AC 2011-262: BENEFITS OF RESEARCH EXPERIENCE FOR UNDERGRADUATE ENGINEERING TECHNOLOGY STUDENTS

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Benefits of Research Experience for Undergraduate Engineering Technology Students

Abstract
Research experience has been proven to be effective in enhancing the overall educational experience for undergraduate students. In this article, two research projects with undergraduate students' involvement are discussed. The projects provided the undergraduate student researchers with motivation for independent research work and learning experiences in the areas of sensor characterization, analog and digital filter design, electronic circuit design, printed circuit board layout, and feedback control design. The students also helped a faculty member to conduct research work and curricular development. The seamless combination of learning, research, curriculum development, and outreach based on the research projects illustrates the importance of research with the involvement of undergraduate students.

1. Introduction

The importance of undergraduate research has been studied by many educators over the past two decades[1,12,14,15,19,20,26,27,32]. Because of the importance of undergraduate research, National Science Foundation has a special program, Research Experiences for Undergraduates (REU), to support efforts in this area[18,21,25]. It sponsors both REU sites and REU Supplement for NSF-funded research projects. REU is getting more and more attention from educators. One of the main benefits of REU that has been extensively discussed in literature is its impact on a students' decision to pursue a graduate degree and a career in the science, technology, engineering, and mathematics (STEM) workforce[3,4,6,8,11,32]. Other benefits include student retention[15], research skills learned by students[8], and learning other skills such as teamwork, communication, and presentation[7]. Hackett[7] studied several impacts of undergraduate research and compared it with cooperative educational experiences for engineering students. Boylan[3] provided an informative survey on undergraduate research. While there is overwhelming evidence provided in literature for the value of undergraduate research, more research is needed in providing practical case studies to illustrate how to use research to achieve the intended benefits. It is also important to study all these impacts on different majors. Schowen[23] studied REU for chemical sciences; Zydney *et al*.[32] and Hackett *et al*.[7] studied impact of REU in engineering; Hunter *et al*.[8] studied REU impact on social sciences; Gonzale-Espada *et al*.[6] studied REU in meteorology; Teller *et al.*[26] studied REU for computer science; Lopatto[11] studied REU for chemical sciences; and Mogk[14] studied REU for geology. After reviewing the literature, it is evident that there is always something in common, as well as something unique, for REU in different majors. No study was found for engineering technology (ET) majors.

For ET majors, only a very small percentage of students went on to get graduate degrees. Most ET graduates pursue careers in engineering and technology related industries. Research skills and soft skills such as teamwork and communication are very important for ET graduates.

As Hunter pointed out[8], the design of student research projects is critically important to success. This is particularly the case for ET programs. Typically, ET students have strong hands-on capability, but they are not motivated to conduct theoretical analysis. For ET students in a two year program, most of them will be hired as technicians. As a result, research capability is not as critical and is usually not required as part of their job functions. Texas A&M University's ET program is one of the many four-year ET programs that offer BS degrees. Graduates from four-year ET programs typically fill engineer positions instead of technician positions. These positions require higher level analytical skills than technician positions. A recent survey conducted by Electronics Engineering Technology (EET) program at Texas A&M University reveals that employers were very pleased with EET graduates from Texas A&M University for their strong hands-on capabilities. Many commented that most EET graduates from Texas A&M University were able to make a quicker transition from academia to industry than a graduate from another typical engineering department. But they also indicated that a certain level of analytical skills is required for engineering positions, and the EET program at Texas A&M University must change its curriculum to improve the current status. Some students could not illustrate the basic understanding of the fundamentals of their major during the interview process and missed the opportunity of being hired. In addition to the traditional curriculum improvement, REU provides a different approach to improve students' analytical skills. Active involvement in a research project for students would motive them to improve their analytical skills. Good practice can be found in the literature, but special consideration must be given for ET students. A simple increase of time spent in learning theories could backfire: ET students may become uninterested in learning theories.

From the faculty side, many faculty members in ET programs do not conduct much research work. Their main job function is to teach undergraduate students and provide them with hands-on experience. As a result, undergraduate research for ET programs is not discussed as much in literature as for other engineering majors. However, recently, there is a trend in ET programs to increase research activities conducted by ET faculty, particularly in applied research. The ET programs at Texas A&M University have been aggressively promoting funded research by faculty for the past ten years. Newly hired faculty members are all required to have a PhD degree in engineering. Publication and external funding are also important factors when tenure and promotion are considered. Since the ET programs at Texas A&M University only offer BS degrees, many faculty members hire graduate students from other departments within the college of engineering to help them conduct research work. An increasing number of faculty members are experimenting with research by undergraduates. There are unique issues related to REU for ET students.

In addition to the benefits for both students and faculty members, REU can also be used to improve curriculum. EET faculty members always try to use research results in lectures and labs as real-world examples[29-31]. Research projects that involve undergraduate ET students can be used to showcase the application of theories to solve practical engineering problems. These examples make it easier to connect the theories to the real world and better motivate students to learn. This benefit from REU projects is not thoroughly studied in literature. Nonetheless, it is a very important benefit for ET programs since undergraduate education is the main objective of the ET program, even with increasing research activities in many ET programs.

The examples presented in literature worked effectively for certain majors and/or certain classes. But these need to be tailored to ET programs in order to obtain the maximum benefit out of REU. Special consideration in the selection of the project and the student are necessary. Effective methods to bring the benefit of REU to other students who were not involved in the research project should also be investigated.

2. Research Projects: DC motor controller and pump jack control

The selection of projects for REU is very important. First of all, major parts of the projects must be related to the educational background of the students involved in the projects. Secondly, the scopes of the projects must be appropriate. If the scope is too small, the benefit will be limited. If the scope is too large, it will take too long to see the benefits. Multidisciplinary projects work better because these projects will broaden the students' views of learning in general[2]. Modeling and simulation are helpful in learning STEM knowledge[13]; therefore, involving some modeling and simulation work in the project can make it more interesting to the students. The students need to have some level of technical background to conduct research. Even though senior students have the most knowledge and skills required for conducting research, they are usually too busy with their course work and capstone design project. Based on these considerations, a sophomore student and a junior student were selected for the projects. The goals of the projects are four-folds:

1. Providing students with research opportunities to enhance their educational experience;
2. Learning to use software, to use test equipment, and to conduct basic testing in the laboratory environment;
3. Completing part of a faculty member's research project;
4. Using the results from the projects for curriculum development to bring the benefit to other students.

With these goals in mind, the following two projects were selected: 1. DC motor speed control; 2. Pump jack and AC motor control system design.

The principles of DC/AC motors were taught in a course at the sophomore level, and both students had successfully completed the course. The pump jack and AC motor control system was initially developed by a group of ET students as a capstone design project under the guidance of their faculty advisor[10]. It was determined that this project had potential to be further improved and receive external funding for research in this area. The DC motor control project is part of the research effort of the sponsoring faculty member[28]. DC motors are also being used in several courses within the Electronics Engineering Technology (EET) program at Texas A&M University. It would be desirable to use the components in the projects in classrooms to provide real-world examples. Both projects are interdisciplinary in nature since they involve electronics, mechanical design, software programming, and control algorithm development.

2.1. DC permanent magnetic motor control project

DC permanent magnetic motors are widely used in industry for their low cost, ease to control, and reliable performance[22]. Two areas of motor application are of particular interest to EET program, from both research and educational perspectives: automotive application and application in power industry. A commercial motor controller made by Kelly Controls, LLC was purchased to evaluate motor and controller performance in electric vehicles. The goal of this project was to develop a control algorithm with better performance than the commercial product. The undergraduate students were tasked to set up a test stand using the Kelly controller, a power supply, and a DC motor. They were also tasked to evaluate the performance of the controller under various test conditions. A LabVIEW Virtual Instrumentation (VI)[16] would be created to measure motor speed and control motor speed using Pulse Width Modulation (PWM). This allows further development of new control algorithms by the faculty member sponsoring the REU project and a graduate student. Based on successful use of DC motors as an educational component by Schubert *et al*.[24], it was also intended that the related research tasks would be used to create educational modules to be used in the courses in the ET program.

The students studied the user manual of the Kelly controller and set up the test stand. Information on the voltage range for the power supply was found in the user manual: It must be between 24 V and 72 V. There is only a 15V power supply with adjustable voltage output available in the laboratory. Hence, a 12 V lead acid car battery was connected in a series to provide the right voltage output for the Kelly motor controller.

After successfully setting up the motor control test stand, the students used an oscilloscope and a digital multimeter to measure voltages and currents throughout the system to ensure safe operation of the system. They also measured the output of the Kelly controller in order to understand how the speed is controlled. The conclusion was that Pulse Width Modulation was used to control the speed. The duty cycle was increased when the throttle position was increased. The frequency of PWM was found to be constant and the duty cycles were measured for different speed values. The response of the controller to an increased load torque was also studied. This information provided a baseline control performance for the DC motor system.

A LabVIEW VI was created for controlling the motor speed. The motor speed was calculated using the digital signal from the encoder attached to the motor. A front panel was designed to allow the user to manually increase the PWM duty cycle.

Through this project, the students reinforced the knowledge they learned in classroom and became more familiar with various equipment. Their work laid a very important foundation for further control algorithm design by the faculty member, a graduate student, and the undergraduate students. The faculty member observed the students and was inspired to create a course project involving DC motor characterization. All four goals of the project were successfully achieved.

2.2. Pump jack closed loop control system design

After the first project, the students were more familiar with laboratory equipment. They started a second project: designing a closed loop control for a pump jack system. The pump jack control system consists of the following components: the mechanical pump jack, an inclinometer or level sensor attached to the beam, a load sensor, and a controller. The system was originally developed by a capstone design team with a microprocessor based open loop controller[10].

The pump jack motor can be controlled by the Toshiba G3 controller either manually or by using a GUI. When the motor rotates, the inclinometer attached at the end of the lever senses a change in the angle of the lever and outputs a voltage proportional to the angle. From testing the device, the undergraduate students concluded that the angle of the sensor is directly linearly proportional to the output voltage of the sensor. Similarly, the load sensor that is suspended by a string from the tip of the lever measures the load and outputs a voltage. The relationship between the weight of the load and the output voltage from the load sensor is non-linear (parabolic). This data from the inclinometer and load sensor can later be used to manipulate the motor speed.

The undergraduate student researchers were tasked to convert the open loop control system to a closed loop control system, where the pump speed is adjusted based on the level sensor and load sensor signals. To make it easier, the control design was done using LabVIEW.

The students first tried to characterize the level sensor and load sensor so they would know how to interpret the voltage signals in terms of their physical meaning, i.e., the angle and the load. During that process, they noticed there was a significant amount of noise in the load sensor. After some discussion with the faculty member, they decided to compare both analog and digital filters. They also learned to use the oscilloscope's Fast Fourier Transform measurement to find the spectrum of the signals, as illustrated in Fig. 1. It can be seen that the high frequency noise in the signal has very small magnitude. Since the DAQ 6251 data acquisition card has a sampling frequency of 80 MHz, according to Shannon's Sampling Theorem, one should not expect any problem with aliasing. Therefore, it was concluded that a digital low pass filter should be used to filter the signal.

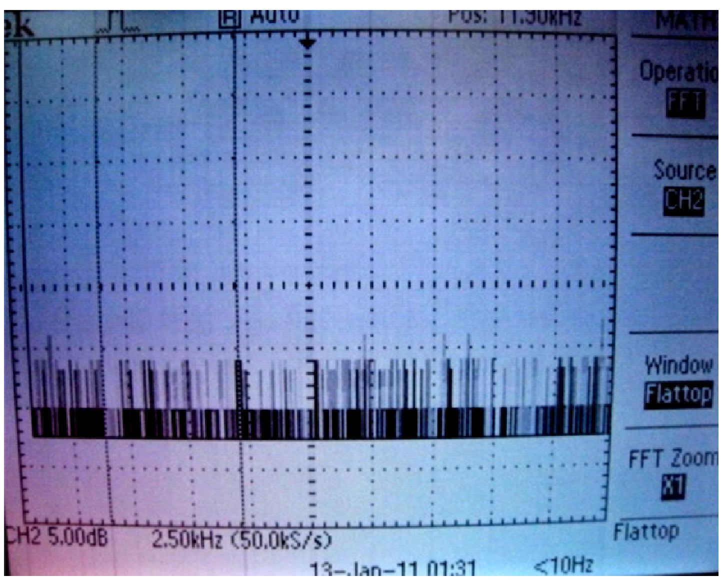
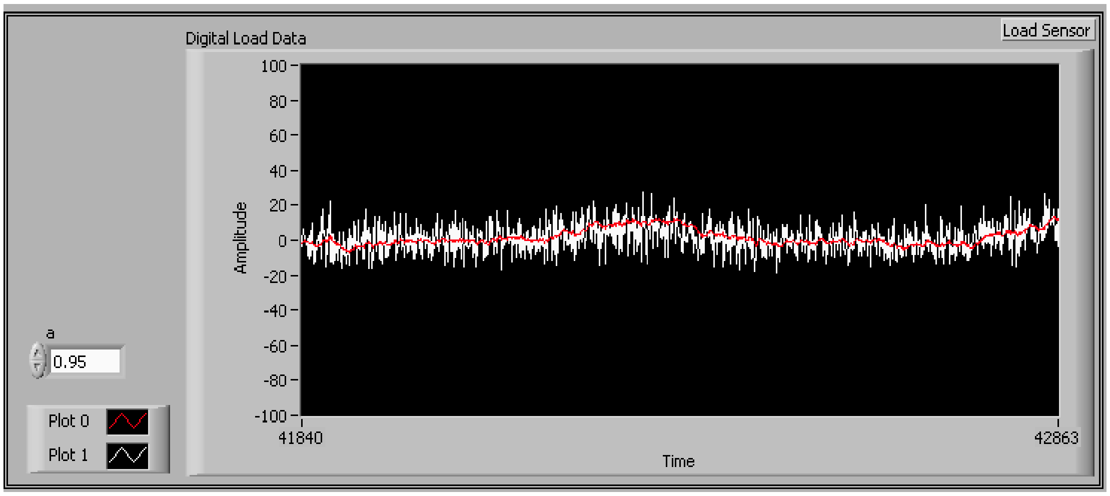
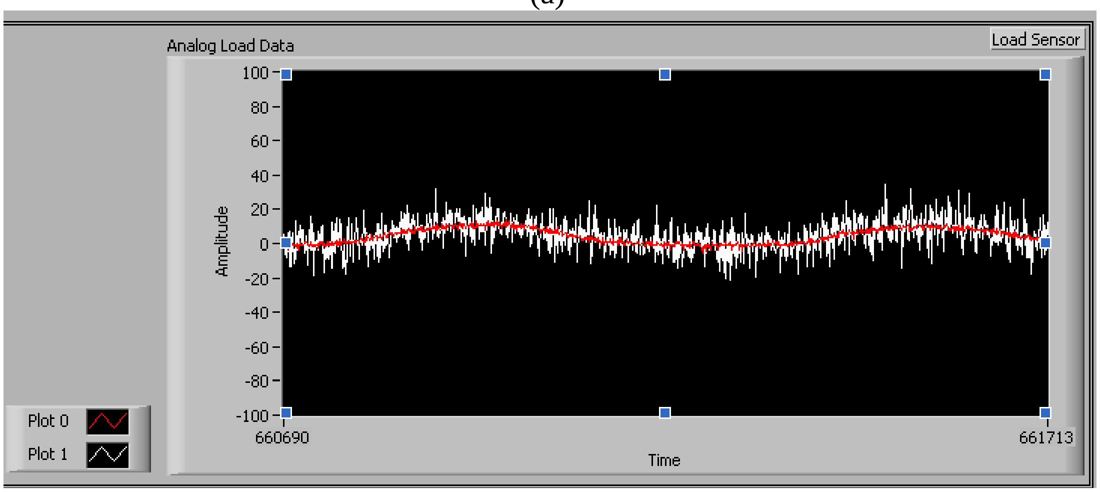


Fig. 1. Spectrum analysis of the load sensor signal

For the benefits of learning, both a digital filter and an analog filter were used to filter out noise with lower to mid-range frequencies so that the digital and analog filtering effects could be directly compared. The raw signal, the filtered signal with a digital filter with the similar cut-off frequencies, and the filtered signal with an analog filter of the same cut-off frequency are illustrated in Fig. 2.



(a)



(b)

Fig. 2. Raw vs. filtered signals (digital (a) and analog (b) filters)

For the actuation part, the main component was the AC motor. The manual for the motor controller was carefully studied. The student researchers had to contact the company that made the motor and controller to gather information they needed. Through this process, they identified an opportunity for immediate improvement: the AC motor controller can take an analog voltage instead of just four discrete voltage levels for motor speed control. The latter was assumed by the capstone design team that developed the pump jack control system. This discovery allowed the student researchers to come up with a classical closed loop control system: with the level and load sensor as the feedback, the AC motor speed would be adjusted according to the feedback signal. This motor speed adjustment can be done instantaneously, instead of the average speed over several pump cycles. The front panel of the LabVIEW VI is shown in Fig. 3.

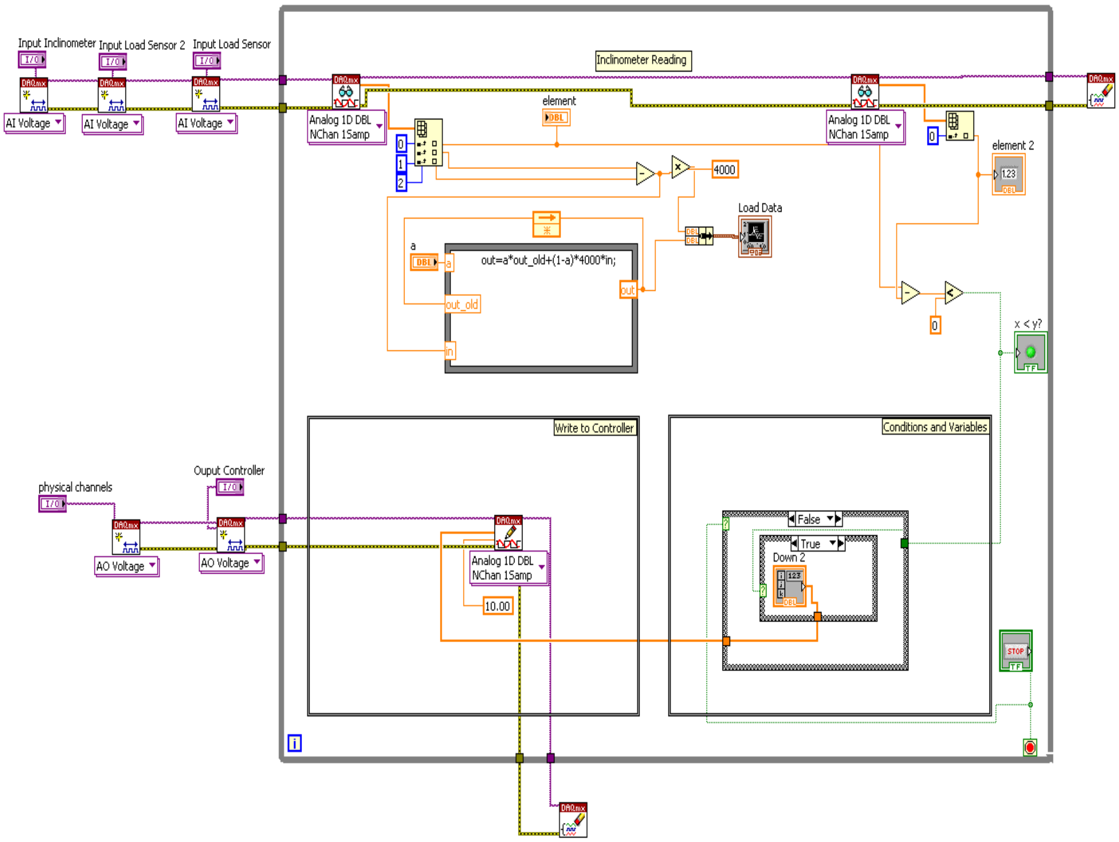


Fig. 3. LabVIEW front panel for pump jack control system

Through this project, the students learned the Shannon's Sampling Theorem, use of an oscilloscope for FFT calculation, analog filter and digital filter design, LabVIEW, and control algorithm design. Their work laid the foundation for further control algorithm design by the faculty member. FFT analysis, digital filter, analog filter, and their comparison were later used in curriculum improvement for two courses. All four goals of the project were successfully achieved.

3. Integration of research, and education

Since undergraduate education is the focus of most ET programs, it is important to explore the potential benefits of REU projects. If the benefit is limited to those participating in the research projects, then the number of students benefitting from the projects is very limited. To increase the impact, the research activities related to several courses were used to develop new educational materials. The student researchers played the roles of a "test bed" and provided critical "Voice of Customers".

The DC motor control project inspired the development of a demonstration system for motor and generator system and a DC motor project for an Energy Systems and Circuit Analysis course.

The course project asks students to characterize a DC permanent magnetic motor with a given set of laboratory equipment including a digital multimeter, an oscilloscope, a signal generator, a DC power supply, and a LabVIEW VI to control PWM duty cycle and to measure motor speed.

A motor driver circuit, speed measurement, and back emf with/without filtering were implemented on a printed circuit board. The schematic was designed in Multisim[17], as illustrated in Fig. 4.

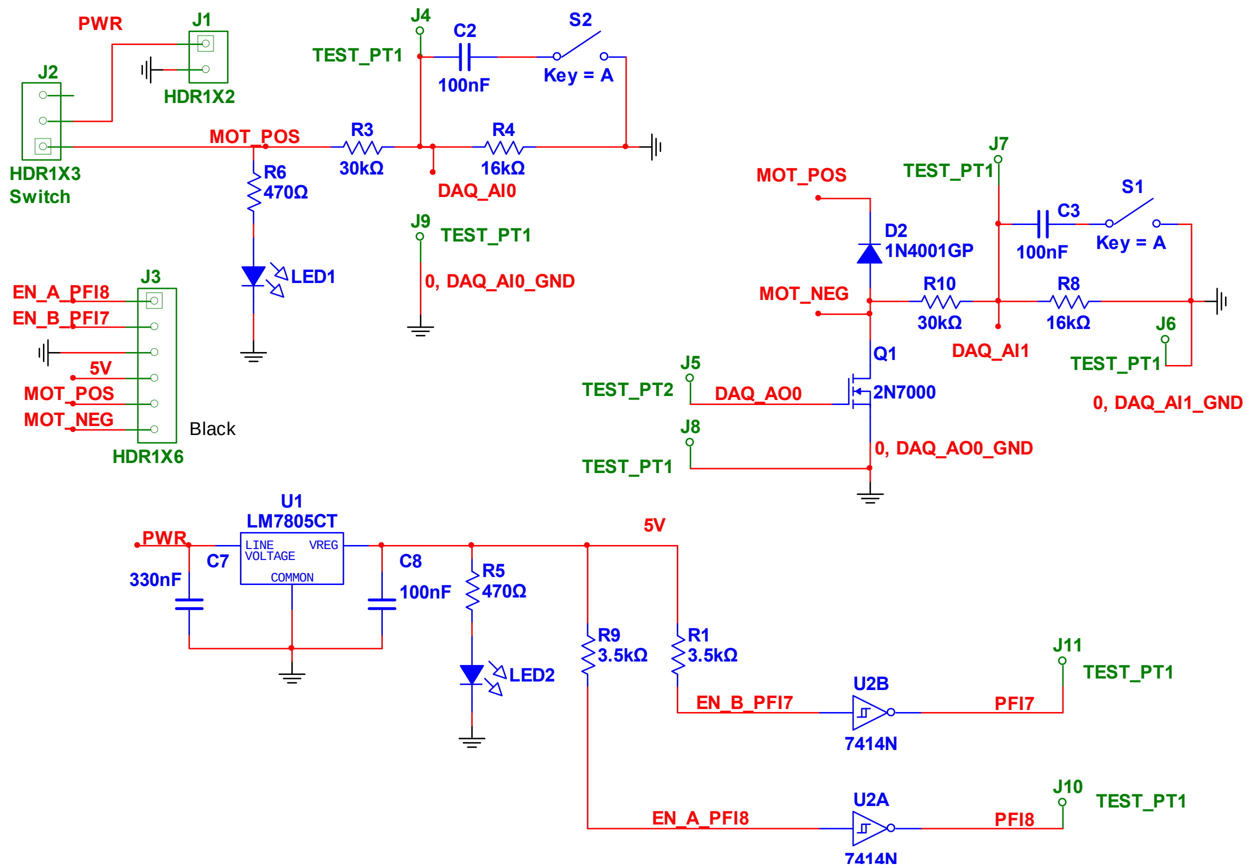


Fig. 4. Multisim schematics capturing

Student researchers designed the board layout, identified the parts with appropriate footprints from the electronics distributor Mouser, and ordered the PCB from Advanced Circuits. They built the PCB board, as illustrated in Fig. 5. This task provided them with training and practice in Multisim/Ultiboard, the entire process of designing a circuit and board layout, finding the right parts, ordering the parts, populating the PCB board, and testing the final product. These skills are usually acquired in various courses in the ET curriculum at Texas A&M University. Putting these skills together to complete a system design is the goal of the capstone design projects, which is a two-semester experience for seniors. The REU projects provided an early preview of the capstone design process. As a result, when they move to capstone design, they will be better prepared. Since they are already familiar with most parts of the design process, they will have more time for technical challenges during their capstone design projects.

Fig. 5. Board layout and a finished PCB

The student researchers not only gained theoretical knowledge, hands-on experience, and software skills, but they also contributed to a product that benefits students in an Energy Systems and Circuit Analysis course. Based on his own experience, one of the student researchers created a detailed step-by-step instruction[9] for building this PCB. The instruction was used in a course project and received overwhelmingly positive feedback from students.

The FFT analysis using an oscilloscope, application of Shannon's Sampling Theorem, design of analog, and digital filters based on the second project are currently being incorporated into the curriculum of a Digital Instrumentation and Control course.

4. Conclusion and Discussion

This paper discusses the experience of undergraduate research, from the selection of projects and students and the execution of the project to curriculum development as a direct result of the research projects. The goal is to present a detailed REU practice within an ET program so that other ET programs can find useful information about the specifics of the implementation of REU projects to get its full benefit.

4.1. The project selection

The selection of the project is critical to the success of REU. The scope and technical content must be appropriate for the undergraduate students. The authors found modeling and simulation an effective tool to relate STEM research to education. Modeling requires knowledge from mathematics and physics. The equations and the operations of a physical system can be related via simulation software, and simulation tools can make the theoretical analysis more interesting to the students. The effective use of modeling and simulation can greatly increase students' interest in STEM. Using modeling and simulation in REU is a natural continuation of the sponsoring faculty member's own research interests[28].

Throughout the project, the students realized the importance of multidisciplinary knowledge for real-world problems. The multidisciplinary training can provide motivation for students to explore outside of their comfort zone, and they will be better prepared for real-world tasks. Apparently, the selection of the project for REU is highly dependent on the major, the interests of the faculty members, the potential for incorporating the research activities into the existing curriculum, and many other factors. This paper only discusses specific consideration for the two research projects.

4.2. The results and the benefits

After these REU projects, one of the student researchers became more interested in pursuing a career in research related to STEM. He decided to change his major to pursue a BS degree from Electrical Engineering and possibly obtain a graduate degree. He has applied for an undergraduate research scholarship from the Louis Stokes Alliance for Minority Participation. It is clear that through the projects the student researchers improved their communication skills, including presentation skills and technical writing skills. They also made significant improvements in working effectively with faculty and graduate students and with peers on teams. The two research projects are being carried out as planned. Initial study has been completed, and the hardware has been completely set up for further research.

If carefully designed, REU can greatly enhance the educational experience for students. It can also provide help for faculty members conducting research. Besides these apparent benefits to the student researchers and the faculty members, which is extensively discussed in literature, this paper illustrates that many components of the research projects can be used for curriculum improvement and outreach activities. The input from students was critical to the success of any curriculum improvement effort. Based on their own experiences, the undergraduate student researchers can make great contributions in bringing the benefits to fellow students and outreach activities such as high school students recruiting. They can come up with ideas of using the research-related materials in classrooms, laboratories, and course projects. In a sense, they can provide the “Voice of Customers” for the educational process. For student researchers who are taking relevant courses, they know which part of the research is interesting and relevant to the course. Their participation in the development of educational modules is an efficient way of bringing the REU benefits to other students and can significantly shorten the curriculum development process. These benefits are in general applicable to other majors and programs but are attractive to ET programs in particular since undergraduate education is their focus.

4.3. The challenges

The two research projects are still on-going. Most likely these projects will last several years. Many undergraduate students are only available for research work for a limited period of time. Sophomore or junior level students are good candidates for participating in REU projects; however, most of them will also be looking for summer internships in industry. Faculty members sponsoring the REU project face the following challenge: How to use the trained students to bring the new hires up to speed?

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