



## **Work in Progress: Reinforcement of Engineering Education with Hands on Learning of Through Technical Skills**

**Mr. Thomas Vernon Cook, University of Pittsburgh**

I am a Electrical Engineering Masters student in the Electric Power program at the University of Pittsburgh. I spent the last year helping to develop a hands on learning environment and curriculum for engineering students of all disciplines. My current research is in power electronic conversion for telecommunications and military use.

**Mr. James Arthur Lyle, University of Pittsburgh**

**Dr. Robert J Kerestes, University of Pittsburgh**

Robert Kerestes, PhD, is an assistant professor of electrical and computer engineering at the University of Pittsburgh's Swanson School of Engineering. Robert was born in Pittsburgh, Pennsylvania. He got his B.S. (2010), his M.S (2012). and his PhD (2014) from the University of Pittsburgh, all with a concentration in electric power systems. Robert's academic focus is in education as it applies to engineering at the collegiate level. His areas of interest are in electric power systems, in particular, electric machinery and electromagnetics. Robert has worked as a mathematical modeler for Emerson Process Management, working on electric power applications for Emerson's Ovation Embedded Simulator. Robert also served in the United States Navy as an interior communications electrician from 1998-2002 on active duty and from 2002-2006 in the US Naval Reserves.

# **WIP: Reinforcement of Engineering Education with Hands on Learning of Technical Skills**

## **Abstract:**

This work describes the enormous benefit of providing hands on learning to students for building engineering instincts and expertise. Fundamentally, current engineering education strives to provide the theoretical background to begin working in a research or industrial role. Particularly in electrical engineering, the ability to translate concept into prototype sometimes takes years to develop and is often not heavily focused on in undergraduate education. Makerspaces can supplement this deficit to a degree, but often only provide the equipment and spatial resources for the students and may lack the technical expertise and training of dedicated staff [1]. By giving early access to specialized pieces of equipment and hands on training early in undergraduate education, allows them to develop innovative ideas that utilize the equipment for their projects. Training also allows students to quickly become comfortable with the tools that electrical engineering depends on, instead of having to develop their proficiency in the first five years of being in the workforce or graduate school.

## **Introduction:**

Back in the fifties and sixties there was a significant push for engineering education to move away from traditional “shop work” and to refocus the curriculum on the mathematics and science of the trade [2]. The “shop work” was then moved to vocational schools for students who supposedly could not handle the rigorous math or science courses [3]. The tradesmen then focused on building the device but lacked understanding of its intricate operation. Engineers knew how a device worked but struggled in implementing a functioning prototype. The trend began to reverse in the eighties and early 2000s as engineering educators and industry employers realized that design deprived engineering graduates were not prepared to do any prototyping work. The advent of inexpensive prototyping equipment and Open Source hardware helped to make this change, thus giving engineers the much needed hands on knowledge to implement ideas directly into concepts and validate the outcome [4].

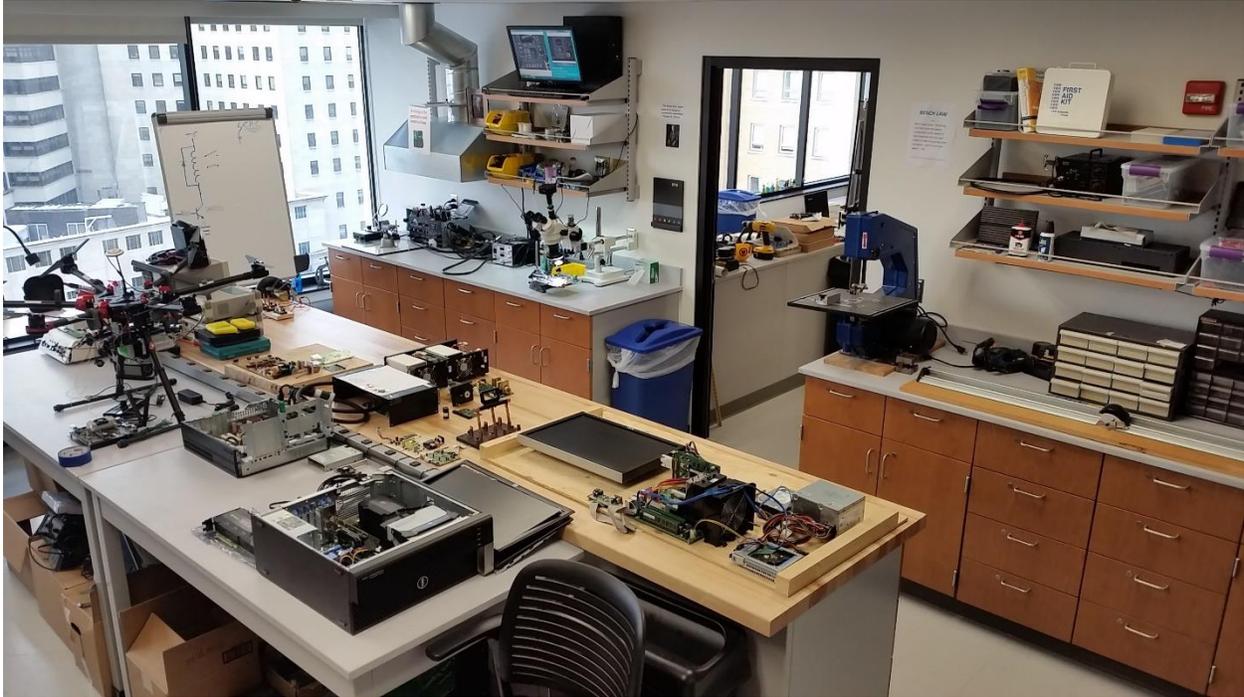


Figure 1: Main SERC Work Area

The Student Electronic Resource Center (SERC) at the University of Pittsburgh provides hands-on learning that complements the theoretical understanding that is being developed in the classroom, and students are able to develop their skills at a rapid pace (Figure 1). Using a system developed by Vincent Wilczynski at Yale University that categorizes makerspaces in a hierarchical level, SERC would be classified as an S-3, A-4-S, U-2, F-1, M-3 makerspace [5]. Meaning that SERC provides support for at least three university missions, access is provided to all current and past students in the university, with attendance of over 300+ members, in a 1200 square foot space, and is staffed with skilled technicians. Students work one-on-one or in a small group with a technician which allows them to collaborate and develop their teamwork and technical skills. Classes can consist of training on various pieces of laboratory equipment, soldering skills, microcontroller implementations, practical electronic components, PCB design, and much more. Once a student has gone through training on the equipment, they are able to use it for their projects, coursework, or research. The classes build on each other to provide a continuous learning environment that can rapidly build student confidence in being able to tackle engineering problems. By integrating the practical side of engineering with the theoretical in a more open environment than a traditional lab course, SERC allows students be actively engaged with the material and develop their engineering skills at their own pace [6].

SERC differs from other makerspaces by offering different levels of guided instruction that students are able to participate in, from one-on-one classes, workshops, or support for design courses [1]. It is always staffed with highly skilled technicians that work closely with faculty to train students and assist in their projects. SERC does not limit students to one field of engineering but is instead is open to the entire campus as well as past alumni. Students are encouraged to interact with each other and collaborate on projects to improve their skills. SERC is not as large as similar programs at other universities such as Yale, Georgia Tech, and Carnegie Mellon University, but it allows for a more intimate learning environment where students and

staff members all work very closely together [5]. The most comparable makerspace to SERC is located at Yale with their Center for Engineering Innovation and Design Center which is a much larger center than SERC with approximately 8,700 square feet of space and serves over 2,000 members [7]. Yale students are able to take classes lead by faculty and staff members for teaching different engineering concepts and training on the equipment, similar to SERC.

### **Integrations into Curriculum:**

SERC was integrated into the electrical engineering curriculum at the University of Pittsburgh as ECE 1270 Special Topics. This is an optional one credit course that meets once a month open to juniors and seniors that is mainly informational and is a precursor to a junior design course that will be a prerequisite to senior design. This development of SERC was used as part of the ABET accreditation for showing continuous improvement in the department and for its support of undergraduate education [8]. While SERC is not mandatory, it is highly encouraged for undergraduates to participate in by the electrical engineering department.

Students are able to participate in SERC in three different ways. The first is through individual or small group sessions that allows for a deep dive into a particular topic and have individual attention and guidance from the instructor. The individual and small group classes are open to any student and are SERC's main focus. Individual classes are where any new class topics are tested and developed. Once a class has been fully developed, workshops are opened up to any students registered in the electrical and computer engineering department under the ECE 1270 class. Currently soldering, PCB design, 3D printing, and microcontrollers are offered department wide. Students must register to take the workshops that are held four times a month with special preference given to those who are enrolled in senior design that semester or who will be enrolled in senior design the following semester. Workshops are designed to easily handle twenty five to thirty students at a time. Finally, SERC supports all students taking senior design by training, providing materials and equipment, and advising on projects. If a student has a question, highly trained and experienced technicians are there to answer and provide possible solutions. Even if a student never took a SERC class or workshop, they are still able to use the facilities after receiving proper training. As many as seventy students per department can be taking senior design a semester with many of the groups spending a considerable amount of time using SERC's facilities. Since integrating SERC with the departmental curriculum in ECE 1270 the overall quality of the senior design projects has improved based on judges' evaluations during the design expo at the end of the semester.

Students who would like to take the individual and small group classes must apply for a one to two hour time slot that meets once a week. Since space and instructor time is limited only approximately twenty students are admitted to take classes each semester, with preference given to previous SERC students. New students submit an application with which classes they are interested in taking, their graduation year, department, resume, and class schedule. Student applications are reviewed by the instructors and potential applicants are then interviewed. Once the list of accepted students has been developed the student class schedule is created. New students are made into groups of two or three based on their availability and desired classes. Previous students have the option to work by themselves or be paired. The class schedule allows the maximum amount of one-on-one time with the instructor while still letting as many students

take classes as possible. Typically twenty to thirty students are able to take individual and small group classes every semester.

### Course Progression:

Individual classes in SERC are not setup as traditional undergraduate classes where there is a lecture and a lab with homework assignments and tests [9][10]. Students work closely with the instructor in a class and are allowed to explore a topic in as much depth as desired. Instructors continuously evaluate competency and understanding of the subject matter. If a topic is outside of the instructor's knowledge base, then the student is directed to more focused resources and experts. There is a baseline level of information that students are required to learn for each class which is described in an instructor's manual. Grades are determined on a pass-fail scale and any concept that the instructor deems insufficient knowledge will be reiterated until total comprehension. Meaning that no student technically fails a course, but instead is required to pass.

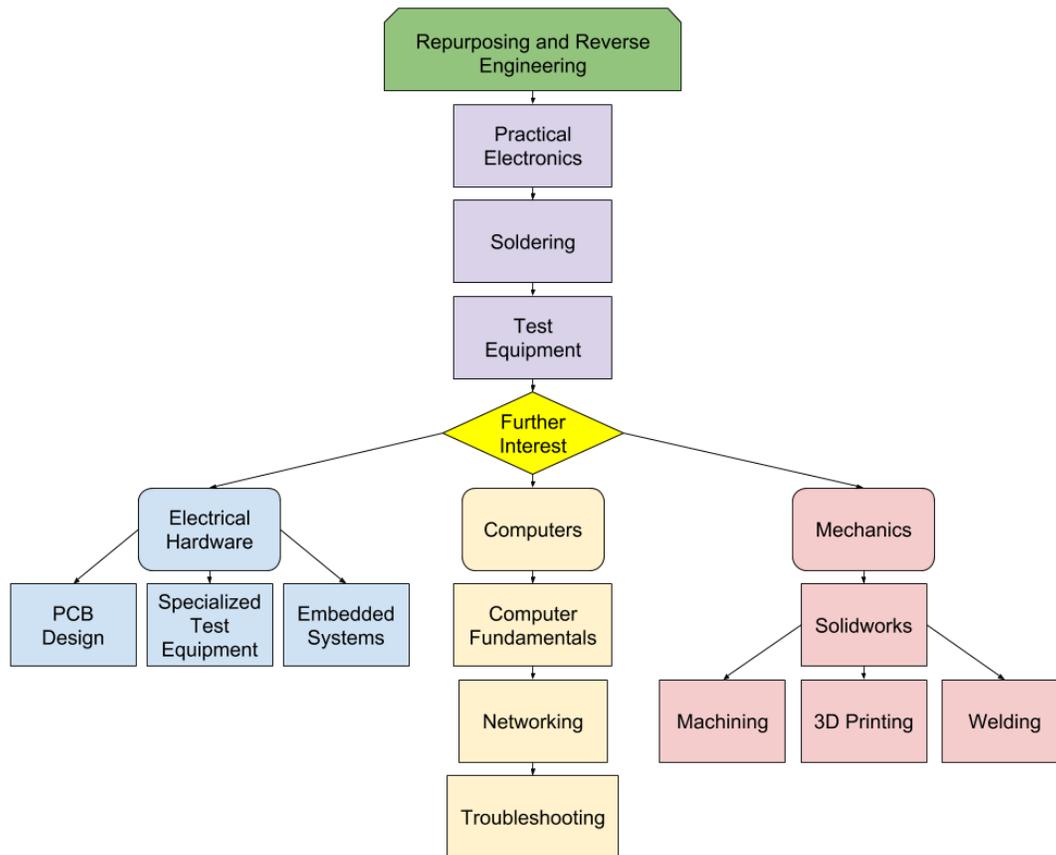


Figure 2 Course Progression Flowchart

SERC currently offers four different tracks of classes that each cover a skill or topic that is often not presented in traditional electrical engineering undergraduate education as seen in Figure 2. The beginner track that all students take starts with the repurposing and reverse engineering class a printer and a hard drive down are disassembled. Students then go through each component and

circuit board to discuss what it is, what it does, and how it could be used for a different application. This leads into the practical electronics course that goes through each of the common types of electronic circuit components and how the physical devices all come together to make electrical functions and the finished product. The useful components are saved and reused later for another SERC class or for a project. Students then take the test equipment class to learn about the necessary tools that electrical engineers use for looking at electrical signals and how to use them properly.

Next, proper through-hole soldering technique and safety procedures is taught. Students have the option of de-soldering the circuit boards they removed from their printer or putting together a small circuit board soldering practice kit. Once that is completed, the student can move onto learning more advanced surface mount soldering. These introductory classes teach the starting foundation for prototype development and lets students develop their skills for working with electronic components.

After the beginner courses are finished, students are allowed to pick what they wish to continue learning about in greater detail. If a strong electrical engineering hardware direction is chosen, SERC offers class on specialized test equipment, PCB design and layout as well as microcontrollers and embedded system development. If computers, networking, and tech support knowledge is desired, classes in computer fundamentals, networking fundamentals, and electronic and computer troubleshooting are available. If mechanical and materials knowledge is desired classes on 3D printing, mechanical design and SolidWorks, machining, physical prototyping, and welding are available. Students are allowed to take all the classes that interest them no matter what their engineering major is [11].

Once all classes have been completed, students are encouraged to think of a final project that uses all the knowledge and skills that they have developed. The skills that have been developed in the PCB design and soldering classes are used to design and assemble their projects, thus providing early prototyping experience. Completion the 3D printing and mechanical design classes allows students to be able to design enclosures and other mechanical elements that let their electrical devices interact with the physical world. The completion of these courses facilitate a vertical integration of knowledge covering the prototyping process that can be highly beneficial for working on senior design, research, or small startup companies.

### **Course Offering Descriptions:**

The repurposing course has a student take apart a modern laser or inkjet printer, which was going to be recycled, down to each of its components [12]. Students are first taught how to approach devices they are not familiar with plus proper disassembly technique. While working on disassembling the printer, the design and development process of each part of the printer is highlighted and modern assembly line manufacturing is discussed. The class can take anywhere from two to five hours, depending on how efficient a student is at disassembly. Some of the most useful pieces that come out of the printers that students find are small stepper and DC motors, limit switches, solenoids, ink heaters, optical encoders, gears, circuit boards, ferritic toroids, and hardened steel guide bars. Next, a hard drive is taken apart and the electric motor, platters, print head, permanent magnets and circuit boards are extracted. The hard drive is looked at under a

microscope to see how all the components work together to store data. Repurposing allows students to get their hands dirty and depending on the student's background, may have been the first time they have been able to take something completely apart. The repurposing class gets students excited to start learning about what each component is and does when they move into the electronics fundamentals course.



Figure 3: Electronics Fundamentals Circuit Board Example

The electronic fundamentals course starts by correctly setting up an oscilloscope in order to view the 120V AC mains power without damaging the scope or endangering the operator. Hot, neutral, and ground wires are identified and the electrical differences between each of them is described. Line voltage is shown to often not be the perfect sinusoidal waveform that is illustrated in textbooks, while the fundamental frequency may still be 60Hz the amplitude and shape of the waveform can be distorted due to harmonics from other devices on the line. After seeing where power comes from, AC to DC rectification on the circuit board and power delivery is explained. Then students are allowed to freely move around the circuit board, pointing out components that they do and do not recognize, giving them the freedom to demonstrate their previous knowledge to the instructor rather than wasting time covering details already known. If any components are missed the instructor can go back and point them out to see what the student thinks it is. For hints, the student is taught to try and find an identifier of the component on the silkscreen layer of the circuit board (Figure 3).

The components covered in the electronic fundamentals course are the isolation transformer and its purpose in electrically isolating the device from the wall outlet in case of a short circuit. The bridge diode rectifier that converts the AC voltage to DC voltage is also covered. The large electrolytic filtering capacitors that smooth the DC voltage waveform coming out of the bridge rectifier. Students are shown other types of capacitors that may be seen in electronics such as polyester, ceramic, or, tantalum and their individual advantages/disadvantages and how their



more solder or new solder paste applied to each pad. By working with small surface mount components, students gain an appreciation of the skill involved with PCB assembly. PCB designers that have never hand soldered may be tempted to use the smallest component possible without paying attention to hand assembly difficulty, individual component repair/replacement, power and thermal ratings, or the effect of package size on device characteristics, all very important concepts for prototyping. When the student designs a PCB for their own or company projects, they have an appreciation for actually assembling the board.

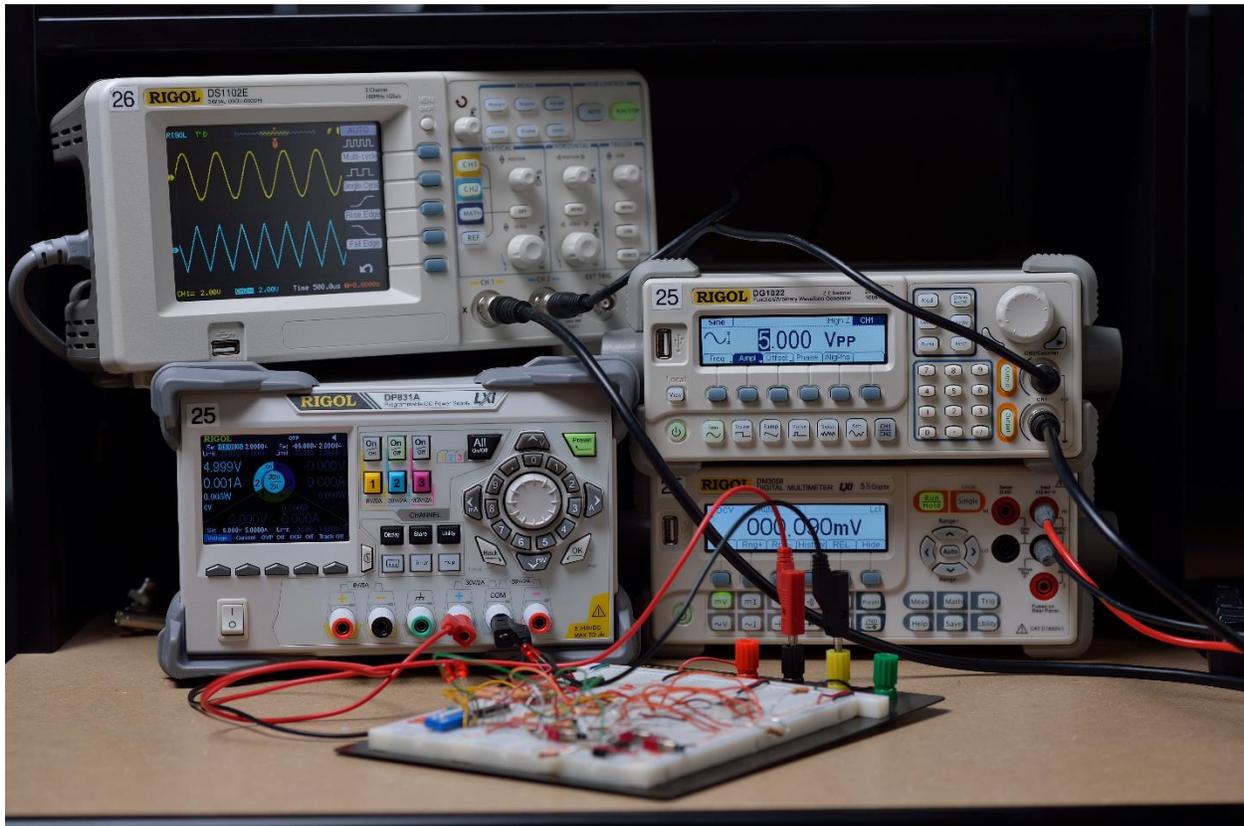


Figure 5: Standard Test Equipment

The oscilloscope, multimeter, DC power supply, frequency generator, and spectrum analyzer are thoroughly covered along with their functions (Figure 5). Probe wiring setup for measuring voltage, current, and differential voltage measurements is shown for both the oscilloscope and the multimeter. Other specialized equipment can also be demonstrated if the student has a particular interest or use for a specific piece of equipment such as a Vector Network Analyzer, Dranetz power quality meter, curve tracer, and logic analyzer.

The PCB design class walks through how a PCB is made, its construction, how electrical connections are made, vias, trace routing, frequency effects, noise, grounding, and how the physical layout of a PCB can affect the electrical part of the circuit. The course covers specifying the physical dimensions of traces for current carrying capabilities, electromagnetic interference and radiation, trace impedance matching, grounding, bypass capacitors, component layout, copper pours, and multilayer PCB stack-ups. The PCB design course is one of the largest courses offered and provides tutorials on how the use several different design software packages such as

Autodesk Eagle and Altium Designer. Students begin with creating and simulating a schematic to ensure the proper function of their design using LTSpice or Cadence PSpice. They are then shown how to create a PCB using the schematic that they came up with or a pre-created schematic. PCBs are evaluated by how closely a student held to good design rules and the end functioning of the circuit.



*Figure 6: Drone Development Platform*

The microcontroller and embedded system class shows how to program common microcontroller platforms such as the Arduino, RaspberryPI, Beaglebone, and Intel Edison. Control loops, data types, and logical functions are shown in C code and Python. FPGAs are also covered with the Altera DE0 FPGA platform. Students are also able to develop code algorithms using a PixHawk drone flight microcontroller on a six rotor drone development platform (Figure 6).

The computer fundamentals course goes over the physical assembly of a desktop from a barebones case all the way up to installing the operating system. Assembly of the motherboard by installing the CPU, graphic cards, and RAM is covered followed by installing the power supply, hard drives, and CD drives. Students are shown how to navigate in both BIOS and UEFI systems. Students are then able to choose a Windows or Linux platform and are shown how to install drivers and security software, as well as navigating around each operating system and changing administrator settings.

Once a computer has been assembled, the network fundamentals class shows how to get a device connected to a network, obtaining IP addresses, navigating to other networked devices, and how a network operates. Setting up a modem and router is also covered with how to modify security settings and monitor network traffic.

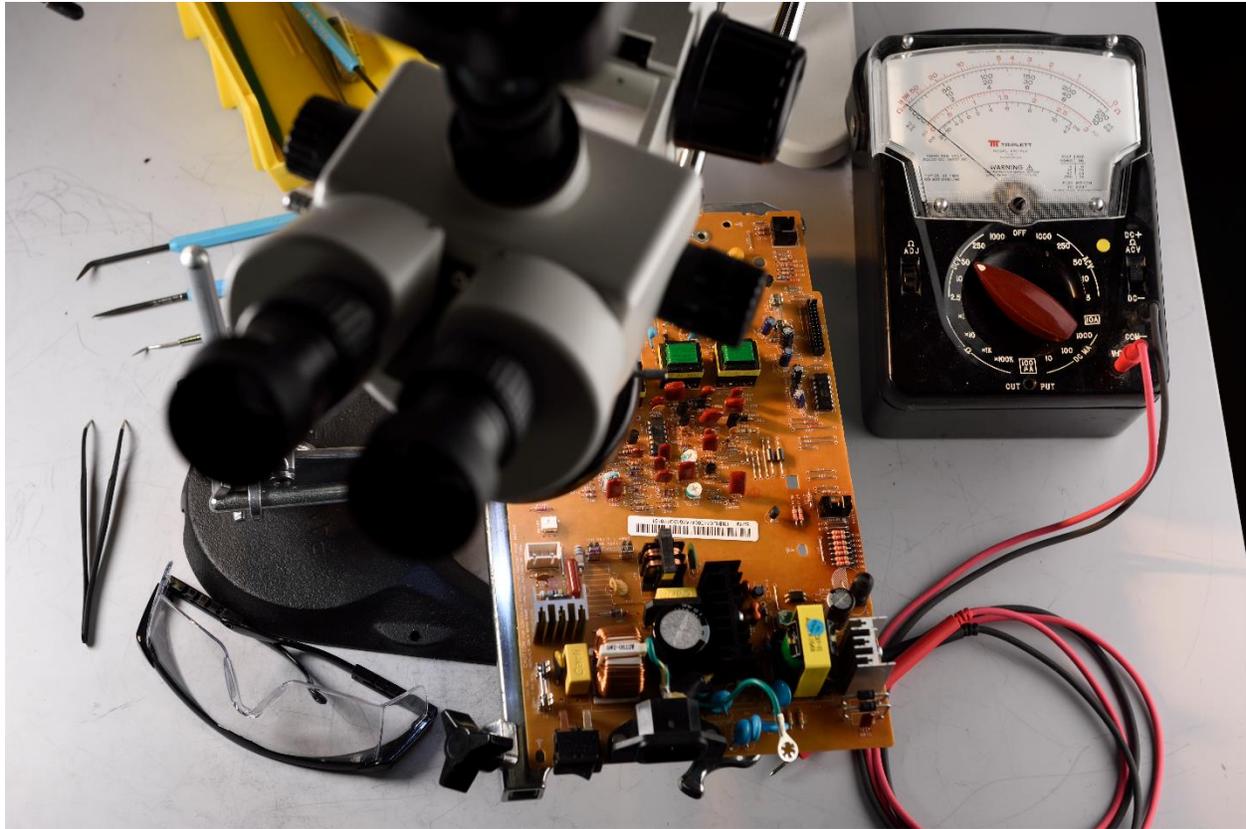


Figure 7: Microscope and Circuit Troubleshooting Equipment

The troubleshooting course covers different strategies of approaching a problem that needs to be fixed, either electrical, software, or mechanical. If a circuit board is not working students learn to break the board up into sections and look for tell-tale signs of a component not working, burn marks, broken leads, shorts, solder lifting, damaged capacitors, etc. (Figure 7). Ohming out components and continuity tests are also shown as diagnostic tools for checking connection resistance, short circuit connections and open circuit connections. Oscilloscopes and logic analyzers are shown how to be used to discover issues with digital systems. Software issues on Windows and Linux machines are handled by checking drivers, crash reports, and registry files. Both mechanical and circuit problems can sometimes be found by looking at the thermal signatures of the part, heat is generally a sign of failure or eventual failure. Mechanical cracks, discoloration, and wear marks are also shown and explored. Once a problem has been diagnosed, methods for repairing the device are covered. Sometimes this means parts replacement, reordering, or applying some sort of patch in order to get the device back to functionality.

Solidworks and mechanical design class introduces basic part and assembly design in Solidworks as well as creating electronic component models. Students start out with a small part and then move into creating an assembly with other parts. Finite element analysis on the parts or assembly also explained to see how a part will perform under mechanical stress. Common mechanical design features such as locking tabs, snaps, springs, screws, camming surfaces, pins, gears, bearings, seals, and hinges are explored. Material choices are also covered for particular applications and functions.

Once a part has been design in Solidworks, the student is able to take the 3D printing course and create a physical model of the part that was designed using a fused deposition modeling (FDM) printer. Students are walked through how to prepare the 3D printer for use, different 3D printed material types and properties, and the software used to create the G-Code used for printing. For FDM printing, the orientation of how the part is printed is discussed and how that affects mechanical stability.



*Figure 8: SERC Machine Shop*

Machine shop training is also available on a variety of pieces of equipment such as traditional milling machines, lathes, band saws, angle grinders, belt grinders, belt sanders, vises, chop saws, and routers (Figure 8). Students are required to read the safety manual and pass a safety exam before using any of the equipment. Part fixturing and indicating is also covered with the mill, lathe, and chop saw. TIG welding is also covered for both mild steel and aluminum. General hand tools like hammers, drivers, sockets, drills, end mills, wrenches, rulers, calipers, micrometers, levels, and plumbs are also covered. How to read precision measuring tools and how to take into account gearing slop when machining in order to produce very precise parts is explained.

## **Final Project:**

The final project for students is a culmination of everything they have learned in each class they have taken. In general, the student must think of a unique design that applies the skills they have learned in taking classes [7]. They design the circuit boards, order all the parts, assemble and solder the board together, and perform different tests to ensure functionality. They design an enclosure and any other mechanical components of the device and machine or 3D print them. If a microcontroller is integrated into the design they are encouraged to incorporate it into their PCB design and program the controller from their board. Students are allowed to work individually for this project or with a group. Overall quality of the design and implementation is highly stressed so that the project looks like a finished product. They can then use this project as the basis for senior design, research, or as the beginnings of a startup company if they desire.

## **Student Responses and Outcomes:**

Students that come to SERC are usually very excited to be able to work with their hands and apply the knowledge that they have learned in the classroom. Applying hands on knowledge has been proven to be an effective learning tool in other makerspace environments [13]. Students are able to see the devices and how all the parts physically come together which provides a deeper insight than just a seeing a schematic on paper. Students are evaluated on their knowledge and technical competency by being asked questions that assess their understanding. Instructors use this information to tailor the courses to each individual student.

SERC, while focused on undergraduate education, is open to graduate students and alumni. Several alumni have come back to campus after several years of being in the workforce and participated in classes in their pursuit of lifelong learning. For example, one of these alumni has been in a managerial position for several years and unable to practice engineering for years and was ecstatic to be able to work on a technical engineering project again. Entire graduate student lab groups have been through training in order to assist in developing their research. Graduate groups generally have specific goals they wish to accomplish, therefore the classes they take are often customized to cover the information they need.

## **Data Collection:**

SERC has been running for several years before a lot of dedicated data logging on student outcomes was performed. The majority of the data collected for SERC has been qualitative, consisting of student feedback that was used and recorded for further development of future classes. Students are questioned and evaluated by the instructor throughout the workshop or class differently depending on how students were participating in SERC. For senior design, students are asked at the end of the class what they thought of the material and its presentation and how it benefitted them. The students enrolled in ECE 1270 fill out an Office of Measurement and Evaluation of Teaching (OMET) report at the end of the semester that report their thoughts on how affective the course material was. For individual classes students are able to give feedback immediately on if they find the material interesting or useful. This data is usually collected from open ended questionnaires or simple conversation. A selection of the most commonly mentioned benefits can be seen in Figure 9. These testimonials help to validate the usefulness of the service

that SERC provides to undergraduate engineering education. The following responses of 150 students from the past two years gives a reasonable picture of student's thoughts on SERC but does not represent the total impact (Figure 9). The students that mentioned an improvement of electronic component knowledge suggests that this has helped improve their lab class experience, although not explicitly stated. Many of the students that mentioned increased interest in electrical engineering are freshmen or are from outside of the electrical engineering department. Not all students put SERC down to get a job or to get into graduate school and only a small number of students have been able to participate in the machine shop classes for welding, although interest is very high.

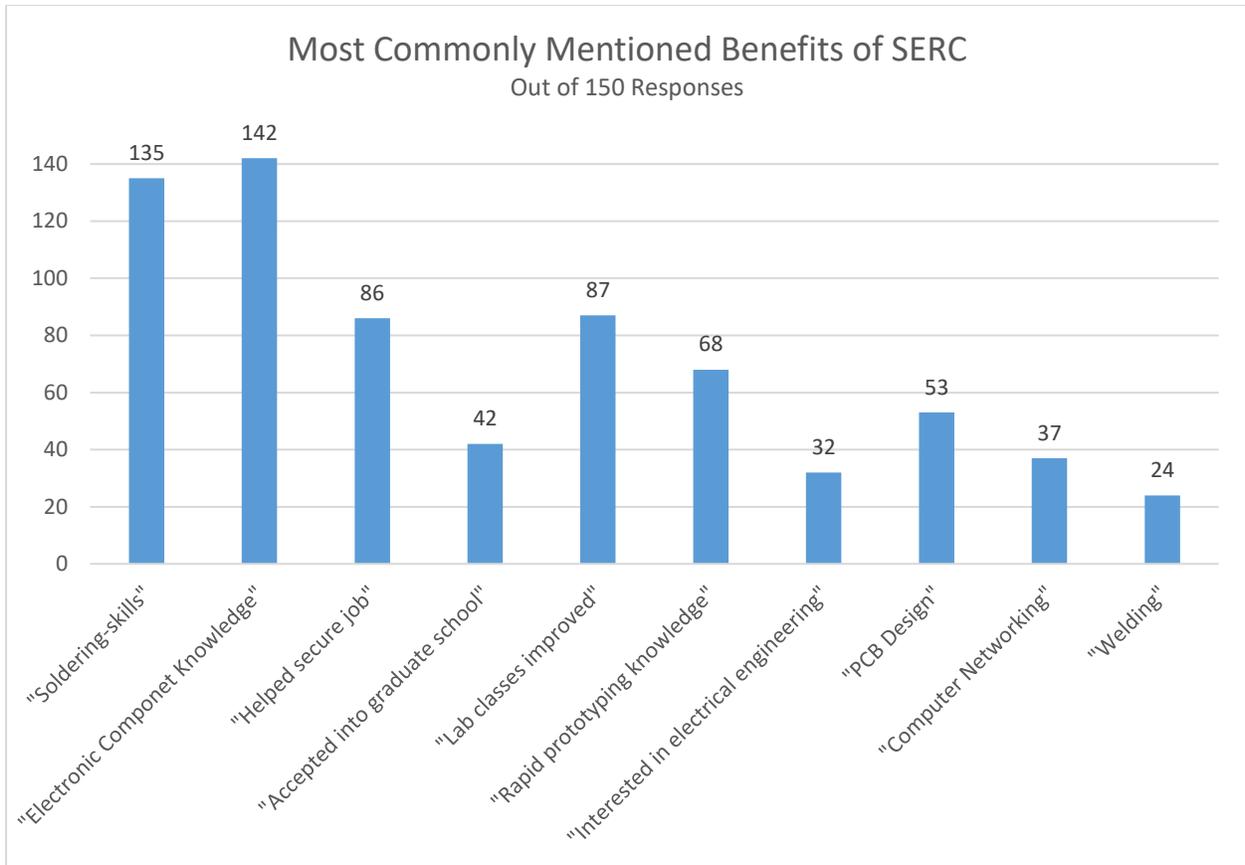


Figure 9 SERC Benefits Mentioned from Student Responses from Past Two Years

Including early data, approximately ninety percent of students that have completed the electronics portion of SERC have commented that they were able to complete and comprehend their electrical engineering lab courses more effectively and have understood the topics covered in other classes better. Since collaboration with other peers is highly encourage, several students have been able to become more effective at working in team settings. The data for SERC students cannot not be compared to students that have not participated in SERC. However, students that started taking SERC classes later in their undergraduate career have expressed how they wished to have participated sooner.

From the 150 students that have participated in SERC over the past two years, forty percent been women and or minority students from across all engineering departments including electrical, mechanical, bioengineering, chemical, and civil. SERC accepts students based on several factors including: merit, interest level, academic standing and personality fitment. Since SERCs founding, several students have used it as a reference for their jobs at Honda, Tesla, Space X, Ecole Polytechnique Federale De Lausanne, Mitsubishi, Eaton, GE, BMW, Norfolk Southern, Phillips-Respironics, Westinghouse, NASA Jet Propulsion Laboratory, Uber and others. Students have also gone on to graduate schools at Columbia, University of Pittsburgh, West Virginia University, Georgia Tech, Gannon, Virginia Tech, etc. The SERC projects and training that students have completed give them something that stands out amongst other applicants and can also be a great talking point for interviewers. Many of the hands on skills that past students attribute their success as engineers to come from what they learned in the classes at SERC.

### **Future Work:**

In order to incorporate a more quantitative metric for tracking student's success and learning, a proposed rubric for surveying and tracking student's progresses can be seen in Figure 10. Before participating in SERC classes, students will be asked to rate their skill level on a variety of topics from "no knowledge" to "expert." Students will then be asked to take the survey again at the end of the classes and see how far they have progressed. This data can then be used, along with the current qualitative data, to improve the course offerings and demonstrate how students are improving.

ECE 1270 content will be moving into a junior design course that will be a required three-credit course for students to take before taking senior design. Junior design is set to meet twice a week with a lecture and lab component to cover all the topics that were covered in ECE 1270 in much greater detail. The lab will have students work on a design project that has set requirements but allows for personal flexibility. The project is intended to impart as much practical design information on component and circuit modeling, microcontroller implementation, PCB design, 3D mechanical design, and soldering. Different communication protocols for wired and wireless communication of microcontrollers will also be covered such as serial, SPI, I2C, and Bluetooth. After successfully completing junior design students should have developed enough skills for prototyping a very successful senior design project.

## SERC Skills

\* Required

How do you rate your through-hole soldering skills? \*

	1	2	3	4	5	
No Knowledge	<input type="radio"/>	Expert				

How do you rate your surface mount soldering skills? \*

	1	2	3	4	5	
No Knowledge	<input type="radio"/>	Expert				

How do you rate your practical electronic's knowledge? \*

	1	2	3	4	5	
No Knowledge	<input type="radio"/>	Expert				

How do you rate your 3D Printing and Solidworks skills? \*

	1	2	3	4	5	
No Knowledge	<input type="radio"/>	Expert				

How do you rate your PCB design skills? \*

	1	2	3	4	5	
No Knowledge	<input type="radio"/>	Expert				

How do you rate your computer and networking skills? \*

	1	2	3	4	5	
No Knowledge	<input type="radio"/>	Expert				

Figure 10 SERC Skills Rubric Survey

### Conclusion:

SERC has been described in this study and its effectiveness is backed up with student testimonials on how it impacted their education and career. SERC has supported numerous faculty members, graduate students, and undergraduates with research and capstone projects by providing the practical and technical training for projects. SERC is multidisciplinary in electrical, mechanical, and biomedical engineering fields and encourages students to collaborate on projects and share ideas with each other. SERC provides student the technical training and hands on knowledge in order to complete their projects and get experience with rapid prototyping.

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