AC 2012-4115: PRACTICING NEEDS-BASED, HUMAN-CENTERED DESIGN FOR ELECTRICAL ENGINEERING PROJECT COURSE INNOVATION

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Abstract

In order to be fully prepared for the engineering workforce, students should tackle design challenges that are both contextually and technically deep. This paper details a curricular innovation in a junior-level, project-based electrical engineering course within the Department of Engineering in Arizona State University's College of Technology and Innovation. Teams of engineering students were asked to develop design project briefs based on the needs of a user or user group of their own choosing and then implement a technical prototype in one semester. Student work from a class with this needs-based, human-centered design pedagogical approach is described.

1. Introduction

Engineering students benefit from working on authentic design challenges that are connected to real users and real context over "toy problems". However, finding subject-matter appropriate engineering projects in addition to securing access to real users for design projects can be immensely challenging and time-consuming for instructors, especially at scale. This innovation relies on students to bring context into the classroom, where the instructor can connect it to the curriculum. In addition, the learning objectives of the Engineering 301 mezzanine Electrical Engineering course described herein are focused solely on developing technical competencies and technical problem-solving. By engaging students in finding and defining the human-centered design aspects for their project and discovering a user and their user's needs in the process, this approach offloads those efforts from the instructor while still providing rich learning opportunities for the student teams. With this approach, students also develop additional motivation toward the project outcome and foundational exposure from previous classes to the tenants of human-centered design is reinforced. Illustrative, example project topics include a parking space counting system for the on-campus parking department, an electronic component test automation robot for a local company, and an electronic coaching glove for a bowling coach.

Student teams were required to propose projects for the course that would allow for the use of an Arduino Uno microcontroller, receive input from at least one sensor and control at least one actuator. In addition, budget constraints ($160/student team) and user testing requirements were given. At the beginning of the semester, teams presented multiple options for potential users / clients / stakeholders and received peer and instructor feedback that guided their selection. Student teams completed detailed benchmarking, user observations and data collection, a mission statement, and defined requirements and specifications based on the user. The majority of the semester was then spent designing and implementing functional prototypes. Time in class mixed "just in time" mini-lectures on relevant topics such as microcontrollers, interfacing, circuit design, and software engineering topics, with mentoring sessions. Real users allowed students to solicit regular feedback and test in-situ to guide their design decisions and help them iterate on their designs. This paper can inform instructors interested in bringing additional student-supplied context into their electrical engineering project courses.

This unique combination of exposure to deep technical issues around microcontrollers crossed with real users and a human-centered engineering design process backbone, appears to be a positive motivating factor for students not only in their interest in a high grade but also a commitment to deliver a product to their real clients and a constant reminder of their project's connection to the real world. More iterations and more innovative solutions appear to have been created with this human-centered design approach then the class of the previous year with the pre-defined project menu. It is hoped that this intervention can have implications for other instructors considering new models for the design of electrical and multidisciplinary project classes.

2. Project-Based Learning

2.1 Advantages and Disadvantages

Undergraduate engineering students are learning to become engineering practitioners. Curriculum for an engineering major consists of foundation courses in engineering, science and math, mezzanine coursework consisting of a focus on technical engineering content knowledge, and capstone courses pulling this material together and often applied to example engineering projects. Course sequences chain together, building on the relevance and complexity of the subject matter. While active-learning techniques can take shape in any classroom learning experience, project-based learning pervade the capstone experience[1]. Project-based learning[2] focuses pedagogical efforts on open-ended, authentic problem solving. The basis of many capstone engineering design courses are engineering challenges undertaken on behalf of a third-party, either as a sponsor or end-user.

For the student, such project-based learning experiences allow for the application of their engineering content knowledge to "toy" or real world problems, providing for additional context or motivation. It is a constructivist approach to learn by doing. By Bloom's taxonomy, this can approach higher levels of sophistication and mastery by analysis, synthesis and evaluation. Benefits for the student are along the lines of connecting their learning to wider applications, developing additional skills of communicating and teaming, and practicing their engineering know-how. For the learner, there is an opportunity to refine their mental model of engineering design process and create what could be a portfolio piece to better show what they know. Sometimes learning experiences have a too high level of ambiguity for students not used to open-ended problem solving, causing some levels of discomfort with less structure and lack of clarity of learning objectives being met, making for a spectrum of learning experiences.

For the instructor, project-based learning teaching experiences can be engaging and frustrating as well. It is an opportunity to bring topics of interest forward beyond what may be available from textbook resources. An active learning approach may provide for a dynamic classroom, through a routine classroom teaching experience may become more uncertain. Just-in-time instruction and individual flexibility may require more work or consternation. Devoting class time to non-technical topics like teaming and communication may lessen the direct amount of technical content able to be lectured. For the instructor, oftentimes, the burden of developing, curating or otherwise rustling up potential project prompts can take up much of the course planning time. Finding appropriately scoped projects, or aligning project prompts with course objectives may also be of difficulty.

The role of project-based learning in the classroom is often part of undergraduate engineering programs, especially with efforts to align curriculum to ABET a-k criteria. Bringing in problem-based and project-based learning approaches and experiences down to the mezzanine level courses with an explicit focus on technical content is new at our campus.

2.2 Project-Based Learning as a Local Context

In Arizona State University's College of Technology and Innovation, the undergraduate program in the Engineering Department is supported by a project spline, having project-based learning experiences within a core course each semester and also throughout the student's tenure in the program from freshman to senior years. It is within this multi-disciplinary undergraduate engineering major that there are opportunities for students to concentrate in civil and land development, electrical systems and mechanical systems areas. Morrell et. al[3] and Roberts et. al[4] have described the context of the undergraduate multidisciplinary engineering program, its origins, objectives and structure. Additionally Grondin & Morrell[5] has detailed the electrical systems focus area within the program.

The junior year courses provide a disciplinary dive into the civil / electrical / mechanical areas of focus. In the program, the freshman and sophomore years provide some foundation in engineering process, an array of technical competencies, and practice in tackling engineering projects; the senior year is comprised of a year-long capstone experience. **Figure 1** shows the matrix of core classes in the undergraduate program mapped to specific learning outcomes.

Curriculum	Fresh 1				Fresh 2					Soph 1				Soph 2				Jun 1			Jun 2			S 1	S 2
Outcomes	EGR 101 Intro Egr Des I	CHM 113/Science Elective	APM 265 Math of Change I	ENG 101 First-Year Comp	EGR 102 Intro Egr Des II	ENG 102 First-Year Comp	APM 266 Math of Change II	PHY 121 Mechanics	EGR 104 Critical Inquiry I (L1)	EGR 201 Fall Multidisciplinary Proj	Engineering Fund (Modules)	EGR 280 Eng Statistics	Chem 113/Science Elective	EGR 202 Spring Multi Proj	Engineering Fund (Modules)	MAT 274/5 Differential Equations	HTY 316 History of Engineering	**EGR 301 Fall Concentration Proj**	Primary Concetration I	APM 267 Math of Change III	EGR 302 Spring Conc Proj (L2)	Primary Concetration II	MAT 343 Linear Algebra	EGR 401 Capstone I	EGR 402 Capstone II
Design					1					2				2				**3**						3	3
Problem Solving	1									2	2				2				3			3		3	3
Professionalism	1													2				**3**						3	3
Communication				1		1			2												3			3	3
Engineering Practice	1				1					2				2				**3**						3	3
Critical Thinking				1		1			2		2	2			2						3			3	3
Technical Competence		1	1		1		1	1			2	2	1		2	2	2		3	3	3	3	3	3	3
Perspective				1		1			2								2							3	3

Figure 1: Program learning outcomes aligned to core courses. (Number indicates levels 1-4 within each outcome the course aims to meet. Some Engineering Program outcomes are described in Table 1).

For the junior level Engineering 301 course, students are positioned between an experience the previous semester (sophomore year, second semester) with a project-based learning course focused on learning a human-centered design process and a senior capstone course applying their design process. The mezzanine level course then is at an interesting juncture, serving as a bridge from the engineering foundations to a capstone experience by way of a deep dive into disciplinary technical proficiency. The learning objectives around design, professionalism and engineering practice are delineated in Table 1.

Table 1: Course Learning Objectives (culled from Engineering Program outcomes)

Design (achieve level 3)
1. Recites the steps and information flow in the engineering design process and uses at least one organizational or technical tool in each step.
2. Given a problem definition, uses a design process and design tools to produce a documented design solution including a prototype and explains how the design meets the constraints and criteria.
3. Evaluates design process and resulting design quality and suggests improvements.

Professionalism (achieve level 3)
1. Exhibits professionally appropriate behavior patterns, appreciates engineering as a learned profession and possesses daily success skills.
2. Accepts responsibility for their education, understands the major professional and ethical responsibilities of engineers, the major specialties of engineering and basic corporate structures and purposes.
3. Uses common moral theories and concepts to guide their ethical decision making and has formulated a probable career path that accounts for current trends in technology and society.

Engineering Practice (achieve level 3)
1. Describes the essential elements of engineering practice including teaming.
2. Given an engineering problem, creates a plan and works within a team using the necessary engineering tools to produce a solution.
3. Evaluates the effectiveness of the planning process, teamwork, and tool selection and use.

The Engineering 301 course gives a uniquely situated experience for students in the multidisciplinary engineering program to apply their engineering foundations and apply disciplinary-specific education to their project work.

3. Course Organization

The course is the first electrical system design-specific course that students take and is structured around a significant electrical or electromechanical project. Juniors with an electrical or robotics emphasis primarily take the course. It met twice per week for 1 hour and 50 minutes over a 16-week fall semester. Every team does completely different projects and experiences identifying and sourcing parts for their particular application. Lecture-based instruction was sparse, focusing on short just-in-time lectures or jigsaw cooperative learning activities[6, 7] on topics relevant to the majority of the class and significant team mentoring by the instructor. Content modules included an introduction to human-centered design, the Arduino hardware and software platform, sensor types and interfacing, actuator types and interfacing, power supply design, creating a power budget, and basic soldering and prototyping techniques. The course is deliverable and deadline-driven, with emphasis on building a community of practice where students both learn from and support each other. The amount of time spent on teaching human-centered design is minimal, since it is applied from previous classes as a context for the project work.

Students were broken into eight teams of 3 – 4 students based on their responses to the CATME Team-Maker Survey team creation tool[8]. Teams were balanced by schedule and to spread experience across teams. Each team was challenged to design and build a fully functioning prototype product during the 16-week course that must:

1. Be a human-centered design for a real client
2. Use an Arduino Uno microcontroller development board
3. Be programmed with the Arduino Programming Language (similar to C/C++), C, or C++
4. Receive input from at least one sensor
5. Control at least one actuator based on input from the sensor(s)
6. Be tested with a real client at least once
7. Stay within a budget of $40 per team member
8. Meet additional requirements as defined and agreed upon by the team and the professor

Each team does a completely different project within these requirements. These requirements are designed to give teams the flexibility to choose their own projects based on their interests and client availability. Students are exposed to the fundamentals of human-centered design in their sophomore-level design courses, so minimal class time in Engineering 301 was spent covering human-centered design concepts. By having a real client, students are challenged with understanding the real context in which their product will work, frame the problem so that it meets both client and class needs, and develop a clear set of criteria and constraints to guide the design and prototyping of the product. In addition, students are also challenged with the multi-disciplinary nature of real design problems, allowing them to experience the boundaries between electrical, mechanical, and software design.

In order to limit the scope of the course to focus on designing a system in context from start to finish, the Arduino platform is used to reduce the time spent on lower-level microcontroller programming. (The follow-up course requires students to choose their own microcontroller and design custom printed circuit boards). The Arduino platform provides a set of easy-to-use C++ libraries and custom IDE that significantly reduce the knowledge and experience required to program a microcontroller. Advanced students can choose to ignore the included libraries and program the on-board ATmega microcontroller at a lower level. In addition, there is substantial documentation and a large multi-disciplinary support community (including educators, engineers, hobbyists, and artists) for the Arduino, giving students experience with identifying what they need to know to solve a particular problem and searching for it in available resources. By making these resources available to students, it further shifts the role of instructor from being the source of all knowledge to the expert guide helping connect students with key resources. This acclimates students to be better prepared to do lifelong learning, one of the key attributes of the *Engineer of 2020*[9].

The technical objectives of the class are for students to learn about using a microcontroller, select appropriate sensors and actuators to meet their design requirements, design interface circuitry to connect their sensor(s) and actuator(s) to the microcontroller, fabricate circuits and wiring harnesses, and write software to glue the system together. As a result of the real context of their problems, students were also exposed to mechanical design and fabrication, with significant consideration of the human interface.

The needs-based, human-centered design start to this project-based learning experience is based on practice in industry from product development and innovation consultancies like IDEO[10-12] and Jump Associates[13]. Particularly, by human-centered design, as applied to the class project, user empathy[14] is core; the technological concern is focused on servicing a specific customer need determined from a specific user or user group. Dym et. al[15] describes it as "design thinking" and academic centers at Stanford and Northwestern have developed in recent years to champion the teaching of innovation through such approaches.

3.1 Deliverables

While each team completes a different project, the course is deliverable-driven with both individual and team deliverable deadlines spread throughout the semester to ensure that teams made progress. All students completed individual weekly status reports, and completed the CATME Team Member Effectiveness Survey in the middle and end of the semester. Teams have a number of general process-oriented deliverables (see Table 2), and are also required to identify project-specific deliverables. A schedule of deliverables is shown in Appendix A: Schedule of Deliverables.

Table 2: Major Course Deliverables

1. **Client Options Presentation** – teams present 2 potential clients and their projects, and receive feedback from the class
2. **Research and Benchmarking Report** – as in the sophomore-level design class, this report documents the mission, schedule, along with user data that has been collected, a user profile, and user research
3. **Gantt Chart** – project management requirement for planning team activities for the semester
4. **Block Diagram, Schematic, Bill of Materials, Software Pseudocode, and CAD Drawings** – teams must create and maintain these documents for their projects
5. **Design Review** – in this team presentation, designs are reviewed in depth by faculty members and classmates
6. **Proof of Parts** – teams must submit proof (e.g., physical parts or invoices) that all necessary parts for the project have been sourced
7. **Progress Demonstration** – teams demonstrate to the class what they have working, discuss what they have learned so far, and describe the next steps for their projects
8. **Final Presentation and Demonstration** – a team presentation in which project results are reviewed in depth by faculty members and classmates. There was no oral or written exam.
9. **Final Report** – this team report documents the project design, implementation, and evaluation.
10. **Team Binder** – electronic on Blackboard, paper in a 3-ring binder, or both. Must contain latest versions of all of the above, in addition to data sheets.

3.2 Human-Centered Design Deliverables

Most students were introduced to basic human-centered design principles in a sophomore-level project spine course, so the human-centered design content was primarily encapsulated in two early course deliverables: the Client Options Presentation and the Research and Benchmarking Report.

3.2.1 Client Options Presentation

Throughout the semester, teams were mentored to ensure they were making design decisions based on the needs of their users. In the second class meeting, teams were asked to brainstorm possible clients for which they could design a product and contact them to evaluate compatibility between client needs and course requirements. Students found potential clients and users through their jobs and internships, contacting various university staff, and even talking to their landlords.

Each team gave a 10-minute Client Options Presentation, where they presented two potential clients with whom they had communicated. Teams were asked to answer the following questions to the best of their ability for each of the two potential clients, with the understanding that the answers would evolve as they learned more about their clients and got deeper into the project:

1. Who is the client? Be specific!
2. What is the mission of the project?
3. What are the deliverables for the project?
4. What are the constraints for the project?
5. What are the users and stakeholders for the project?
6. What are the requirements and specifications?

Students and instructors challenged teams on their potential clients to help them determine what they needed to know to make a choice, and provide opinions of which proposed project would be a better fit for the class both technically and pragmatically. Clients included companies, individuals, and the university, while some proposals specified no real client. Examples of the clients students found and their proposed projects are shown in Table 3.

Table 3: Proposed Potential Clients and Projects

Companies	**Individuals**	**University**	**Technology-Centered**
• Technology startup (continued R&D on existing product) • Large IC fab (control system for testing) • Restaurant chain (order automation) • IC fab startup (manufacturing line robotic tester) • Public library(book checkout)	• Avid boater (Boat navigation logger) • Bowler (swing feedback) • Busy mom (baby alarm) • Sports trainer (training automation)	• Mechanical design course (rocket dynamics logging) • Another course (design a course project) • Campus gym (unknown project) • Campus greenhouse (plant maintenance) • Parking services (full lot notification)	• Automatic Drink Dispenser • Rain collection/weather station • Rube Goldberg® machine • Smart toy

3.2.2 Research and Benchmarking Report

Following the Client Options Presentation, teams were asked to make a decision as to which project they would pursue for the remainder of the semester, and to do deeper research on their client and potential users through interviews, surveys, site visits, observations, and web research. The Research and Benchmarking Report, due 1.5 weeks after the Client Options Presentation, asked students to demonstrate understanding of the client and problem (see Table 4). The final clients and mission statements generated by the students are shown in Appendix B: Final Clients and Mission Statements.

Table 4: Research and Benchmarking Report Specifications

- **Project Name, Team Members, Date, Version**
- **Client.** Be specific! The client should be at least one real person with a name and contact information. Consider having multiple clients for your product (e.g., a manager who approves the project and an employee who will actually use it).
- **Mission Statement.** "To design…" (see examples, **Error! Reference source not found.**)
- **Project Deliverables.** Be specific!
- **Constraints.** Describe in table form. Include a second column for the rationale for each constraint.
- **Schedule.** Include (1) design process stages, (2) class deliverables, (3) project-specific deliverables, and (4) planned times to meet and get feedback from the client and users.
- **Benchmarking Data Collection.** Discuss data collection expeditions and associated results. Augment text with tables and figures of collected data. Also, look for analogous situations and people that you can study.
- **Users and Stakeholders**
- **User Profile (3 pages minimum).** In this narrative, describe the environment in which the product will be used, and how the client currently interacts with that environment. Use all of your senses!
- **Research.** Include links to relevant materials, methods, and technology (e.g., a light sensor or stepper motor), and discuss how they might be useful for your project.
- **Requirements and Specifications.** Describe in table form. Include a column for the rationale for each requirement and specification.
- **Assumptions**

The balance of the semester was spent focusing on the technical aspects of the project, with frequent reference to making design decisions based on data-backed user needs. For example, the faucet project for university food services had a user-defined requirement that the water flow not be slowed by the device. The team used a calibrated container and a stopwatch to measure the flow of the faucet, and used these data to choose a solenoid valve that would allow sufficient flow.

4. Examples and Discussion

In a phenomenographic study of student designers, Zoltowski et. al[16] identified 7 different ways (see Table 5) that human-centered design is experienced, ranging from technology-centered (no human-centeredness) to empathic design.

Table 5: Categories of Human-Centeredness (from Zoltowski et. al[16])

Category of Description	Human-Centered Design is…
1	Technology-Centered
2	Service
3	User as Information Source Input to Linear Process
4	Keeping the Users' Needs in Mind
5	Understanding the Design in Context
6	Commitment to Involving Stakeholders to Understand Perspectives
7	Empathetic Design

4.1 Discussion: Examples of Human-Centeredness

Eight teams created projects in the course, and six of the teams had a significant human-centered component to their designs. Table 6 lists the eight team projects and their level of human-centeredness, based on how users were described in final project reports.

Table 6: Project Human-Centeredness

Client	Project	Description of Students' Experience of Human-Centered Design
Technology startup	Automotive Nanny Cam	Category 1: Technology-Centered
University recruiter	Electronics Demonstration Device	Category 3: User as Information Source Input to Linear Process
House rental company	Automatic Plant Watering System	Category 3: User as Information Source Input to Linear Process
IC fab startup	Automatic Quartz Crystal Test and Sort Machine	Category 3: User as Information Source Input to Linear Process
University parking services	Parking System	Category 3: User as Information Source Input to Linear Process
Avid boater	Trifoiler Data Acquisition and Display	Category 4: Keeping the Users' Needs in Mind
Bowling coach/bowler	Smart Bowler	Category 4: Keeping the Users' Needs in Mind
University dining services	Ultimate Faucet	Category 5: Understanding the Design in Context

As can be seen in Table 6, projects spanned a number of levels of human-centeredness. The Automotive Nanny Cam project had a real client but superficial mention of a user, but was primarily driven by solving technical problems with student-assumed context. This resembled a typical industry-driven widget design project. The Electronics Demonstration Device, Automatic Plant Watering System, Automatic Quartz Crystal Test and Sort Machine, and Parking System had users who provided information and support of the projects, primarily in the form of design constraints. The results were primarily proof-of-concept prototypes that needed another revision to be useful for the user. The Trifoiler Data Acquisition and Display and Smart Bowler teams kept users' needs in mind while designing, pushing the boundaries of disciplines to create useful prototypes. The Ultimate Faucet team put significant effort into understanding the context in which their design would be used, from the engineering constraints such as water flow to usability concerns such as the user interface for their product.

4.2 Discussion: Examples of Technical Rigor

All eight projects met the technical requirements specified at the beginning of the course: they programmed an Arduino Uno (or in the case of two teams who needed more I/O pins or processing, an Arduino Mega), received input from at least one sensor, and control at least one actuator based on input from the sensor(s). A summary of the technical characteristics of the projects is shown in Table 7.

Table 7: Project Technical Characteristics

Project	Input/Sensors	Output/ Actuators	Other Circuitry	Other Features
Automotive Nanny Cam	Automotive CAN bus transceiver IC	Embedded solid-state video recorder module	Multi-output power supply	Custom OBD2 (CAN bus) library
Electronics Demonstration Device	Resistive pressure sensor, Sharp IR distance sensor, thermistor, accelerometer, resistive flex sensor, ultrasonic ranger, PIR motion sensor, photocell	LCD (serial), many LEDs (digital/PWM), laser, servo motor (PWM)	Arduino Mega	Significant coding effort
Automatic Plant Watering System	Soil moisture sensor	Water pump	MOSFET, SLA battery	Solar battery recharging, μC sleep
Automatic Quartz Crystal Test and Sort Machine	3 microswitches (positioning), testing machine (serial/analog)	3 stepper motors (PWM, via stepper driver), solenoid valve, buzzer, LED	MOSFET	Microstepping to reach accuracy requirements
Parking System	4 ultrasonic rangers	Many LEDs	MOSFET, solar charger, SLA battery	Solar battery recharging
Trifoiler Data Acquisition and Display	Anemometer (PWM), GPS (RS232), water leakage sensor	Graphical LCD with touch screen (serial), SD card (UART), 2 servos (PWM)	Arduino Mega, battery monitor, RS232 to TTL converter	Wind tunnel calibration data
Smart Bowler	Inertial measurement unit (I^2C), 2 resistive force sensors	SD card (SPI), speaker (PWM)	Multi-output power supply	LabVIEW for 3-D data visualization, LabVIEW Interface For Arduino (LIFA), state machine, custom PCB
Ultimate Faucet	Flow meter (Hall Effect), flexible button pad	ASCII LCD (serial), solenoid valve	MOSFET	LabVIEW for UI prototyping, state machine

In summary, teams used between 1 and 8 input devices/sensors and between 1 and 6 output devices/actuators. Of particular interest in Table 7 is the number of different types of sensors and actuators used across all of the teams in this junior-level course. Since the course included frequent opportunities for teams to share what they had learned and receive peer feedback along the way through presentations and progress demonstrations, they were able to learn vicariously from other projects. In addition, some teams had members with particular interests or specialties that were reflected in the "above and beyond" features of their designs. For example, the Smart Bowler team had members who were very interested in LabVIEW, so they figured out how to interface it with the Arduino and create a 3-D arm movement visualization based on the position data captured from the inertial measurement unit and stored on the SD card.

4.3: Example: The Ultimate Faucet

The Ultimate Faucet project was designed for the university dining services, which needed a device to automatically dispense measured amounts of water into large containers. The identified users are the campus catering staff, who were contacted by the team when in search of a problem to solve. The team gathered data from the catering staff through interviews, observations, and by taking photos of the space in which the product would be used. The identified stakeholders were the university's students, staff, faculty, and visitors all of whom are patrons of the dining hall. In addition to the technical requirements and constraints provided by the instructor, the design requirements and constraints identified by the team through client data collection are listed in Table 8 and Table 9.

Table 8: The Ultimate Faucet Project Requirements

Requirement	Rationale
No change in water pressure	Campus safety regulation
Run continuously for a minimum of 15 seconds	Campus dining service regulation
No training required for use	Easy to use
Dispensing accuracy to 10 mL	Purpose of product
Not noisy	
Faucet off on power outage	Minimize wasted water
AC adapter or battery	Circuits need power

Table 9: The Ultimate Faucet Project Constraints

Constraint	Rationale
Local water pressure	Campus dining service regulation
Local water temperature	No change to water temperature
Run continuously for a minimum of 15 seconds	Campus dining service regulation

As described in Table 7, the final design incorporated a flow meter based on a Hall effect sensor, a flexible button pad, a text-based serial LCD, and a solenoid valve connected via a MOSFET. The flow meter was calibrated by measuring the time it took to fill containers of known volume. Multiple versions of the user interface were simulated in LabVIEW and tested with the catering staff. The product was controlled by a state machine. This project met all design requirements and is now in use in a university kitchen.

4.4: Example: Trifoiler Data Acquisition and Display

The Trifoiler Data Acquisition and Display project was designed for an avid boater who wanted a system to record GPS coordinates and associated apparent and true wind velocity and direction. The identified client/user was a specific individual that owns a sailboat and is a colleague of one of the team members. The team gathered data from the client through interviews. The client was also identified as the primary stakeholder since he would be the only user of the product. In addition to the technical requirements and constraints provided by the instructor, the design requirements and constraints identified by the team through client data collection are listed in Table 10 and Table 11.

Table 10: Trifoiler Data Acquisition and Display Project Requirements

Requirement	**Rationale**
Shockproof	Environmental requirement
Waterproof enclosure with access for sensors and actuators	Easy servicing
Conforming shape	Not obtrusive
Attachment points	Easy installation

Table 11: Trifoiler Data Acquisition and Display Project Constraints

Constraint	**Rationale**
Read data at 10 Hz	Client specification
Gather wind direction, magnitude, and GPS data	Client specification
Log all data	Necessary to create graphs
Waterproof	Environmental constraint

As described in Table 7, the final design incorporated an off-the-shelf anemometer that measured both wind direction and wind speed in PWM form, a GPS unit that interfaced via RS232, and a water leakage sensor. In addition, a graphical LCD module with a touch screen was used for the custom user interface, along with an SD card slot for data logging and 2 servos to show the calculated true wind direction. The team used an Arduino Mega for greater processing power and extra serial interfaces, and interfaced with a RS232-to-TTL IC for the GPS and a battery monitor circuit. In order to show correct data on the LCD screen, extensive calibration of the anemometer was done in a wind tunnel. This project met all design requirements and is now in use in the client's trifoiler sailboat.

5. Conclusions and Future Work

This paper described how two traditionally disparate topics, human-centered design and a junior-level electrical engineering design course, were combined in an efficient manner. Adding human-centered design to a junior-level electrical engineering design class has a number of advantages. By providing a real-world context, students are more motivated and share sustained interest and excitement with their peers throughout the semester. Students are also afforded a differentiated instruction environment, where they can choose their own level of challenge through the projects that they select. Allowing students to select their own projects is also a more efficient use of instructor time, as instructors do not have to find and test projects in which the students may or may not be interested. Students with little experience in designing and building circuits and students with extensive real-world design experience alike can choose their own projects that fit their experience level. As one satisfied student said, "I was reasonably impressed with the way that you taught the class. You provided us ample help when we needed it, and the structure of your class was good. You made yourself available to us and provided just enough structure for us to 'choose our own fates' as it were. I look forward to next year's class." While instructors may not be the source of all project knowledge and answers with this approach, they can be expert learning guides who create an enriching and cohesive educational experience for students. In addition, this model better prepares students for lifelong learning by teaching them judgment skills, also known as ABET criteria (k) "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."

Next year, possibilities for changes include scaffolding more checkpoints for feedback and encouraging students to do real-time documentation of their projects online. By shifting their binders entirely online, it will better support collaboration within groups when students are working separately. The human-centered design aspect of the course could be better served through more user feedback and testing along the way, perhaps with early rough prototypes tested with students as a proxy for real users. Additional content modules on parts selection (e.g., transistors, MOSFETs, and op-amps), I/O pin expansion, and microcontroller interrupts could be added. Teams could have peer project partners and SCRUM-style meetings to mentor each other. Teams could also review reports from previous years to get additional ideas. Finally, teams could generate Instructables on something they learned from working on their projects. In the follow-up class, students will be exposed to entrepreneurship and business models as a framing for their design projects.

6. References

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7. Appendices

7.1. Appendix A: Schedule of Deliverables

Table 12: Schedule of Deliverables

Week	***Deliverables (I = individual, T = team)***
1	• CATME Team-Maker Survey (I)
2	• Client Options Presentation (T) • Week 2 Status Report (I)
3	• Week 3 Status Report (I)
4	• Research and Benchmarking Report (T) • Preliminary Gantt Chart (T) • Week 4 Status Report (I)
5	• Preliminary Block Diagram (T) • Week 5 Status Report (I)
6	• Week 6 Status Report (I)
7	• Preliminary Schematic (T) • Bill of Materials (T) • Week 7 Status Report (I)
8	• Preliminary Software Pseudocode (T) • Preliminary CAD Drawings (T) • Week 8 Status Report (I)
9	• Design Review (T) • Team Binder (T) • Final Gantt Chart (T) • CATME BARS Team Member Effectiveness Survey (I) • Week 9 Status Report (I)
10	• Proof of Parts (T) • Week 10 Status Report (I)
11	• Week 11 Status Report (I)
12	• Progress Demonstration (T) • Week 12 Status Report (I)
13	• Week 13 Status Report (I)
14	• Week 14 Status Report (I)
15	• Progress Demonstration (T) • Week 15 Status Report (I)
16	• Week 15 Status Report (I)
17	• Final Presentation and Demonstration (T) • Final Team Binder (T) • Final Report (T) • CATME BARS Team Member Effectiveness Survey (I)

7.2 Appendix B: Final Clients and Mission Statements

Table 13: Final Clients and Mission Statements

Client	**Mission Statements: To design…**
House rental company	A product that automates the watering of plants
IC fab startup	A semiconductor checking system that improves manufacturing line performance
Technology startup	A circuit that reads data from the CAN bus of a car and embeds it in a video stream
Avid boater	A product that measures, displays, and logs wind direction and velocity for a boat
Bowling coach/bowler	A wearable feedback mechanism to improve a bowler’s performance
University food services	A faucet that monitors filling a large container of water
University parking services	A product that advises people whether or not a parking lot is full
University recruiter	An educational device to teach middle school students about electrical components