Enriching the Undergraduate Program with Research Projects

While some engineering departments struggle with low enrollment today, the Preston M. Green Electrical and Systems Engineering (ESE) Department at Washington University in St. Louis, Missouri, more than tripled over the last ten years. This was done under the guidance of Dr. Arye Nehorai, who was appointed its chair in 2006. This growth, including 34% female enrollment, is mostly due to students joining our department during or after their freshman year. The growth was fueled by improvements to the undergraduate educational experience including creating an undergraduate research program, improving the instruction quality, revising old courses, creating new courses, modernizing our laboratories, creating study abroad programs, and communicating the new opportunities in the ESE Department to the engineering student body. This article focuses on the undergraduate research program.

Introduction

The undergraduate research program was created in response to student interest and current trends in education and gave us an opportunity to add more exciting design elements to our curriculum. Our students gain valuable experience in research, design, algorithm development, project implementation, and verification. These are skills that students can share during job interviews for both academia and industry. Also, some of our undergraduate researchers have decided to pursue careers in academia as a direct result of their involvement in undergraduate research projects.

Over the years, we have streamlined our approach and developed the program described here that works well for students interested in gaining independent project experience at the undergraduate level. This approach includes both undergraduate participation in faculty research as well as projects with Ph.D. students and our Professor of Practice, Ed Richter, as mentors. Overall, we have had more than 200 students from the ESE Department and from other departments participate in our undergraduate research projects program.

ESE297: Introduction to Undergraduate Research Projects

Freshmen and sophomores who are interested in undergraduate research projects are encouraged to take our Introduction to Undergraduate Research Projects (ESE297) course [1]. This three-credit course provides exposure to signal processing topics and introduces the design process early in the curriculum. By introducing design earlier, the students are not only preparing for undergraduate research projects but also for our Capstone Design course. The students learn valuable teamwork skills by working in groups of two. They are guided through the design process for two signal processing projects. These projects were selected after a few early undergraduate researchers and their mentors worked on these projects for a few semesters.
The first project is acoustical source localization using a four-element microphone array [2]. The students are guided through an algorithm for triangulating a source location using a four-element microphone array. Next, they develop the signal processing implementation using LabVIEW as the programming language and a simulator that we provide them. Once the triangulation works in simulation, they test their implementation on the actual acoustic array. In the next phase of the project, the students implement the triangulation using a central computer and two modified National Instruments Dani Robots, each equipped with Wi-Fi and a microphone pair as shown in Figure 1(a). In their final presentation, we move a chirping speaker around and their mobile robots automatically track it.

The second project in this course is a multidisciplinary electroencephalogram (EEG) signal processing application to create a brain–computer interface (BCI) to control robot motion in one dimension. We use a commercial 14-channel EEG electrode array from Emotiv, portions of the BCI2000 framework, and MATLAB as the programming language. The students are guided through the algorithm development to measure the average signal power in 2-Hz bandwidths for the 14 electrodes and to build a classifier to detect a power change in the “best” channel/frequency pairs.

We start with the clinical data provided with the BCI2000 framework collected during an experiment where the subject was asked to raise his legs or to relax. The clinical data file contains the raw data from the EEG sensors as well as the timing information of the action and rest trials. The BCI2000 framework also provides the MATLAB functions to extract the raw data and timing information from the file. The students then implement the signal processing and classification in MATLAB working on the clinical data. After they validate their implementation against the BCI2000 results for the same data, they collect their own data with the Emotiv headset while being prompted to clench their fists or rest. Using their collected data as the training set, the students design their own classifier using their “best” channel/frequency pairs. When they are satisfied with the receiver operating characteristic (ROC) curve of their system, they design/implement a real-time LabVIEW/MATLAB/Emotiv software development kit (SDK) application that processes the EEG data in real time and moves the mobile robot every time they clench their fists as shown in Figure 1(b) [3].

ESE497: Undergraduate Research Projects

The top students from ESE297 are encouraged to sign up for the course Undergraduate Research Projects (ESE497) [4]. However, ESE297 is not necessarily a prerequisite for ESE497. We also encourage the top third- and fourth-year students from across the engineering school to get involved in our undergraduate research projects. The students are required to work on their projects for at least ten hours per week for two credits, create a blog/webpage of their project, and participate in several poster sessions. The required presentations are a good experience for the students, where feedback is provided from their peers as well as from the faculty. Where applicable, we encourage our students to publish their projects in a peer-reviewed journal.

Students are given a choice of 50 projects [5] listed on our website that cover topics such as signal and image processing, machine learning, optimization, power and energy, controls and operations research. We interview each student to find a good match between his or her interest and the available projects. One of the themes of our projects is multidisciplinary robotic sensing [6], merging signal and image processing, robotics, and biomedical and environmental sensing. We are also flexible when an entrepreneurial-minded student comes to us with a good idea. Sometimes the student’s ideas/projects are part of our design
competition, like our Engineering School Discovery Competition. Additionally, many of our younger faculty post projects directly related to their research interests to attract potential Ph.D. students. When the proposed projects are part of a faculty member’s active research, that faculty member is the mentor and the students work on their projects in the faculty member’s lab.

More commonly, we have more student interest than our faculty can support. For some of these cases, we carefully select Ph.D. students working in a related area to mentor these students. The undergraduates benefit from this because they get more one-on-one opportunities with a top Ph.D. student than they might otherwise get with a busy full-time faculty member. It is mutually beneficial for the Ph.D. student as they get an opportunity to work with our bright undergraduates. In many cases, the projects are multi-semester, and the more senior undergraduate students are also involved in the mentoring. Additionally, we have a Professor of Practice, Ed Richter, who mentors projects and supports other mentors in their efforts.

We have developed many platforms that students can use for their projects and we provide “Getting Started Guides” [7] for these platforms on our undergraduate research webpage. This infrastructure allows the students to focus on the signal processing algorithm development instead of spending the semester figuring out the low-level communication details to some new piece of hardware. Several of the platforms available to our students are listed below:

1) ESE297 students can continue to work with the mobile robots used in ESE297 to develop autonomous navigation algorithms.
2) ESE297 students can continue to work with the EEG headset to develop more advanced classification applications for BCI projects [8].
3) In 2012, we purchased an industrial robotic arm (Figure 2) [9] made by Fanuc, and we developed a communication scheme using the National Instruments Ethernet/IP tool kit that allows the students to position the robotic arm using LabVIEW or MATLAB. Then, we attached a Microsoft XBox 360 Kinect camera to the chassis of the robot and developed a Kinect SDK application that passes images from the camera to a MATLAB program. The students use this platform to calibrate the Kinect camera to the Robotic coordinate system and develop image processing applications to locate objects for the robotic arm to pick up.
4) In 2010, we purchased several National Instruments USRP 2920 and USRP 2921 for wireless communication and array signal processing applications. Students have used this platform for localization and Doppler measurements (video [10] by Prof. Ed Richter and Dr. Martin Hurtado).
5) In 2014, we purchased two inertial movement unit sensors [11] as part of our collaboration with researchers at KTH in Sweden. Students have used this platform to analyze tremors in patients who have Parkinson’s disease.
6) In 2012, we developed a 64-channel microphone array as shown in Figure 3. Students can work with the array to develop audio beamforming applications (beamformed audio file created by Ricky Chen and Xiangyang Mou [12]).

7) Our labs are equipped with data acquisition systems that we use in our...
courses but that are also available for undergraduate research projects that can use the computer as the digital signal processor. Real-time applications with data acquisition can be easily written in both LabVIEW and/or MATLAB.

Undergraduate research examples
Some of the more successful undergraduate research projects to date from the ESE497 research course are as follows:

- Ren Liang Liang, Tsinghua University (supervisors: Arye Nehorai, Martin Hurtado, and Ed Richter), Radio Tomographic Imaging-Based Fall Detection, Summer 2015 [14]
- Daniel Wasserman (supervisor: Zachary Feinstein), Grid Search Algorithm for Set Optimization, Spring 2015 [16]
- David Sehloff and Celso Torres (supervisors: Arye Nehorai and Ed Richter), Predicting the Solar Resource and Power Load, Spring 2015 [17].

ESE Department growth
We created our undergraduate research program in 2006 as part of the effort to attract more students to electrical and/or systems engineering. The result of these efforts has shown a big jump in undergraduate research enrollment in 2009/2010 shown in Figure 4. This is one of the reasons our department has tripled in size since 2008 as shown in the bold red line in Figure 5.

Other factors contributing to the growth of the ESE Department include improving the instruction quality, modernizing our laboratories, adding introductory courses in electrical and systems engineering, and offering study-abroad opportunities. Additionally, we have improved our outreach to attract the undecided students and inform students from other departments about our unique programs. These presentations and web documents highlight our flexible curricula and give examples to show how to add a second major in electrical or systems engineering. One more way we are successful in increasing the enrollment is by interacting with students and getting their feedback. In particular, Dr. Nehorai contacts every student who decides to move to our department to understand his or her motivation for changing majors, and he has personally mentored more than 100 students in his lab over the last ten years. The success of these efforts is shown in Figure 5. Our entering class size is small (shown by the dark blue bar) but the class size has increased from freshman year (dark blue) to senior year (purple) every year since 2010 as students join our department after arriving at Washington University.

Conclusions
Student interest in undergraduate research projects continues to grow. We have tried to meet that demand by developing a “training” course (ESE297) and by offering many diverse topics and platforms for them to use.
for their own projects. In general, the students find ESE297 and undergraduate research projects (ESE497) extremely rewarding, albeit challenging. The students really appreciate the opportunity to apply the theory they have been studying. The one-on-one mentoring with tenured, tenure-track faculty, Professor of Practice, or Ph.D. students is a valuable opportunity to our students. The feedback they get from their peers and the faculty about their presentations forces them to think about their work in a new light. The students can often showcase these projects in job interviews and graduate school applications. Our undergraduate research program is just one way that we have expanded the enrollment in the ESE Department over the last ten years.

Authors

**Ed Richter** (ed@ese.wustl.edu) is a Professor of Practice in the Preston M. Green Department of Electrical and Systems Engineering at Washington University in St. Louis. He brings 30 years of real-world engineering experience to the classroom and to undergraduate research projects.

**Arye Nehorai** (nehorai@ese.wustl.edu) is the Eugene and Martha Lohman Professor of Electrical Engineering in the Preston M. Green Department of Electrical and Systems Engineering at Washington University in St. Louis. He served as chair of this department from 2006 to 2016. Under his leadership, the department’s undergraduate enrollment has more than tripled in four years and the master’s enrollment grew sevenfold in the same time period. He is a Fellow of the IEEE, Royal Statistical Society, and the American Association for the Advancement of Science.

**For More Information**

All references in this article can also be found by visiting https://sites.wustl.edu/spmrefs2016.

**References**

[8] BCI hand control download