs • Challenges: rising fuel costs, climate change and advancing technology
MATLAB/ Programming	• Provide a background in computer programming through MATLAB software and Arduino microcontrollers. • Learn about different programming statements and embedded systems.	• Programming languages • Embedded systems
Electrical Circuits	• Overview of basic circuit laws, passive electrical components, transistors and operational amplifiers. • Applications of these components are detailed by presenting basic circuit topologies.	• Circuit analysis • Passive and active components • Filter design • Circuit testing • Test equipment and tool usage
SolidWorks	• To emphasize the importance of 3D modeling in the context of additive manufacturing, a critical part of the future prototyping and manufacturing process.	• 3D CAD software • Additive manufacturing process

The MATLAB/Programming, Electrical Circuits, and SolidWorks modules all had an active learning component in which students were provided a challenge in which they had to design, build, assemble, and essentially tinker to solve. There was also opportunity for exploration, modifying their design, and prototyping. An exception was the EV lab, which was a lecture-based technical session with the use of questioning.

Sessions in the four technical modules were designed to provide fundamental skills. However, the Education and Workforce team also provided training in wide bandgap (WBG) semiconductors, an emerging cutting-edge technology. WBG technologies “allow power electronic components to be smaller, faster, more reliable, and more efficient than their silicon (Si)-based counterparts” [11]. The benefits of WBG technology cuts across various applications including industrial motors, electronics, grid integration, utility applications, electric vehicles and plug-in hybrids, military, geothermal, and lighting. The ERC works collaboratively with an organization that focuses on this technology. WBG has become a component of the ERC’s efforts in research. This technical lab was an opportunity to expose students to this technology but also recruit into this high demand and specialized area.

An Electrical Engineering Ph.D. student designed a four-part WBG course to expose students to power electronics and their vast applications within the technology and transportation sectors [2]. WBG semiconductors were introduced by first providing an overview of how they compared to traditional silicon-based semiconductor technology. The implications of WBG technology on the power electronics industry was emphasized along with the importance of such technology in the context of climate change and fossil fuel dependence. The course culminated in a hands-on lab portion in which students assembled and tested a gallium nitride based buck converter and characterized its high-performance attributes. These technical labs are not only significant for student success by providing highly marketable technical skills, but also creating a well-trained workforce.

Methods

This section details the methods used for the data collection and the composition of the REU cohort analyzed in this study.

Data Collection

The evaluation of the technical modules was based on the pre- and post-surveys, technical assessments, and the REUs' e-portfolios. The pre- and post- surveys were developed from the *Assessing Women and Men in Engineering's Longitudinal Assessment of Engineering Self-Efficacy* [12] assessment. The survey questions focus on STEM and research self-efficacy, inclusion, career success, engineering creativity and global kinship.

For each one to two-hour session, students had a 4-5 question multiple choice quiz that was taken at the beginning of the session and then again at the end of the session for the Electrical Circuits, Electric Vehicle, and MATLAB/programming labs. There was no assessment developed for SolidWorks. For the WBG workshop, the nine question assessment was also taken in the beginning and the end of the session. Each question focused on general concepts to measure the objective of the lab and understanding of the content. The questions were developed by the Electrical Engineering Ph.D. student who developed the labs and workshop.

Using the e-portfolio platform Portfolium, students created posts with an artifact (image, video, document, file, etc.), a short description, selected technical and professional skills, "tagged" teammates, and generated hashtags. This platform was user-friendly and familiar to REU students since it is similar to LinkedIn and Instagram. The aim of the descriptions detailed by the REU participants were to provide evidence of learning and skill development. E-portfolios help to develop transferable skills alongside supporting reflective learning, which makes it an ideal assessment technique for the technical modules [13].

The REU Cohort

The 2019 Program consisted of nine participants from NCSU and the two neighboring community college schools. Of the nine participants, 56% were from a two-year institute (n=5) and 44% of the participants were from a four-year institution (n=4). There were five participants from two-year institutions who were also transferring to a four-year institute following the REU

Program. Of the five, there was one female participant, one Asian participant, and one African American participant. Three of the five participants were younger than 25 years old and two were between 25-34 years old. Three of the five participants were transferring to the ERC's university. The other two participants were transferring to two other local four-year institutes.

Results & Discussion

This section details the results obtained in this study with an accompanying discussion to provide insight as to their significance.

Program Impact

In the 2019 program, all REU participants reported they would recommend the program to others and 8 of the 9 participants shared that their goals were met from participating in the program. Additionally, the REU participants indicated they were confident they would complete their degree to graduate in their current engineering major at their institution. Lastly, the program provided quality instruction, relevant knowledge, and contributed to their future career decisions based on self-reported satisfaction provided by the participants.

Content Comprehension

For technical modules, assessments were created for the WBG workshop, Electric Vehicles (EV), MATLAB/Programming, and Electrical Circuits modules. As indicated previously, there was no assessment for the SolidWorks module.

Figure 1. The technical assessment comparison of participants' scores

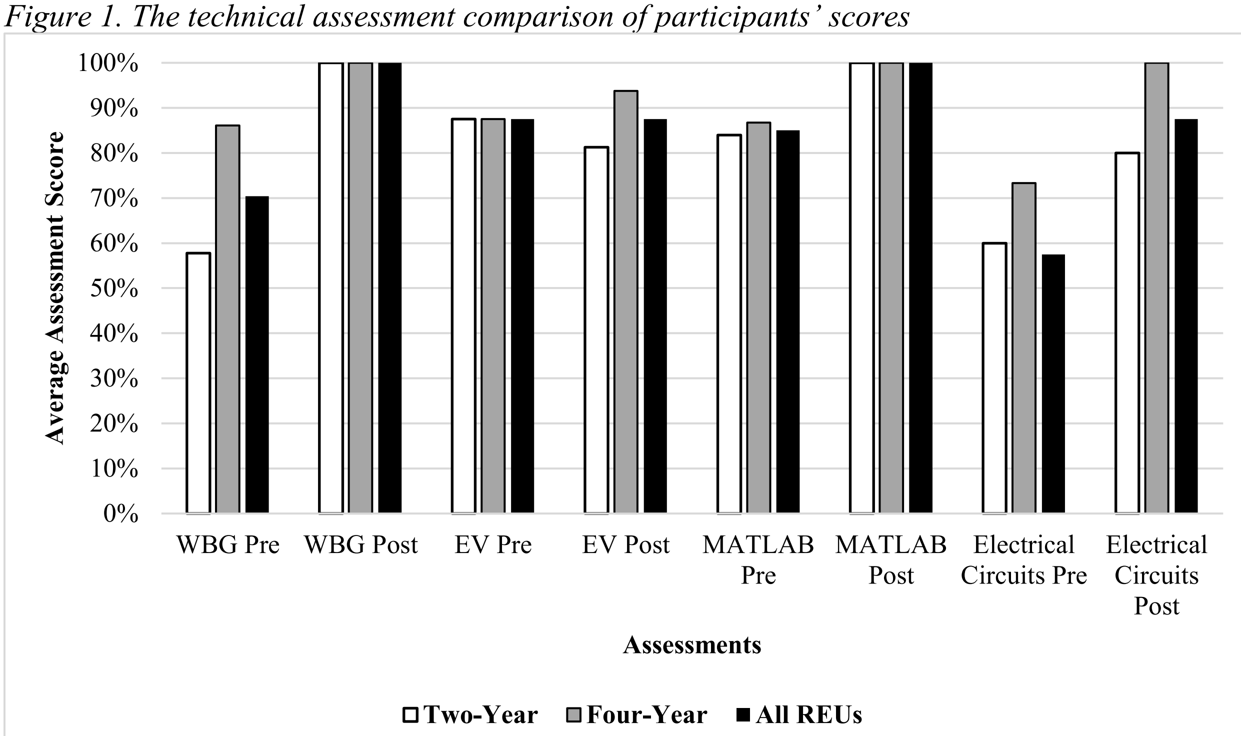

Figure 2. The technical assessment variation comparison of the two-year, four-year, and all REU participants' scores from the pre- and post-assessment

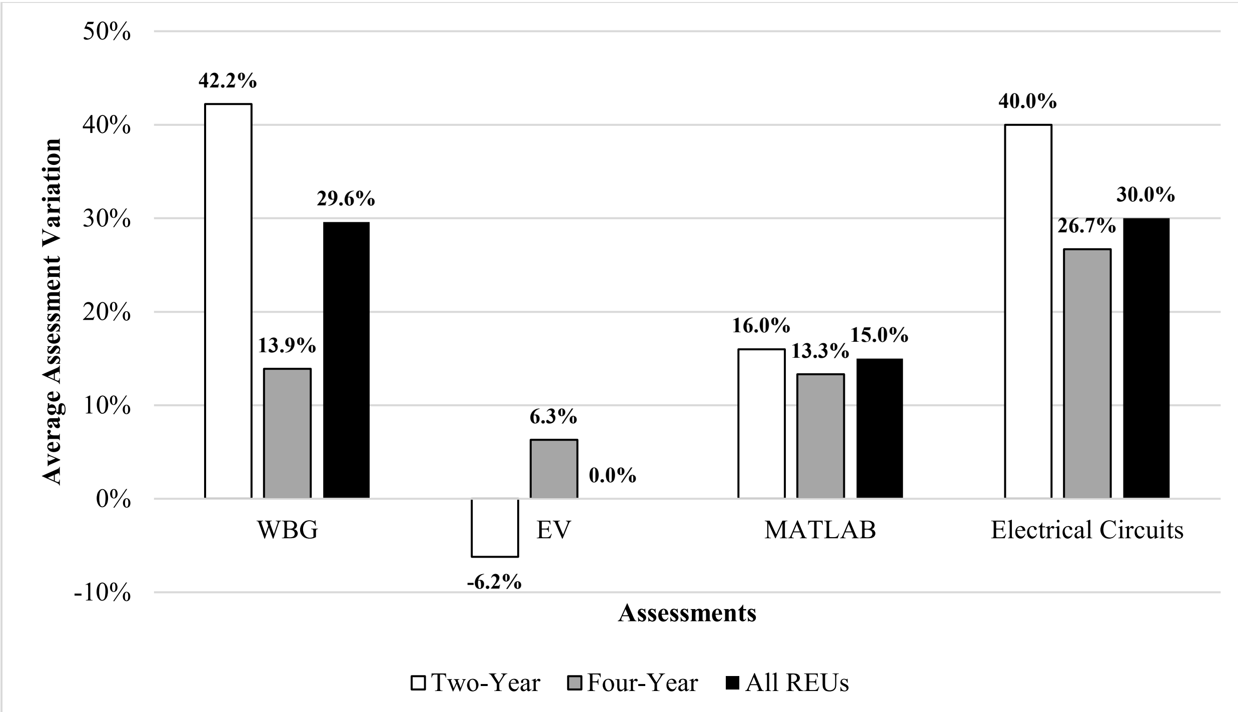

Figure 1 provides a summary of the two-year, four-year, and REU cohort average pre-assessment and post-assessment scores taken from the technical labs. The participants coming from a two-year institution had a lower pre-assessment score than the four-year institute participants and the cohort for the WBG workshop, MATLAB/Programming lab, and Electrical Circuits lab. In the post-assessment, all students had improved their scores through all assessments except for the EV lab. As referenced above, the EV lab utilized question and answer format in a lecture-based approach. But, as shown in Figure 2, the two-year participants demonstrated a greater increase than the four-year participants. In the WBG workshop and Electrical Circuits lab, two-year institute students demonstrated at least a 40% average increase in their technical labs. For the MATLAB/Programming session, students demonstrated growth that was similar regardless of background. However, for the EV session, the module exhibited the significance of active learning for students with the two-year background as they scored worse in their pre-assessment compared to the four-year participants who demonstrated a small amount of growth.

Technical Reflective Learning through E-Portfolios

All students' e-portfolios contained entries related to the technical sessions. Each entry that was referenced provided an image of the work completed, actively tinkering, or building a design. Students described specific content they learned, referenced different active learning approaches, tool usage, and collaborative work.

Table 2. Two-year institute participants e-portfolio excerpts from entries.

Lab	E-Portfolio Excerpts
WBG Workshop	**Active Learning/Collaborative**: *"... Along with this knowledge, my teammates and I observed the behavior of the WBG semiconductor technology by building, soldering, and testing a GaN-based buck converter."* **Content**: *"During the first half of our lab, we learned details about wide bandgap semiconductors. For example, wide bandgap devices have a larger energy range than normal semiconductors. They are also able to operate at a higher frequency, voltage, and temperature than other semiconductor devices. Devices that require higher voltages tend to be made with silicon carbide (SiC), while devices that require high switching frequencies tend to be make using gallium nitride (GaN)."* **Collaborative/Tool Usage**: *"As I had no prior experience soldering, I got assistance from my experienced teammate and learned how to properly use a soldering pen, flux, and solder. Although it was difficult at first keeping the SMD in place, by the end of the session I was a lot more adept at using the tools."*
Electric Vehicles (EV)	There were no entries related from two-year institute students.
MATLAB/ Programming	**Active Learning/Exploration/Tool Usage**: *"I was tasked with programming an Arduino micro-controller for the device. The Arduino would detect voltages as well as frequencies, and interpret these measurements to be displayed on a LCD screen. In addition, the Arduino was to control an analog switch operated by a button to switch between different axes from the tri-axial probe. As someone unfamiliar with the Arduino IDE, I found myself looking up online resources to help me in writing the program in multiple test stages."*
Electrical Circuits	**Active Learning/Content/Tool Usage**: *"We learned more about basic circuit components such as integrators, op-amps, and high/low pass filters. We also gained hands-on experience through designing some of these newly learned components on a breadboard and verifying their uses through an oscilloscope."* **Active Learning/Tool Usage/Collaborative**: *"My team and I built three different Inverting Amplifier using electronic components and a SparkFun breadboard and tested the input and the output of the circuits using an Oscilloscope. Also, we observed the behavior of each circuit by looking at their generated signal on the oscilloscope."*
SolidWorks	**Active Learning/Collaborative/Tool Usage**: *"Under instruction by one of our more experienced peers, we were shown how to create designs that could be used in drafting or be printed out from a 3D printer. As part of the session, we designed a simple flange and pulley and experimented with basic SolidWorks features like fillet, smart measure, and circular pattern."*

**Note: Being excepts, not all technical two-year institute participants' e-portfolio entries are included in this table.*

In the two-year entries described in Table 2, the Education and Workforce team could observe the students' knowledge of technical skills being applied at various levels of comprehension.

Engineering and Research Self-Efficacy

As the technical assessment and e-portfolio entries provided evidence that all students were gaining relevant technical knowledge and skills, the modules helped to foster self-efficacy development for their transition between the two-year and four-year institutes. This was reflected in the post-survey where students demonstrated a strong self-efficacy in their research and engineering capabilities. In Table 3 and 4, students indicate that they felt confident in their research and engineering abilities. This validates the impact of the REU program on their future career decisions. Additionally, two-year institute students described that through participating in the program, they have increased their interest in a career in renewable energy (5.0), STEM (4.2), and research in STEM (4.2) on a 5-point Likert-scale.

Table 3. Self-Reported Research Skills Abilities from two-year REU participants (5-point scale)

Statements	Average
The research skills I gained will help me in terms of future work or research.	4.8
I gained experience in research practice.	4.6
I gained self-confidence as a researcher.	4.4

Table 4. Self-Reported Engineering Skills Abilities from two-year REU participants (7-point scale)

Statement	Average
I can succeed in an engineering curriculum.	6.8
Someone like me can succeed in an engineering career.	6.8
I believe that I will do well.	6.8

Discussion

Although it would be ideal that two-year and four-year institutions would collaborate to develop a more linear curriculum, it may not be realistic. Through the technical assessments, e-portfolios, and self-efficacy results, the two-year participants demonstrated significant technical growth with active learning, and its impact onto their engineering and technical self-efficacy. The interventions conducted in the program provided an even playing field for all students regardless of their background.

Even though the technical labs and workshops could be described as impactful, there are areas of improvement. In the EV lab, the lecture-based approach proved not as effective as the other modules and workshop. When designing future labs, the Education and Workforce team will incorporate different active learning approaches to increase comprehension and understanding. Furthermore, retention is increased in an active learning setting as demonstrated in the results. Additionally, the authors are mindful of the fact that the sample size is small. However, one of the aims of this study was to provide insight for future research.

Conclusion

With a simple technical module intervention into an REU Program, a student's learning experience can be monumentally different with the necessary technical scaffolding. The foundational skills allow students to be successful in research and coursework. It also provides an opportunity to recruit and retain STEM professionals in the field to address this national need of a well-trained, innovative workforce. To continue to advance in science and technology and to thrive in a global economy, the United States will have to rely on well-trained scientists and engineers to develop innovative and high value-added products and services, as well as to improve productivity through the use of technology-based tools [14]. The REU program and approach detailed in this study may serve as a framework for addressing this need for two-year and four-year institutes.

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