Research Experience for Undergraduate Students and its Impact on STEM Education

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Abstract

Research experience has been proven to be effective in enhancing the overall educational experience for undergraduate students. In this article, two engineering 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 conduct research work and develop curricular materials. 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.

Keywords: undergraduate research, curriculum development, simulation, data acquisition, control and instrumentation

I. Introduction

The importance of undergraduate research has been studied by many educators over the past two decades (Bauer & Bennett, 2003; Cox & Andriot, 2009; Gray et al., 1996; Lopatto, 2003; Lopatto, 2007; Mogk, 1993; Nagda et al., 1998; NSF, 2003; Russell et al., 2007; Seymour et al., 2004; Teller & Gates, 2001; Tomovic, 1994; Tuss & Smalley, 1994; Zydney et al., 2002). Because of the importance of undergraduate research, the National Science Foundation has a special program, Research Experiences for Undergraduates (REU), to support efforts in this area (NSF, 1990; Russell et al., 2005; Singer et al., 2003). 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 (Boylan, 2006; Fitzsimmons, 1990; Gonzalez-Espada & Zaras, 2006; Hathaway et al., 2002; Hunter et al., 2006; Kremer & Bringle, 1990; Lopatto, 2004; Zydney et al., 2002). Other benefits include student retention , research skills learned by students, and learning other skills such as teamwork, communication, and presentation (Nagda, 1998; Hunter *et al.*, 2006; Hackett et al., 1992). Hackett et al. (1992) studied several impacts of undergraduate research and compared it with cooperative educational experiences for engineering students. Boylan (2006) 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 (1998) studied REU for chemical sciences; Zydney et al. (2002) and Hackett et al. (1992) studied REU impact in engineering; Hunter et al. (2006) studied REU impact on social sciences; Gonzale-Espada et al. (2006) studied REU in meteorology; Teller et al. (2001) studied REU for computer science; Lopatto (2004) studied REU for chemical sciences; and Mogk (1993) 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 et al. (2006) pointed out, 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 always 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 System Engineering Technology (ESET) program at Texas A&M University reveals that employers were very pleased with ESET graduates from Texas A&M University for their strong hands-on capabilities. Many commented that most ESET graduates from Texas A&M were able to make a quicker transition from academia to industry than a graduate from a typical engineering department. However, they also indicated that a certain level of analytical skills is required for engineering positions, and the ESET program at A&M 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 by companies that they would like to work for. 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 motivate 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.

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 compared to other engineering majors. However, recently there has been 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. However, 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. ESET faculty members always try to use research results in lectures and labs as real-world examples (Zhan et al., 2010; Zhan & Porter, 2010; Zhan et al., 2009). 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 the 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 achieve the maximum benefit. Special consideration in the selection of the projects and the students are necessary. Effective methods to bring the benefit of REU to other students who were not involved in the research project are also worth investigating.

The rest of the paper is organized as follows: Section 2 presents two research projects with the involvement of undergraduate students, Section 3 discusses the use of the research for educational and outreach purposes, Section 4 discusses the impact of the REU projects, and discussion and conclusions are given in Section 5.

II. Research Projects: dc Motor Controller and Pump Jack Control

The selection of projects for REU is critically 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 (Bischof et al., 2007). Modeling and simulation are helpful in learning STEM knowledge (Milano et al., 2008; Porter et al., 2004). 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 projects. Based on these considerations, a sophomore student and a junior student were selected for the projects. The goals of the projects are four-fold:

1. Providing students with research opportunities to enhance their educa tional experience
2. Learning to use software, to use test equipment, and to conduct basic testing in the laboratory environment
3. Participating in 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 and 2) Pump jack and AC motor control system design. Two students were hired as student workers to work on these projects.

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 (Legendary, 2009). 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 (Zhan, 2009; Zhang & Zhan, 2008). DC motors are also being used in several courses within the ESET 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.

a. DC permanent magnetic motor control project

DC permanent magnetic motors are widely used in industry for their low cost, ease of control and reliable performance (Santan et al., 2002). Two of the motor application areas 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) (NI, 2003) would be created to measure motor speed and control motor speed using Pulse Width Modulation (PWM). This allowed further development of new control algorithms by the faculty member sponsoring the REU project and a graduate student. Based on the successful use of DC motors as an educational component by Schubert et al. (2009), 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, as shown in Fig. 1.

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 was only a 15V power supply with adjustable voltage output available in the laboratory. Hence, a 12 V lead acid car battery was purchased and 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 was 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

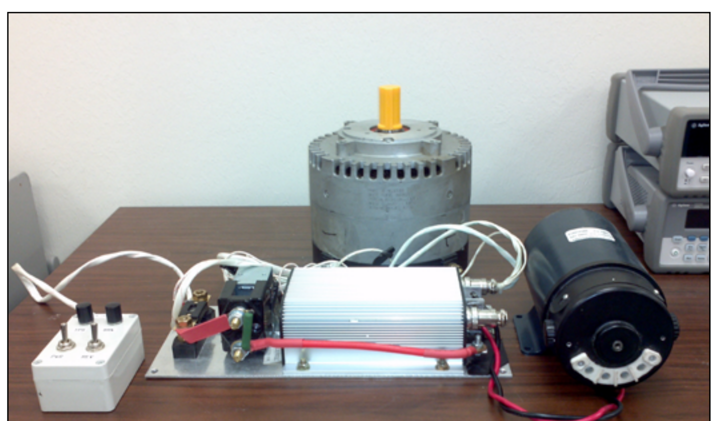


Figure 1.

Figure 2.

increased load torque was also studied. This information provided a baseline control performance for the DC motor system.

A LabVIEW VI was then 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 class 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.

b. 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 (Legendary, 2009).

A figure illustrating the pump jack motor with its components is shown in Figure 2. 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 was directly linearly proportional to the output voltage of the sensor. Similarly, the load sensor that was suspended by a string from the tip of the lever measured the load with a voltage output. The relationship between the weight of the load and the output voltage from the load sensor was found to be non-linear (parabolic). The data from the inclinometer and load sensor were later 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 would be adjusted based on the level sensor and load sensor signals. To make it easier, the control design would be 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 the effects of analog and digital filters. They also learned to use the oscilloscope's Fast Fourier Transform measurement to find the spectrum of the signals. It was found that the high frequency noise in the signal had 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.

For the benefits of learning, both a digital filter and an analog filter were used to filter out noise so that the digital and analog filtering effects could be directly compared. The raw signal, the filtered signal with a digital filter with, and the filtered signal with an analog filter are illustrated in Fig. 3.

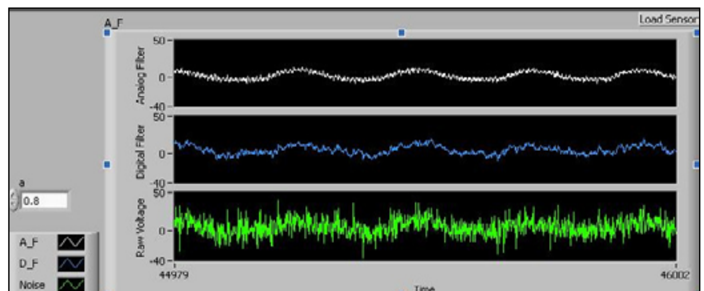
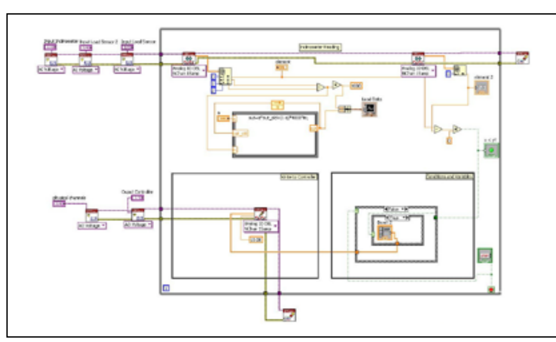


Figure 3.

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 continuously adjusted according to the feedback signal. This motor speed adjustment can be done instantaneously, instead of the average speed over several pump cycles. The block diagram of the LabVIEW VI is shown in Fig. 4.



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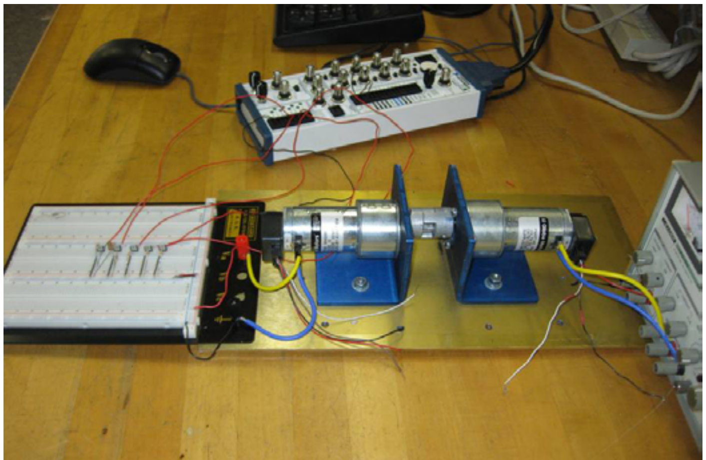


Figure 5.

Through this project, the students learned the Shannon's Sampling Theorem, the 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 with the help of two additional undergraduate researchers. All four goals of the project were successfully achieved.

III. Integration of Research, Education, and Outreach

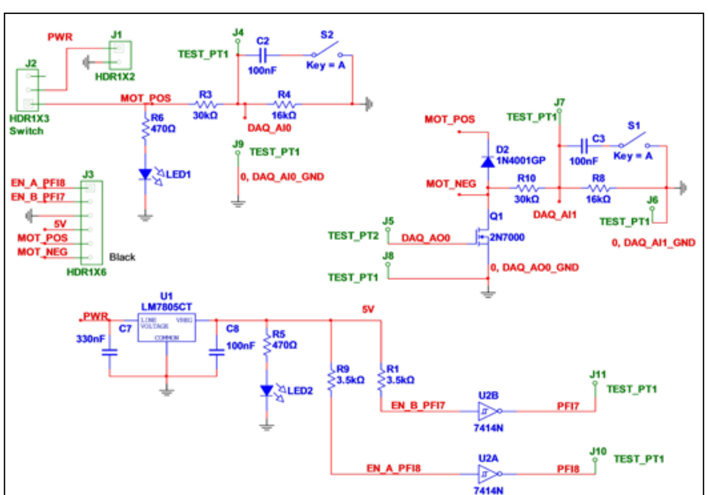
Since undergraduate education is the focus of most ET programs, it is important to explore the potential benefits of REU projects. If the benefit is limited to those participating in the research projects, then the number of students benefitting from the projects is very limited; in this case it would be four. 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". Some of the materials were simplified for high school recruiting efforts, thus further increasing the impact of the REU projects.

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.

n Fig. 5, two DC motors were mechanically coupled. One of the motors is controlled by a LabVIEW VI through a DAQ card. This motor drives another motor that works as a generator with an electrical load attached to it.

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 and without filtering were implemented on a printed circuit board. The schematic was designed in Multisim (NI, 2007), as illustrated in Fig. 6. 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. 7. This task provided



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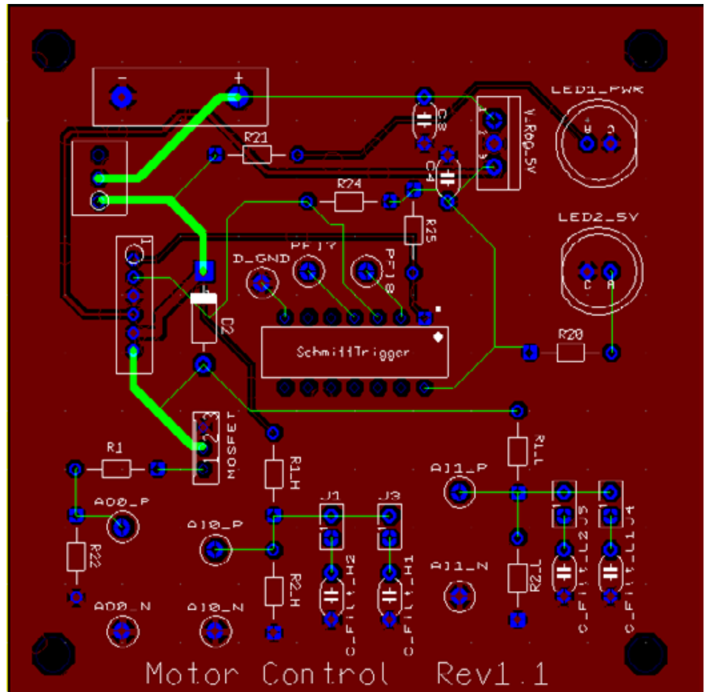


Figure 7a.

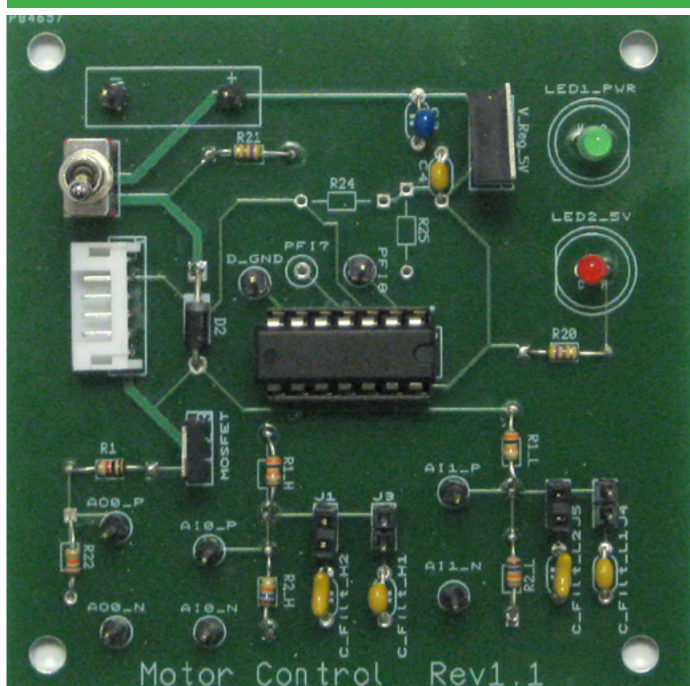


Figure 7b.

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 project, 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.

The student researchers not only gained theoretical knowledge, hands-on experience and software skills, but also they 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 for building this PCB (Lam, 2010). The instruction was used in a course project and received overwhelmingly positive feedback from students.

The same PCB board is also being used by an instrumentation course where a closed-loop motor speed control via the Modbus digital communication bus was developed as a course project. In this project, the measurement of the back emf voltage and its filtered value were not needed. Students simply populated the part of the PCB they needed, as illustrated in 8. By using the same board design for two different courses, this effort directly contributed to the curriculum integration effort within the ESET program.

In addition to the curriculum development result, the motor control system was also implemented on a NI development board. Together with a USB 6008 DAQ card, as illustrated in Fig. 9, a low cost portable motor speed control demonstration system was developed for recruiting high school students.

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

IV. Evaluation of The Impacts

For the two projects discussed in this paper, the benefits of research experience for undergraduate students can be seen in several different areas: 1) The impact on the four student researchers; 2) The impact on the students who

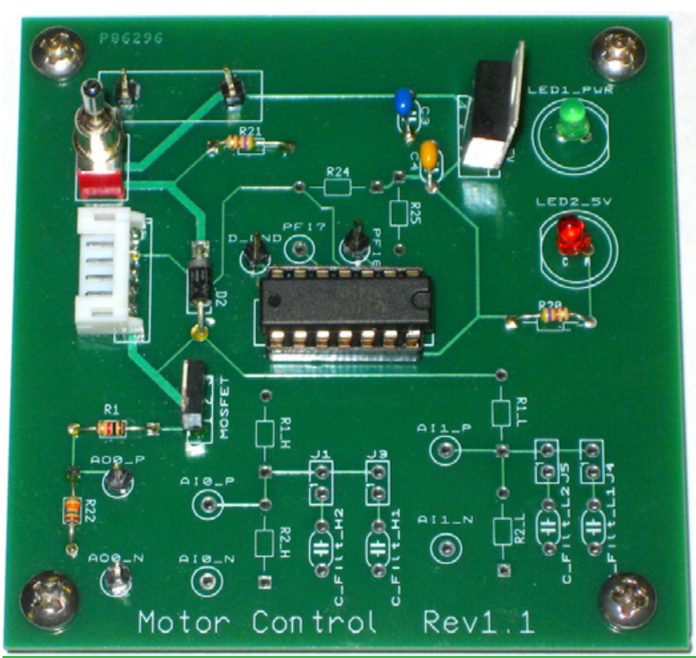


Figure 8.

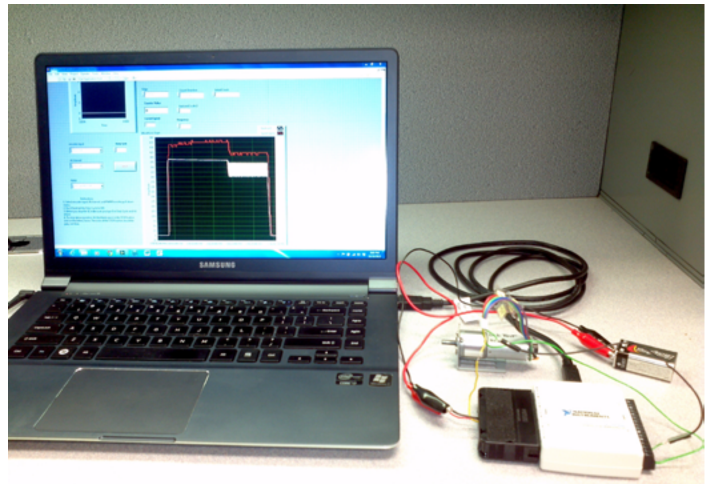


Figure 9.

used the motor control board designed by the four student researchers; and 3) The impact on the high school students during an outreach activity where the portable motor control test stand was used. 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. Another student became more interested in simulation and testing using LabVIEW, the software that he used extensively in both REU projects. He later worked as a summer intern using his LabVIEW skills and is currently working as an instrumentation engineer. The two other students who are currently continuing the research work are doing well in their course work. It is clear that through the projects the student researchers improved their communication skills, as well as presentation skills and technical writing skills. They all became more self-motivated and needed less guidance from the faculty member in finding new research topics to work on. They also made significant improvements in working effectively with faculty and graduate students and with peers on teams.

Student surveys were conducted in two courses where the motor control boards and digital filter design were used in laboratories and course projects. Students were asked to rank from 1 to 5 (1 being strongly disagree and 5 being strongly agree) for the following questions:

1. Were the instructions for building the motor control board clear and helpful?
2. Was the motor control board easy to use?
3. Did the motor testing laboratories help in understanding the motor and generator principles?
4. Was the digital filter lab helpful in learning digital filter design and the Sampling Theorem?

	Q1	Q2	Q3	Q4
No. of responses	83	83	62	21
Mean	4.8	4.7	4.9	4.5
Standard deviation	0.32	0.41	0.31	0.44

Table 1. Student survey result

Based on the mean and standard deviation analysis for the four questions, it can be seen that the students were overwhelmingly positive about the curricular materials developed by the student researchers.

Over the past a couple of years, enrollment to the ESET program at Texas

A&M University increased significantly; however, it can be a result from many different efforts including the use of the portable motor test stand. Due to the lack of specific data, the impact on the high school students is not analyzed in this paper.

V. 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.

The selection of the project is critical to the success of REU. The scope and technical content must be appropriate for the undergraduate students. It is clear that modeling and simulation is 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 (Zhan, 2009; Zhan et al., 2010). 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. The contents of the two research projects discussed in this paper involves many analytical skills such as math, modeling and simulation, signal processing, and control design. The four student researchers improved not only their analytical skills, but the curriculum they created also benefitted more than 80 students in the ESET program at Texas A&M University.

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.

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. A motor control PCB board has been successfully designed, tested, and implemented in two ESET courses. Several other components of the research projects are being packaged for two courses in ESET. A low-cost portable motor control system has been developed for outreach activities.

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 are 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 is 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 in particular to ET programs since undergraduate education is their focus.

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?

The transferring of one of the student researchers to Electrical Engineering may appear as a loss to the ESET program, but as far as STEM is concerned it is not a loss. On the other hand, because of these kinds of research opportunities the ESET program offers, there are more transfer students from other engineering departments to the ESET program.

While the author strongly believes in the benefit of REU based on the past experiences, it is difficult to draw a general conclusion with the limited number of students involved in the REU effort discussed in this paper. Further investigation in REU to come up with some rigorous evaluation methods for quantitatively analyzing the benefit discussed in this paper is another challenge for educators (Frechtling, 2002). Future works include collecting feedback from high school students during outreach activities and analyzing the data.

References

Bauer, K. W., & Bennett, J. S. (2003). Alumni perceptions to assess undergraduate research experience. *Journal of Higher Education, 74*, 210-230.

Bischof, G., Bratschitsch, E., Casey, A., & Rubeša, D. (2007). Facilitating engineering mathematics education by multidisciplinary projects. *Proceedings of ASEE Annual Conference.*

Boylan, M. (2010). The impact of undergraduate research experiences on student intellectual growth, affective development, and interest in doing graduate work in STEM: A review of the empirical literature. *Doctoral Education and the Faculty of the Future,* Ithaca, NY: Cornell University. Retrieved November 15, 2010, from http://www.ilr.cornell.edu/cheri/conferences/doctoralEducation.html.

Cox M. F., & Andriot, A. (2009). Mentor and undergraduate student comparisons of students' research skills. *Journal of STEM Education, 10*(1-2), 31-39.

Fitzsimmons, S. J., Carlson, K., Kerpelman, L.C., & Stoner, D. (1990). A preliminary evaluation of the research experiences for undergraduates (REU) program of the National Science Foundation. Washington, D.C.: National Science Foundation.

Frechtling, J., Frierson, H., Hood, S., Hughes, G., & Katzenmeyer, C. (2002). The 2002 user friendly handbook for project evaluation. *NSF 02-057.*

Gonzalez-Espada W., & Zaras, D. (2006). Evaluation of the impact of the National Weather Center REU program compared with other undergraduate research experiences. *15th Symposium on Education, American Meteorological Society,* Atlanta.

Gray, P.J., Diamond, R.M., & Adam, B. E. (1996). A national study of the relative importance of research and undergraduate teaching at colleges and universities. Center for Instructional development, Syracuse University.

Hackett, E., Croissant, J., & Schneider, B. (1992). Industry, academe, and the values of undergraduate engineers. *Research in Higher Education, 33*(3), 275-295.

Hathaway, R.S., Nagda, B.A., & Gregerman, S.R. (2002). The relationship of undergraduate research participation to graduate and professional education pursuit: an empirical study. *Journal of College Student Development, 43,* 614 -631.

Hunter, A., Laursen, S., & Seymour, E. (2006). Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. *Working Paper, Center to Advance Research and Teaching in the Social Sciences, Ethnography & Evaluation Research,* University of Colorado.

Kremer, J.F., & Bringle, R.G. (1990). The effects of an intensive research experience on the careers of talented undergraduates.*Journal of Research & Development in Education*, *24,* 1 -5.

Lam, A. (2010). Motor control board setup. Texas A&M University.

Legendary final report, (2009). Texas A&M University Capstone Design Project Report.

Lopatto, D. (2003). The essential features of undergraduate research, *Council for Undergraduate Research, Q.24,* 139-142.

Lopatto, D. (2004). Survey of undergraduate research experiences (SURE): First findings. *Cell Biology Education, 3(*4), 270-277.

Lopatto, D. (2007). Undergraduate research experiences support science career decisions and active learning. *Cell Biology Education*, *6*, 297-306.

Milano, F., Vanfretti, L., & Morataya, J.C. (2008). An open source power system virtual laboratory: The PSAT case and experience. *IEEE TranSactions on Education, 5*1(1), 17-23.

Mogk, D.W. (1993). Undergraduate research experiences as preparation for graduate study in geology. *Journal of Geological Education, 41*, 126-128.

Nagda, B. A., Gregerman, S. R., Jonides, J., von Hippel, W., & Lerner, J. S. (1998). Undergraduate student-faculty research partnerships affect student retention. *Review of Higher Education*, *22*, 55-72.

National Instruments (2003). *LabVIEW User Manual.*

National Instruments (2007). *NI Circuit Design Suite.*

National Science Foundation (1990). NSF's research experiences for undergraduates (REU) programs: An assessment of the first three years. *NSF 90-58.*

National Science Foundation (2003). Undergraduate research centers program, *NSF 03-595.*

Porter, J. R., Morgan J. A., & Ochoa, J. A. (2004). Project LIVE: A classroom for students on the go. *Proceedings of ASEE Annual Conference.*

Russell, S. H., Hancock, M. P., & McCullough, J. (2007). Benefits of undergraduate research experiences. *Science, 316*, 548-549.

Russell, S., et al. (2005). Evaluation of NSF support for undergraduate research opportunities; 2003 NSF-Program Participant Survey: Final Report. *SRI International.*

Santan J., Naredo J. L., Sandoval, F., Grout, I., & Argueta, O. J. (2002). Simulation and construction of a speed control for a DC series motor. *Mechatronics, 12,* 1145-1156.

Schowen, K. B. (1998). Research as a critical component of the undergraduate educational experience. *Assessing the Value of Research in the Chemical Sciences.* NRC, National Academy Press, 73-81.

Schubert, T. F., Jacobitz, F. G., & Kim, E. M. (2009). Exploring the basic principles of electric motors and generators with a low-cost sophomore-level experiment. *IEEE Transactions in Education, 52*(1), 57-65.

Seymour, E., Hunter, A.-B., Laursen, S., & DeAntoni, T. (2004). Establishing the benefits of research experiences for undergraduates: first findings from a three-year study. *Science Education*, *88*, 493 -594.

Singer, J., Mayhew, M., Rom, E., Eisenstein, K., Kuczkowski, R., & Douglas, L. (2003). The research experiences for undergraduates (REU) sites program: Overview and suggestions for faculty members. *Council on Undergraduate Research Quarterly,* 158-161.

Teller, P., and Gates, A. (2001). Using the affinity research group model to involve undergraduate students in computer science research. *Journal of Engineering Education, October*, 549-555.

Tomovic, M. M. (1994). Undergraduate research—prerequisite for successful lifelong learning. *ASEE Annual Conference Proceedings 1,* 1469 -1470.

Tuss, P., & Smalley, L. (1994). Introducing undergraduates to research: Long-term impacts of the D.O.E. student research participation program. *CUR Quarterly, 15,* 65-69.

Zhan, W. (2009). Monte Carlo analysis for the inverse problem for motor PWM control. *IAENG Transactions on Engineering Technologies, 2*, 186-197.

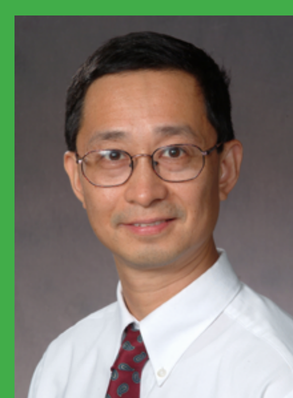
Zhan, W., McDermott, M., Zoghi, B., & Hasan, M. January (2010). Modeling, simulation, and analysis for battery electric vehicles. *Machine Learning and Systems Engineering*, ed. by Ao, S.I., Amouzegar, M. A., and Rieger, B., *Lecture Notes in Electrical Engineering, Springer, 68,* 227-241.

Zhan, W., & Porter, J.R. (2010). Using project-based learning to teach Six Sigma principles. *International Journal of Engineering Education, 26*(3), 655-666.

Zhan, W., Zoghi, B., & Fink, R. (2009). The benefit of early and frequent exposure to product design process. *Journal of Engineering Technology, Spring*, 34-43.

Zhang, W., & Zhan, W. (2008). Sensitivity analysis of motor PWM control. *Proceedings of the International Conference on Modeling, Simulation and Control,* 835-839.

Zydney, A., Bennett, J. S., Shahid, A., & Bauer, K. W. (2002). Impact of undergraduate research experience in engineering. *Journal of Engineering Education, 19,* 151-157.



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