Practical Skills and Design: A Maker Course for ECE Students

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Abstract - **This paper describes a sophomore-level ECE course that bridges the gap between the maker movement and typical engineering design courses. This course incorporates the practical skills of fabrication, assembly, and hardware integration found in makerspaces but deepens the perspective from one of *getting it to work* to *designing it to work well and efficiently*. This paper discusses mastery-based education in practical skills, an open-ended student-defined design project, and a logistics model that incorporates support staff as partners in the course. The relationship between this course and an ECE-themed makerspace is also discussed.**

I. INTRODUCTION

In the last decade, there has been a movement amongst engineers, designers, and inventors for advanced do-it-yourself (DIY) projects developed in workshops such as Techshops, Fablabs, and MakerSpaces [1]. These spaces contain mid-level and consumer-level manufacturing technology in the form of 3D printing, CNC machining, and laser cutting to allow rapid prototyping and development of individual ideas and designs [2-4]. Research shows that the interactions in these spaces improve collaboration skills and innovation [5]. This result is not only beneficial for the individual, but also for the industry. DARPA and other maker organizations have begun partnering to leverage the open community of 'making' and its crowdsource infrastructure to improve access to these facilities on both the commercial and institutional levels [6,7]. There is a wealth of DIY resources for makers on how to do specific tasks or how to build specific projects [8-10]. The emphasis in those resources is more on *how to get it to work* rather than *how to get it to work well and efficiently*, which is an engineering design perspective.

The course described in this paper, Practical Skills and Design, is a sophomore-level course for electrical and computer engineering (ECE) students that teaches engineering design as well as trains students on practical fabrication and integration skills. It also has a final project that is open ended, where the students determine their own product concept by first deciding on their needs for a product, then determine appropriate requirements, and specifications. They then design and build a product that meets their purpose using the practical skills and design process that are taught. In essence, the course supports students in a makerspace by encouraging innovative yet systematic design thinking, providing students with training on technical skills, and providing them with expert engineering advice as they design and build their own projects.

The format and objectives of this course differ from other similar courses taught at other universities. For example, the DIY aspect of the maker movement is infused in an introduction to electrical engineering course at Stanford, where students learn how to build three EE-themed projects [11]. That course introduces students to some underlying EE concepts in the projects, but students do not design their own projects. Many other schools offer electrical engineering design courses during the first or second years that tend to concentrate on the systematic design process or on professional skills, such as teamwork and communications. These courses are good at introducing students to systematic problem-solving, hardware integration, embedded systems, and testing and possibly modeling and simulation. However, the design projects in these courses are generally not open-ended; instead, they have prescribed goals, requirements, and materials, see for example [12-14]. Senior design courses are at the other end of the spectrum, where the emphasis is on the design methodology, the economic aspects, the project management, and the professional skills at the loss of learning the practical technical skills and the excitement of students designing and building personal projects.

Some mechanical engineering programs do offer courses that have some practical skills training modules that are similar in intent to Practical Skills and Design but are targeted to a different discipline and generally still have preset design projects. Courses that teach computer aided design (CAD) include one that teaches the use of CNC machines [15] and two that focus on 3D printing [16,17]. The projects described in [15,16] are instructor designated, for example designing a cup, so that students are given a set of requirements and specifications. Reference [17] does describe a course where students design and fabricate their own part using a 3D printer.

One sophomore-level mechanical engineering course taught at Georgia Tech, ME2110 Creative Decisions and Design [18], was somewhat of an inspiration for the ECE Practical Skills and Design course described in this paper. ME2110 introduces mechanical design and trains students on tools, including mills, lathes, 3D printing, pneumatic devices, and mechatronic devices. There are several mini-projects and one final project for which students work on teams to meet a design challenge that involves mechatronic operation. The students then compete against other teams to see which one best meets design criteria and has the best performance. Like the ME courses described above, Practical Skills and Design, has a very strong emphasis on both engineering design and on training students to be proficient in practical skills, but this

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course is targeted to design and skills that are suitable for electrical and computer engineers. In addition, Practical Skills and Design replaces the usage of instructor-defined design projects with one that is open-ended. Thus, this course can be considered an engineering maker course where there is a combination of technical skill training, flexibility of design for students to pursue their own hobbies, and enforcement of an engineering design process.

This course fits in with several other design courses offered in ECE at Georgia Tech. An elective freshman Introduction to ECE Design investigates embedded programming, understanding and effective use of sensors in design, and design thinking using Lego challenges [13]. A required sophomore-level digital design course uses FPGAs to teach digital design and has a final project where students work in teams to meet the requirements and specifications of the project. Georgia Tech also has a very large Vertically Integrated Projects program (VIP) where students earn credit to work in multi-disciplinary project teams. Similarly there are a set of entrepreneurial courses, CREATE-X, the last of which requires students to design and build a prototype. The Practical Skills and Design course supports the VIP, CREATE-X, and Senior Design courses by teaching students practical skills and a formal introduction to design.

II. COURSE RATIONALE AND OVERVIEW

Practical Skills and Design infuses engineering methodologies with instruction in practical skills in order to prepare students to put together their projects for capstone design, other courses, competition teams, personal projects, and co-op jobs and internships. This course is a one-credit hour elective lab class with a major design project. Students choose their own ideas for that project and must follow a basic engineering design and analysis process. The project has some constraints: it must contain a microcontroller, one or more sensors, and outputs. Also, the electronics must be soldered onto a printed circuit board (PCB) or a protoboard, and the electronics must be mounted to a structure or enclosed. The latter requirement is so that ECE students understand that electronics do not normally stand by themselves and must be interfaced with a physical system. The project must display many of the practical skills that they learned in the workshops including part sizing and selection (using datasheets), soldering (through-hole and surface mount), building electrical connectors, hardware integration with microcontrollers (sensors, LEDs, and motors), basic hand and power tools (saws, drills), PCB CAD layout and milling, and 3D CAD and printing.

A number of logistics fell into place for the development and offering of the course. The course was co-developed and co-taught by a faculty member, electronics engineers who run the senior design labs, and two students. This diversity of perspectives allows the course to have a number of essential features: a pedagogy built around student-oriented learning and design thinking, instruction by people who are experts in the practical skills, and student perspectives on making the course fun yet valuable.

The development of this course coincides with the building of a large ECE-centric makerspace on campus, which supplements a network of existing makerspaces that have other focus topics. For example, the original makerspace on campus is outfitted primarily with laser cutters, 3D printers, woodworking equipment, and other mechanical engineering-focused machines. As part of the initial design for the space, we did a large student survey to determine the types of themes that should be supported in that space. The themes with the most interest were embedded systems, electronics prototyping, soldering, PCB layout, devices connected wirelessly, and 3D printing. Five of these topics are emphasized in this new course. We also asked the students in the survey what sort of educational delivery they would prefer in order to learn the skills needed to work in that space, with the results shown in Figure 1. Four models of delivery were considered and are shown on the horizontal axis. Students were then asked to rate the desirability of each method among four possible responses ranging from the extremes of “will not use” to “will definitely use”. Each delivery method in Figure 1 shows the distribution of these responses.

Although the survey results indicate that the least preferable option for most students is having a dedicated course, such as Practical Skills and Design, this course will play a significant role in the success of the space. In particular, students who complete this course will be certified to be the student leaders in the makerspace and will also run specialized workshops and develop the self-paced tutorials. Thus, this course is leveraged to provide support for all four delivery models shown in the figure. This course is currently being taught in the ECE Senior Design open lab space and will be moved to the new makerspace once it is completed.

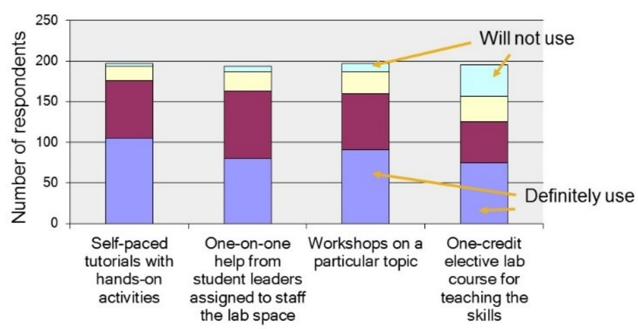

Figure 1: Results of a student survey identifying the most preferred means of learning skills for a new makerspace.

III. WORKSHOP DESCRIPTIONS

The course is structured into ten three-hour workshops, leaving the last four weeks of the term open for students to complete their final projects. It is important to note that the engineering design process is covered early in the term, Workshops 2 and 3, with the remaining weeks devoted to how-to workshops that focus on practical skills and hands-on experiences. This scheduling allows students to start their final project conceptual design early in the term and then to fabricate it as they learn the practical skills.

The goals of Workshops 4-10, the ones devoted to practical skills, are for students to learn the fundamentals of the topic and practical tips as well as to gain a mastery-level proficiency in the skill. Students are required to watch a how-to video on the subject, selected from a variety of existing DIY web sites, before the workshop and then take a basic concept quiz on the topic at the beginning. The mastery-based approach [19] is where students work towards achieving a certain desired level of competency on the skill. There are check-points in each workshop where students must demonstrate a skill at sufficient level of quality of workmanship. If there is a problem, students are given feedback on how to improve or correct their work and given additional opportunities to demonstrate it. There is no required analysis or write-ups that is typical in lab courses. Instead, workshop grades are based on the ability of students to reach the check-points in the workshops as well as their grades on the concept quizzes. The emphasis during the workshops is for students to be able to craft more eloquent engineering solutions on projects with an emphasis on craftsmanship and safety.

Workshop 1: Basic Safety The first workshop is a course orientation with an emphasis on lab safety. Lab safety is not to be overlooked. Our lecture includes common mistakes and injuries with graphic images attached. The hard lesson here is that machines are indiscriminate, and if a user is careless, they are putting themselves and others in danger. Some chemicals, although seemingly harmless can be life threatening. We emphasize a "Two Person" working policy, along with general lab etiquette, emergency procedures, and emergency kit locations throughout our lab space. Different chemicals and/or environments will require particular safety equipment. For example, different gloves are required for certain chemical use.

Students are required to earn a lab safety certification, and afterwards students will be able to understand Material Safety Data Sheet (MSDS) in order to select the proper safety equipment along with other necessary precautions. We also use this time to emphasize a good lab culture, and a respect for the shared space.

Workshop 2: Introduction to Engineering Design We introduce students to the design process and give them experience with a mini-design project that lasts two workshops. The first workshop gives a formal lecture on the engineering design process, using a waterfall procedure and morphological analysis of the options as shown in Table 1 and Figure 2. The intent of the remote-controlled blind opener mini-design project, also described in Table 1 is to give scaffolding for more open-ended design projects. As a class, the students develop the right side of the table and the morphological chart shown in Figure 2, and are given some background information on tradeoffs between different components such as different types of motors or sensors. They are then tasked with selecting their design option and going to two vendor sites to select specific parts for their design by filling up the two shopping carts with parts (but not actually buying the parts). The biggest challenge is to size the battery. Students need to look at the data sheets for their different components and determine the voltage needed and maximum current draw. Current draw is especially challenging for them to find for microcontrollers since it depends on the mode of operation. After choosing all of the parts, including the battery, they are asked to use the battery datasheet to determine how long the battery will last for their design under a specific operating scenario for the system. The calculations from the students ranged from 1 hour to 10 days, depending on the design choices made. Many students went back and changed their design to use an ultra low-power microcontroller to save energy.

Table 1: Engineering Design Procedure and Example

General Procedure	Remote Blind Opener Mini-Design Example
Needs Analysis: What need would the product fulfill? Driven by market forces? Social needs (need for clean water)? Artistic needs (techno-art)?	*Needs:* Convenience for people with a lot of windows who do not want to spend time opening each one manually
Requirements: Functional (what is its function), performance (high-level and qualitative), safety, interface (how it interfaces with people or other devices), security	*Requirements:* (sample items): Functional (must open and close blinds with electric activation from a remote control); performance (must fully open and close); safety (must turn off if power draw is too high); interface (human operator and wireless communications); security (ideally, immune to cyberattacks); other (cost < $30)
Specifications: Quantitative	*Specifications:* Must fully open or close < 30 sec
Task/System Decomposition: break the problem into subtasks or subsystems that can be integrated together	*Task/Subsystem Decomposition:* electromechanical; microcontroller; power, sensor, communications, remote controller
Ideation: brainstorm for each subsystem, morphological chart to compare options;	*Ideation:* See the options listed in the morphological chart in Figure 2.
Subsystem Design and Testing	
System Integration and Testing	

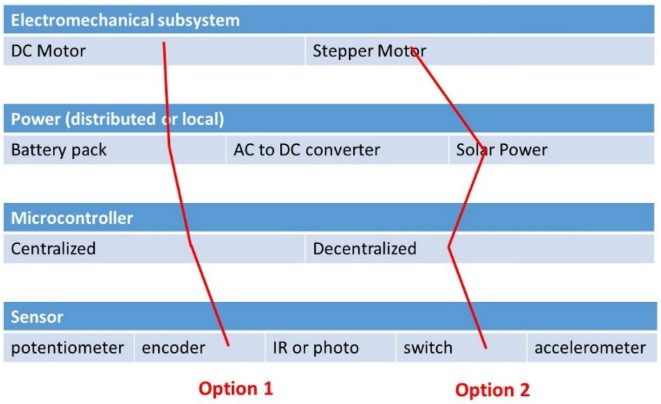

Figure 2: Morphological chart example for the remote blind opener mini-project.

Workshop 3: Microcontroller Integration The mini-design project is continued in this week, with a simplification in the design. Rather than a complex remote control interface, the blind opening is done automatically. When it gets dark, the blinds close. They open when it gets light. Students are given a specific microcontroller, motor, H-bridge circuit, encoder, and photosensor and asked to write the software and integrate the components in order to perform this functionality.

Systems-level engineering design principles, including software engineering, are introduced here and students are required to design their software first on paper. This approach differs from a hacker or typical maker approach where the goal is to get it done. In that approach, people tend to download sample sensor code and start modifying it to do the larger system-level tasks, essentially doing a bottom-up design that is often very hard to trouble shoot and not very portable to other platforms. A systems-level diagram is shown in Figure 3. The behavior of the blind opener is shown in a state diagram form in Figure 4. The layered architectural approach for the software, shown in Figure 5, is modular and starts at the top level with increasing detail in the lower levels. This approach is easier to read (and troubleshoot) and is more portable to other platforms since the lowest layer is the one that is platform dependent.

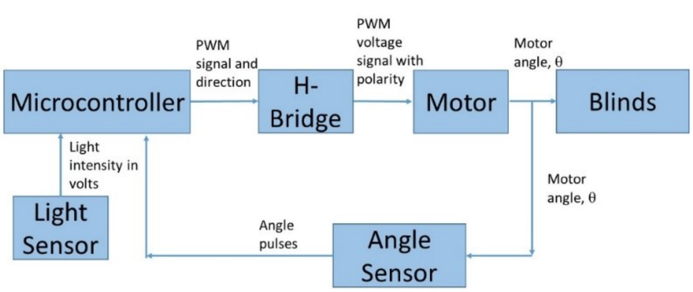

Figure 3: Systems-level view of the automatic blind opener mini design project.

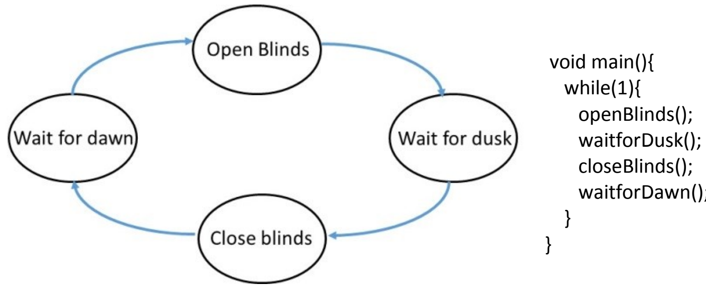

Figure 4: State machine transition diagram for the behavior of the blinds (left) and corresponding pseudocode for the main loop (right).

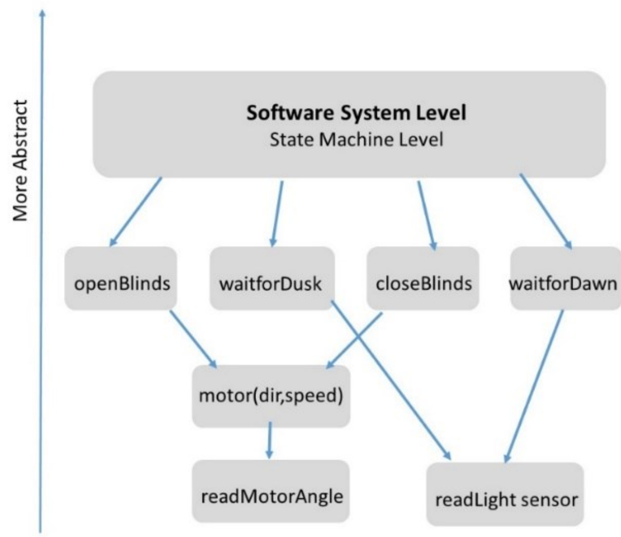

Figure 5: Abstract layers for the automatic blind opener.

Students are given some time to work in groups to attempt their system-level design on paper. After a discussion, they are given the systematic approach shown in Figure 3-5. They then need to write the corresponding software for that design and test it with the components. Other scaffolding in the workshop, done before the design step, is for students to experiment with interfacing a variety of sensors with the microcontroller using existing code and learning how to wire the sensors and measure and display results.

Workshop 4: Wires and Connectors Too often, we see students implementing awkward solutions or poor quality of work when it comes to wiring. The results of such work can result in hazards or inconsistent performance of the design. Here we explain about various wire types and voltage/amp ratings. This will include topics of safe load amperages, and when to use various common type of wires (e.g. PVC, magnet, bus). We also delve into some examples of specialty wiring for certain situations such as harsh environments. Lastly, since safety is utmost importance of any project, we explain to the students how to properly select and implement a fuse for a particular project. The workshop itself consists of fabricating commonly used connectors (e.g. BNC cables, RJ-45s, Molex ™, DC Barrel Jacks, Misc. Crimped Connectors, Banana Plugs, etc). The goal here is to expose the student to many options for connectors whether it is for signal use or power.

For each style of connector fabricated by the student, we emphasize consistency in quality, and have the students use specialty tools to verify the integrity of the signal. They are also required to diagnosed a randomly defective cable/connector, and repair as needed.

Workshop 5: Through-Hole Soldering Soldering is one of the most essential basis skills of a good engineer, and often times students do not learn how to solder until their senior year. We want to introduce soldering to them early, as to gain their confidence and curiosity of their chosen field. We were also motivated to teach this portion due to the number of senior capstone projects we have witnessed using breadboards in their final prototype. Breadboards are fine for testing, but over time can become unreliable due to field use. It also takes up excessive space. Like wiring, poor quality soldering can lead to poor performance. Although some students might have some prior soldering experience, most have not been shown the proper way to solder.

The hardest thing about debugging a board that is poorly soldered is that it is difficult to determine which of the soldered connections are defective. We use this lesson to explain the physics and material portions of soldering. By understanding the fundamentals of soldering, students can make consistently reliable solder joints. Consistent quality will result in consistent electrical performance.

For the workshop here, we use soldering kits and check students' soldering progress along the way for quality control. By inspecting each soldering joint meticulously, we can observe if consistent and acceptable levels of solder were used, along with an adequate amount of heat application to the solder joint.

In addition, we hold a discussion on common soldering situations, and how to debug defective soldered boards. Each student is taught how to visually inspect soldering joints, as well as how to use tools such as a Digital Multimeter (DMM) to effectively diagnose a defective board. Repair methods including using wicker wire and solder pumps are practiced with demo boards. Different type of solders are discussed, and when is it appropriate to use them (e.g. lead free for ROHS compliance). Flux is also introduced as an aid for difficult or sensitive soldering situations.

Workshop 6: Surface Mount Soldering Once the students gain confidence with through-hole soldering, the next natural step would be to learn how to surface mount solder. As modern electronic devices continue to shrink in size, the need for surface mount designed printed circuit boards (PCBs) become more important. Here in the classroom they learn about the common resistor, capacitor, and IC packages used in industry. A discussion of through-hole compared with surface mount soldering is held, with advantages and disadvantages of both discussed.

Like the through-hole workshop, consistent techniques are once again emphasized. Students learn to surface mount solder using both soldering irons and ovens with commercial off-the-shelf practice kits. Microscopes and magnifiers are introduced and used to aid with soldering, and for board inspections.

Debugging boards with surface mount components are discussed. Surface mount component repairs and removals are also taught using both soldering irons and heat guns. Students are then required to remove and replace surface mount components in an efficient manner on a difficult multilayer PCB board we supply. As a finishing touch to soldering craftsmanship, students are shown proper ways to clean their PCB boards to rid of impurities and potential shorting issues with certain flux applications.

Workshop 7: PCB CAD This workshop introduces the fundamentals of designing a Printed Circuit Board (PCB). The students learn to use both Eagle and Design Spark CAD programs for their PCB designs. The purpose of a PCB is to minimize the size of the prototype circuit board in an organized fashion, and to increase reliability.

Students start with the schematic editor window. This is important as it helps keep the circuit design robust and systematic. They proceed to familiarize themselves with the program layout and schematic editor capabilities (e.g. how to place, remove, connect, notate their parts and check their schematic layout). Once the students finish laying out their circuit design, they proceed to import their schematic circuit into the board layout window.

The board layout window has the ability to wire, notate, drag, rotate, ERC, DRC check, add vias, and auto-route their circuits. Students are then introduced to the idea of working with PCB layers (e.g. silkscreen, mask, solder paste).

To prove their understanding of PCB fundamentals, we supply a prototype circuit built on a breadboard. The students are then required to observe the circuit, and model an efficient PCB that meets the circuit requirements (i.e. size, power ratings).

After the CAD tutorial, we demo a PCB milling machine and give a quick overview of how it works. The goal of this workshop is to get the student thinking about how circuits are designed and implemented. This will allow them to create efficient and reliable boards for their projects.

Workshop 8: Basic Tools In this workshop, we introduce students to a variety of hand tools. The main theme to teach here is "The right tool, for the right job". Many times we find ourselves misusing tools, which can result in damage to the project, tool, or the users. For many, this will be the first time they use something other than a screw driver. They also learn about common build materials such as screws (e.g. sheet metal, wood, machine, etc.), and their relating properties (e.g. strength, coating, etc.). We go into detailed discussion of the mechanical design criteria that went into the different styles of each tool (e.g., what are the advantages to using a star bit driver and screw versus a phillips-head driver and screw; what are the different types of hammers used for and why). Since these are EE and CmpE students, this is the only exposure that they would have to design considerations of mechanical tools.

During the workshops students learn how to mark measurements properly using various tools. A discussion on metric and SAE standards follows. "Measure twice, cut once" is one of the important rules to work by in the machine shop. They also learn how to use hammers, socket wrenches, clamps, hand saws, vice grips, and other common tools. Some specialty tools are introduced such as tap and dies, pipe cutters, pipe benders, and rivet drivers. By introducing the students to a variety of tools, they will more likely use the correct tool for fabricating their project.

For their check-offs, they have to show a basic mastery of the tools that were introduced to them. We create multiple stations that will allow them to demonstrate proper selection and usage of tools. We also check for accuracy of measurements by giving them varying pieces of material, and students will have to apply basic geometric calculations for custom measurements and tool use.

Workshop 8: Power Tools Once they have a handle on the basic hand tools, we move onto power tools. Power tools are wonderful because they make our lives easier with their efficiency, speed, and power. They are, however, indiscriminately powerful and can cause injuries quickly. Before this particular workshop, safety protocols are once again emphasized.

There is a discussion about the various types of materials that are used (e.g. wood, acrylics, steel, aluminum). We also introduce the students to the various tools they will be using ahead of time, and how to prepare and inspect the machines and materials for the fabrication (e.g. machine integrity, measurements, bit/blade selections, cutting oils). Each student is taught how to properly use a power drill, impact hammer drill, vertical/horizontal bandsaws, and sanders. Demo stations are set up, and students have to show proficiency in using each demoed power tool. We find that prior to this shop, most students have some limited use and exposure to the power tools, and by the end of the workshop we hope they gain confidence and respect for the tools they are working with.

In this particular lab, each student builds a wooden box starting from 1"x4" boards. They use a miter saw, drills, power screwdrivers, and a table top mounted belt sander. Due to the low cost of wood, many student design teams employ wood in building their structure. Prior to this class, most ECE teams asked the senior design lab staff to build the structures for them or they needed extensive help. Many of the students in the class use the box built in this lab for their term project since the design requires an enclosure for the circuit.

Figure 6: Power Tools workshop.

Workshop 10: 3D Cad 3D CAD allows for rapid design of parts. We use Solidworks in the course. The ability of using CAD allows the students to output to machines such as 3D printers, laser cutters, CNC milling machines, and waterjets. Thus it is considered a versatile program to learn, and aids in creating a fit and flush prototype. In addition, using CAD is important when learning how to 3D scan an object. Sometimes it is not enough to scan a replica, but we also have to be able to modify the scanned object in a CAD software.

The students go through a tutorial which explains the fundamentals of CAD design, and goes over the commonly used software tools and interfaces. We then give a walkthrough of how to systematically approach a design, and how to setup the software for efficient use. Various CAD tips and design tricks are shown, and students are taught to create scalable models and relationships for design fluidity.

For their assignment, students design a basic enclosure that could potentially house their circuitry for their final project. The enclosure will be created in two parts to allow accessibility to the circuit, and both parts have to fit properly using an "Mate" tool in the assembly phase of Solidworks CAD software. They also design another piece of their choosing, and then use a 3D printer to fabricate their design. The model they choose to design in CAD has to meet a criteria of certain complexity. When the model is completed, it is checked for proper CAD fundamentals such as design approach and measurements.

IV. DESIGN PROJECT

Each student must design and build a project of his/her own choosing. They are given the requirements of the project in the second week of the semester and the project must be completed and demonstrated by the last week of the semester. The project must contain each of the following components:

- 1 or more sensors
- 1 or more outputs (motor, multiple LEDs, solenoid, etc.)
- A microcontroller
- PCB or vectorboard on which the electronics and/or sensors are mounted and parts soldered
- Enclosure/structure that contains the circuitry or that is used to mount the circuitry

A modified waterfall design process must be followed and documented in a design notebook. The notebook must capture all important project documentation in chronological order. The project has the following project milestones:

1. Initial Design Idea: sketches and description of the idea in sufficient detail to discuss the suitability of the project with an instructor
2. Initial Project Review: sufficient details in the lab notebook in order to discuss the design with an instructor and to document the design process.
3. Second Project Review: The project should be completely designed with the description of the physical component systems that will be used and how they will be integrated. The parts need to be ordered by that time.
4. Demo of the final project and submission of the design notebook

Students have 12 weeks to work on their projects. Moreover, the labs do not meet during the last four weeks of the term in order to allow students ample time to complete their work. They have full access to the open senior design lab spaces and to the expertise of all the senior design lab support instructors.

Sample student projects done in previous semesters include an automatic dog feeder, interfaces to musical instruments, wearable electronics, electronic games, automatic door openers, alarm clocks, and motor tracker mechanisms (to track light or sound). Figure 7 shows an automatic fish feeder, where the student designed the round bin that contains the food and 3D printed it and then connected it to a motor that was programmed to turn the bin based on a time schedule. It releases food when it turns, and has a mechanism built into the design for adjustment of the amount of food. Figure 8 shows a battleship game. The boxes were designed in CAD and cut with a laser cutter. Each box has a microcontroller and a display to show the locations of the battleships and the hits, along with a keypad to input ship positions and hit locations.

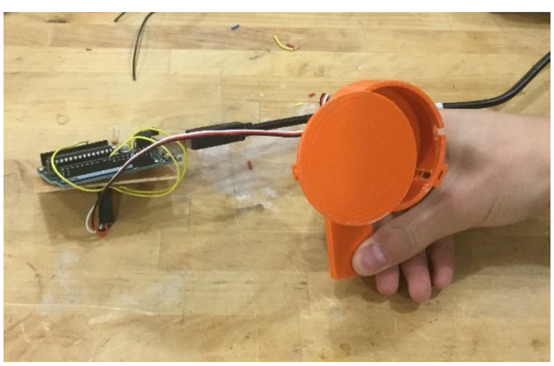

Figure 7: Automatic fish feeder.

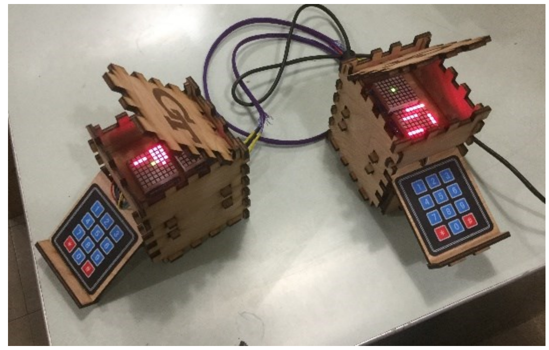

Figure 8: Battleship game.

V. ASSESSMENT

This course has been taught six times. Due to the currently available space, it is limited to 20 students per term and usually is at maximum capacity. The practical skills portion of the course is taught using mastery-based approach, where their workmanship in the workshops must reach a threshold in order to be approved. Therefore, we can guarantee that the skill level is high. We also did student surveys to determine the confidence level of students in both design and practical skills, where confidence is determined by asking students to rate their competence in the skills. Figure 9 shows the Spring 2016 class pre-survey results and a longitudinal survey (taken one year after the course) of their competence of practical skills taught in the class, where 1 is the lowest rating and 5 is the highest. A comparison of the pre and post-one-year results show that there is a significant gain in all categories one year after the course ended. Figure 10 shows a similar plot for the confidence in the design aspects of the course, also for Spring 2016.

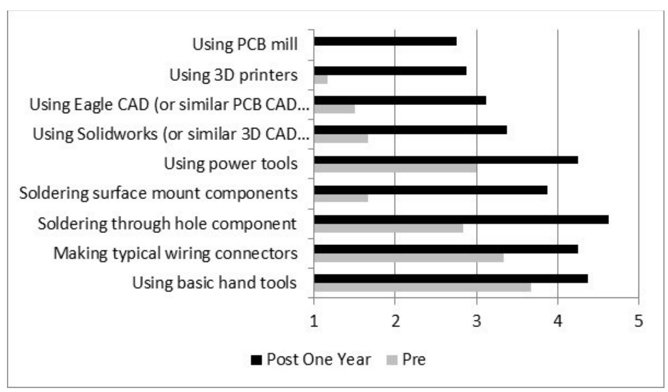

Figure 9: Student survey results for the Spring 2016 course offering, where 1 is the lowest and 5 is the highest self-reported rating of their competence on that skill.

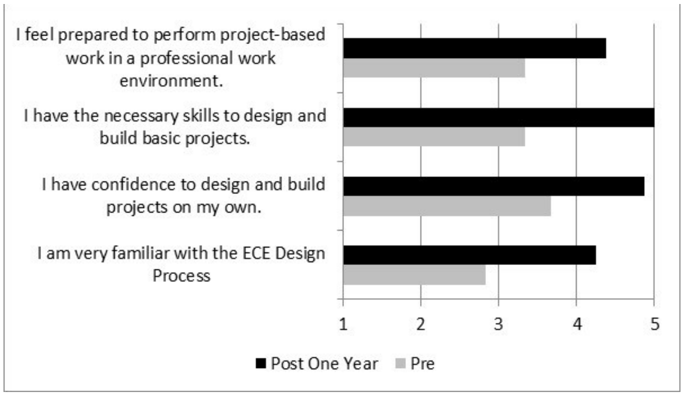

Figure 10: Survey results for Spring 2016 course offering showing confidence in design.

In Fall 2016, the design portion of the course was enhanced to include the blind-opening mini-design project described above. Figure 11 shows the self-reported competence of the skills in the course for the Fall 2016 class, including the pre survey, end-of-term post survey, and longitudinal survey taken one semester later. The two top questions (writing C code and datasheets) were added to the survey to access the impact of the mini-design project. Figure 12 shows the results of the confidence levels for the design portions of the course. The gains in design confidence in the pre versus post survey results are larger for the Fall 2016 cohort versus the Spring 2016 cohort. Part of this may be due to the fact that the Fall cohort were slightly younger (more sophomores versus juniors, who might have more initial experience).

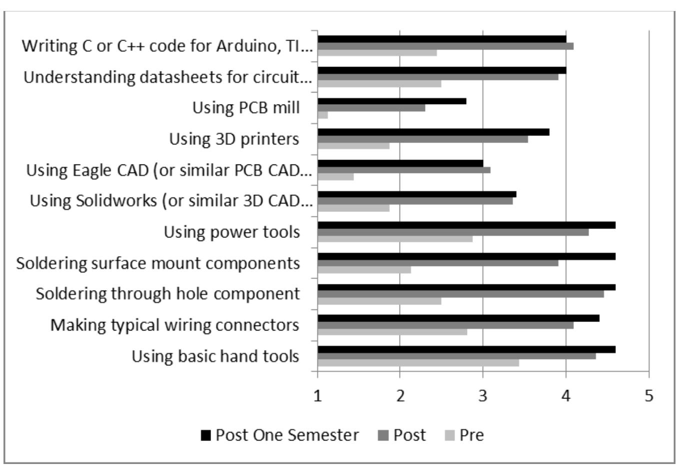

Figure 11: Student survey results for the Fall 2016 course offering, where 1 is the lowest and 5 is the highest self-reported rating of their competence on that skill.

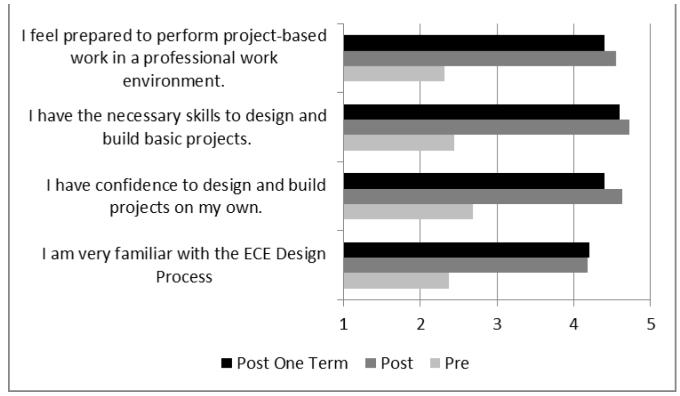

Figure 12: Survey results for Fall 2016 course offering showing confidence in design.

The written comments at the end of the course and on these surveys are extremely positive about the course and how much fun they had. The suggestions for improvement include expanding the course either by adding credit hours or by adding a follow-on course that goes into more depth in PCB design and CAD design for mechanical components. Several students suggest dropping the hand tools topic in favor of adding more advanced topics. However, there are some students in the course who have never used most of the hand tools, and we want this course to be open to all students of all levels in the department. Also, the corresponding hand tools workshop is likely the only exposure that the students will have in their curriculum to mechanical design considerations in everyday items.

VI. SUMMARY

This course, Practical Skills and Design, fuses the makerspace mentality with engineering design education. The workshops on practical skills require students to reach a level of mastery of these skills with an understanding and appreciation of craftsmanship. It also introduces students to the engineering design process with a mini-design and with a final project of their own choosing. The success of the course is heavily dependent on the partnership between faculty/staff/students in developing and teaching the course. The faculty perspective enforces some pedagogical design education framework on the course. The staff who teach this course also run the senior design labs and have tremendous practical experience in design and building projects. The student who suggested the course in the first place and the student who developed much of the content of the course, both worked to make the materials and the delivery fun and interesting for students.

From a student perspective, they get to build a fun project of their own choosing and have dedicated experts to help them along the way, and they learn how to apply the engineering design process. From a larger departmental perspective, this course will play a significant role in the success of a new ECE-centric maker space that is being built on campus since the students who complete this course will be certified as the student leaders in that makerspace.

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