A Second-Year Project-based Course for Embedded Systems

Prof. B. Lorena Villarreal, DigiPen Institute of Technology

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Jeremy Thomas is an Associate Professor and Chair of the Electrical & Computer Engineering Department at DigiPen Institute of Technology in Redmond, WA. He has a BA in Physics from Bard College, and a MS in Physics and a Ph.D. in Geophysics both from the University of Washington. Jeremy is also currently an Affiliate Associate Professor in the Earth & Space Science Department at the University of Washington and a Research Scientist/Engineer at NorthWest Research Associates. Jeremy believes that curricula should be student-centered and embedded within an engaged, collaborative community who understand the broader, societal implications of their work. He aims to achieve this through the design of project-based and experiential curricula, including a recent redesign of the Computer Engineering program. He also leads ABET accreditation and coordinates assessment for the Computer Engineering program.

Jeremy's research is in space physics and electrical engineering, including atmospheric electricity, radio wave propagation, and digital signal processing. He receives external support through grants from agencies such as the US Geological Survey and the National Science Foundation. Currently, Jeremy's main projects are an embedded balloon platform to study the global electric circuit and a tool to integrate satellite and lightning data to help predict hurricane intensity change. He has authored more than 30 peer-reviewed publications, often with DigiPen students.

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Abstract

A project-based course commonly requires that students solve problems based on knowledge and skills acquired from previous course work. However, even during the early years of study, students can develop a better intellectual independence when they have the opportunity to learn how to discover theory through design. Project-based courses increase the motivation, self-confidence of students, their level of resilience and leads to better retention rates. This paper describes an innovative, early project-based course recently developed and implemented in the 3rd semester of the computer engineering program at DigiPen Institute of Technology for embedded systems design. The main objectives of the course are for students to identify authentic engineering problems, select one and characterize it to propose a solution through the design, implementation and testing of an embedded system of their own. They are expected to apply knowledge from prerequisite and concurrent courses, learn how to do research and document all their work via written technical reports. Furthermore, they acquire practice and theoretical understanding through design and implementation.

In this course students are required for the first time to complete a full design for a project of their own instead of only fulfilling a design component of a project. They must achieve a basic electronics development cycle within one semester: inception, research, design, implementation and prototype testing. The semester project culminates with a demonstration of the system and a poster presentation.

In our paper, we describe the computer engineering program at DigiPen Institute of Technology, the 2nd year course, the methodology implemented including examples of the projects proposed by students and analyze the successes and limitations of the project-based course. We have observed that students gain confidence in their theoretical knowledge after completing the course, they get more involved in engineering projects and they feel more technically competent. Students agree that this course helps them practice and improve the ABET Student outcomes. We assess their technical and soft skills using different rubrics and also compare the grades with results from subsequent years. Even when the course has been recently developed, we find that there is a trend between the grades of different courses. The tendency shows that if students are proficient in this project course, they will do better in further theoretical courses.

Introduction

A critical goal of an engineering program should be to expose students to state of the art and emerging technologies in order for them to achieve and develop all the skills and abilities required in industry. Today, easy access of information and knowledge through the internet has brought new concerns for younger generations. Students are able to find quick answers through online videos, blogs and similar websites but they do it without any deep analysis and sometimes without questioning the source [1]. It means that they have quick access to half-delivered information to finish full projects in easy steps without understanding the underlying theory. Without the motivation of learning, the student-engagement with the program, its academic work and retention can be affected [1-4]. There is evidence that academic disengagement increases steadily over an undergraduate engineering experience [5] and that students have low level of resilence and discipline due to lack of motivation [6]. These are some of the reasons why newer models and methods are required to keep students engaged and motivated for constant learning. Students should discern how to increase and apply their knowledge and where to find reliable information. They should be aware at an early stage of their program degree that as engineers they are designers and not only builders.

The traditional model for engineering undergraduate programs in the US prepares students with all necessary fundamentals at the beginning of their studies, where they learn physics, electronics, programming, mathematics and humanities, mostly during the first and second year [7, 8]. In this way, students gain basic knowledge before they start working with design projects, tools and equipment.

Nevertheless, some studies have shown that a lack of student involvement and motivation acts against their learning skills and that graduates often lack an understanding of the complexity of real industry related projects [6]. According to [5], knowledge-acquisition approaches are often out of alignment with professional practice. Students are more focused on obtaining short-term rewards as exams and passing grades than in knowledge discovery. Commonly, to excel in these rewards they usually rely on memorization which leads to poor long-term retention. Moreover, by the use of these methods, students are being trained to seek the one correct solution instead of finding alternatives [6]. Learning requires feedback, and students are able to really master theory until they can apply their knowledge [5].

Other research efforts show that students also have a lack of confidence, interest and sense of belonging [4, 9, 10] in engineering programs. There is evidence that they still struggle with career decisions into their fourth year [5]. To have a positive impact on student motivation and problem-solving skills, these concerns must also be addressed. The sense of belonging, the feeling of being technically competent and socially comfortable, the ability of students to ask their own questions, plan their research, analyze their own findings and communicate their own knowledge enable a more effective and lasting learning [5, 11].

This is why active learning methods can increase student retention rates and engagement in engineering programs [12-14]. In these cases, students receive the tools and not only know theory but discover it and understand it while practicing. They learn how to discover new knowledge and to be always up to date which is very important in engineering programs because by the time they finish their degree, what they know will be soon out of date [5]. For this reason, some engineering programs have changed their model of education to include engineering courses in the first and second year with a design component [15-23].

In the computer engineering (CE) program at DigiPen Institute of Technology, students must take two fundamental embedded systems courses, (1) a 2nd year project-based course which we describe in this paper and (2) a theoretical class with labs. We find that when offered in parallel at such early stage of the CE degree, students reinforce their skills to work in teams, they boost most of the abilities suggested by ABET and gain confidence in how to use the equipment and tools by practicing. Moreover, they gain confidence in their own skills and motivation because they are able to build their solutions and designs at a high level.

The project-based course helps students face the principal obstacles and possible failures that a project might represent. They learn that all the engineering projects require not only that they use the correct equipment and tools but also that they know how every component works and how to use it. They understand that every design requires knowledge either from math, physics, chemistry or many other theoretical fields which is one of the common outcomes of project-based approaches [23]. They learn that not everything works at the first attempt and that they must do research to know how to tackle any failures in their designs. Most importantly, students learn that if they use all the available and reliable theoretical background, implement the right calculations and technology and prepare a reasonable action plan, they will design something that will work as expected in most cases. This course helps them to gain confidence and motivates them to keep learning and be more involved in engineering projects. Moreover, by the time they face the theory in further courses, they have already worked with some engineering problems and equipment and should be able to appreciate the importance of each one of the topics, therefore accelerating the process of learning theory.

The implementation of the 2nd year project-based course at 3rd semester introduces the students as soon as possible to the design of embedded systems, the use of sensors, actuators, tools and equipment necessary to complete the entire product development cycle. The students are guided to find their own motivation and define projects that could solve actual problems in the real world. They are encouraged to think as if everything they design could culminate in a commercial prototype, comparing it with the market competition and state of the art (journals, conferences, patents, etc.). They must prepare a case that defines a problem and present the use model in a formal proposal presentation to ECE faculty and peers in a similar way as if they were presenting a proposal in industry. This leads the student to get early skills beyond a class project. The implementation of the basic electronics development cycle during the course, encourages students to solve more complex designs later on their curricula and also increases their motivation and accelerates the understanding of deeper theory.

In our paper, we describe the Computer Engineering program at DigiPen Institute of Technology, a university with about 1200 students in Redmond, Washington. Then, we introduce a further description of the project-based course (ECE220L 2nd year project) and methodology, including examples of the projects proposed by the students and their achievements. We analyze the rubrics to assess the technical and soft skills of the students but also the assessments that we obtained from the students regarding the course. Finally, a discussion of the results highlighting the successes and limitations of the project-based 2nd year course is presented.

Project-based learning

According to [24], young people are more attracted to engineering education with a student-centered problem and project-based approach, focused on engineering solutions. They also agree that to help the students face the challenges of the future, the curricula and pedagogy must be transformed and should use information and experience in more active, project-based learning, combining just in-time theory with hands-on applications.

The most significant difference between problem-based and project-based is that the solution for problem-based is around one unique issue, while project-based requires the student to design a solution for an open-ended question, solving a real problem and creating something tangible.

Commonly, some of the topics of problem-based implementation are of academic nature and may not resemble industry challenges [6]. Contrary, project-based learning also must have open-ended outcomes according to [8, 25].This means that the student must have initiative, project management ability, team-based capabilities, strong observational skills, and the application of knowledge in addition to the acquisition of knowledge.

Authors in [26] developed five criteria that a project must have in order to be considered an instance of project-based learning, these include that the projects are: central, not peripheral to the curriculum, realistic and not school-like projects, focused on questions or problems that "drive" students to encounter (and struggle with) the central concepts and principles of a discipline, projects that involve students in a constructive investigation and should lead the student to some significant degree.

Currently, there are several engineering programs that include engineering courses in the first and second year with a design component. Milwaukee School of Engineering introduce students with embedded systems at 3rd quarter, which is a course that includes problem-based laboratory practices [15]. Introduction to Embedded Systems is also considered a 2nd year course at Rose-Hulman Institute of Technology. There are other institutions that have a project-based engineering curriculum. An example is Aalborg University in Denmark [21]. Every year, students must credit at least one project-based course as requirement for graduation. For their bachelor in robotics, the 1st year project involves a programmable computer, sensors and actuators as an introduction to the field. University of Michigan through the engineering division also offers project courses at an early stage of the curriculum [22]. The reader can refer to [18, 23, 27] for more examples.

Overview and outcomes of computer engineering program curriculum at DigiPen

The Computer Engineering degree consists of 146 credits over eight semesters with 17-20 credits per semester. Eight of these courses are project courses where they must design a solution and apply integrated knowledge and skills acquired through all their curricula. These are designed to support student outcomes recommended by ABET. Fundamental courses of CE curriculum include mathematics, physics, computer programming, electronics, composition and communication. All the project courses at the Electrical and Computer Engineering (ECE) Department include a significant design component which is restricted by the typical constraints that could be encountered in industry such as use model, cost, power and portability. Through these project-based courses the students acquire the ability to design, build, program and test interactive embedded devices and implement human-machine interactions. Nevertheless, one of the most important goals of the program is that they learn to do research, find their own solutions, develop team management skills, presentation and documentation skills, they get the sense of critical design processes getting confidence and motivation to persevere until the objective is reached.

During the lectures of these courses the students learn different topics as history of computer engineering, the electronics development cycle, professional ethics, common development tools used in industry, interview, resume/CV writing, and presentation preparation, management, testing and quality control, and statistical methods. A full description of the program can be found in [28].

Second-year project course description

ECE220L (CE 2nd year project) is offered in the 3rd semester of the Computer Engineering program. Students work in teams of two or maximum three students each. The class size varies from two to ten students every semester. In this paper, we are analyzing the data obtained from the 2013 to 2017 student cohorts. In the last 4 years, 25 students have taken the course. Women comprise 24% of these students.

One of the principal objectives of this course is to involve students as soon as possible into real engineering problems. This should enable them to understand and recognize the key obstacles and bottlenecks present in the development of a product, from the formulation stage to testing and prototype construction. These can be achieved at such early stage because students already have knowledge about calculus, physics, basic electrical circuits, digital electronics as logic gates, timers and programming due to the corresponding 1st year courses of our curriculum. Moreover, this knowledge has been reinforced in a previous project-based experience [16, 26] which is the prerequisite for this embedded systems 2nd year project. It means that, to be able to enroll in this course, students can either complete the ECE110 1st year project or GAM150 Project I. Additionally, starting on Fall 2016 we required students to enroll to the Embedded Systems course (ECE300) in parallel with this project-based design course. In the theoretical course, students learn the technical concepts about sensors, actuators and communication protocols using an embedded platform and C programming.

Since students must make use of the laboratory facilities and fabrication tools (Appendix E), by the time they have been enrolled in this course, they already have attended some lectures about laboratory safety procedures and standards in previous courses.

Course methodology and promoted skills

As mentioned before, it is important for the students to be already familiarized with electronic circuits, some tools and programming in such a way that allows them to have the lead in a project of their own. For this course, sessions are a mix between lectures and hands-on project work. The coursework includes 4 hours in the classroom where all students and the faculty must be present. The principal task of the faculty is to guide students through the semester, their role is to be an advisor and evaluator of a project own by the students. Faculty should be considered more of a stakeholder than a technical leader of the project. Nevertheless, they should provide materials, test and assignments that can be accessed at any time. Moreover, it is their responsibility to prepare the lectures and adequate them to fit in the topics of the student projects.

Along the semester, students learn concepts of electrical and computer engineering and process documentation. Some of the lectures delivered in the classroom include introduction to academic research, sensors and actuators, the electronics development cycle, common tools and equipment used in industry, introduction to control systems and signals, testing and statistical methods, professional ethics, presentation and poster preparation.

As stated before, the students decide their own project. The faculty role is to help them improve the use model or the innovative component and to find the scope and limitations. This guidance is implemented through discussion during office hours, class hours and graded assignments. One of the first assignments is to create a report of literature review about materials, equipment, similar designs and theory behind their project. The second assignment is a written proposal report with the first draft of their design, at least one block diagram, bill of materials and timeline of their project. For the bill of materials, the laboratory manager provides a format with all the specifications that they should include. The bill of materials must fulfill the budget restrictions per each team. In this report, students also provide their own metrics for considering their results as a successful project. Other documentation assignments distributed through the semester include the mechanical and power requirement analysis, flow diagram, schematics, pcb layout, control diagram, experimentation set-ups, user manuals, poster, among others.

In the first lecture, faculty mention some examples of projects solved in previous semesters and some examples of projects that are within the scope and limitations of this course. A list of restrictions and requirements is also provided. However, students are at liberty and encouraged to define their own problem, use model and motivation. At the beginning of the course, it is important for students to gather all the information quickly enough to provide a well-structured proposal and list of parts by the second week. For this reason, first lectures are about how to do research, which are the sensors and actuators commercially available and the development cycle. The following lectures are delivered according to the necessity of the student projects. The last lectures are about poster and oral presentations.

At the end of the semester students are graded based on the assignments, quizzes, presentations, poster and video/live demonstrations of their prototype. The complete syllabus for ECE220 L is in Appendix A.

Through this methodology, students learn how to do research and implement their knowledge into a real design, they also develop and reinforce their management, documentation and presentation skills through the hands-on work and assignments. They learn how to get knowledge, how to look for trustworthy information in books, datasheets, patents, and journals, as it will be required in industry and society. This is possible due to the role of faculty as an advisor and evaluator instead of facilitator.

Project description, outcomes and timeline

In the 2^{nd} year project course, students are expected to work on a team to design and build a functional device using high-level components and tools such as integrated circuits, embedded microprocessors, sensors, professional integrated development environments (IDE's), etc. This is not a course where they only implement basic logic gates ICs or simplified IDE's such as Arduino or Energia.

The goal or final product of the course usually takes the form of a robot or electronic tele-operated system. Students can only achieve this objective by being exposed to sophisticated hardware and software tools during the semester that allows them to design, build, analyze and interpret their own results. Some examples of this tools are Matlab, Spice, Eagle, µVision, 3D printers, lab equipment for signal analysis, etc. Additionally, they must work with at least one microcontroller platform and professional IDE.

The course outcomes are aligned with the ABET student outcomes. Through the semester the successful student should practice and demonstrate the ability to a) apply knowledge of mathematics, science and engineering, b) design and conduct experiments, as well as to analyze and interpret data, c) design a system, component or process to meet desired needs within realistic constraints, d) function on multidisciplinary teams, e) identify, formulate and solve engineering problems, f) understand professional and ethical responsibility, g) communicate effectively, h) understand the impact of engineering solutions, i) engage in life-long learning, j) understand contemporary issues and k) use the techniques, skills, and modern engineering tools necessary for engineering practice.

To ensure these outcomes are fulfilled, the students are assessed at 3 different stages: Proposal Presentation, Design Milestone and Final Prototype and Presentation. The grading rubrics are shown on Appendix C. Every item of the rubrics has been matched with the ABET criterion that is being evaluated.

For the first stage, which is the proposal presentation, students identify a service, problem or product needed in the industry or the market and build a case around the importance of this situation. They figure out its relevance in all possible impact areas, technological, environmental, economic, social and scientific, etc. Then, they analyze the impact that can be achieved through the implementation of an innovative embedded system design, built and tested by themselves.

There are some restrictions and requirements that students accomplish, for example, the device interacts with people or the environment, includes digital communication protocols, uses at least one sensor, one actuator and one communication protocol and meets certain guidelines as regards to its functionality and cost. Therefore, students do some research about the state of the art, the market and look for similarities in other projects or products from competing companies. Furthermore, they find out the technological limitations in the real world which include finding the correct components for the required mechanical and power restrictions and the necessary equipment to fulfill the design. This stage gives them motivation to continue the processes of design, implementation and testing. At the end of this stage, they have a complete conceptualization of their solution and prepare a presentation for faculty and peers that includes the problem definition, use model, function, block diagram, and parts list. The proposal focuses not only on the technical description of the system, but also describes its impact in terms of environment, society, economy, science, technology, etc.

The second stage includes the further design based on the first feedback from faculty and peers. The students create different diagrams such as, flow diagram, wiring diagram, assembly diagram, schematic, and control diagram. Through this process and depending on their solution, they acquire practice, knowledge and theoretical understanding on C programming, communication protocols such as the Inter-Integrated Circuit (I2C), Universal Asynchronous Receiver-Transmitter (UART), Serial Peripheral Interface bus (SPI), Universal Serial Bus (USB), radio frequency modules and basic digital control as Pulse Width Modulation (PWM). They are required to write their own code and correct their own diagrams to build a functional prototype.

In the final stage they are expected to use CAD tools to create a PCB, fabricate it and populate it. Some of the students model and build their own mechanical parts using 3D printers. Nonetheless, if the piece will require too much time from them, they can buy the print externally or ask the lab manager for some help. This is allowed since this component is not the main focus of the course. Students also learn to analyze the testing data, identify which are the testing variables, the difference between ideal and real components, controlled and real environment, etc.

All these “hands-on” practices accelerate the student process of understanding theory in the subsequent semesters because they already have worked with the components. Therefore, they already know the difficulties in the implementation and now they can understand the importance of design and analysis of all systems. Moreover, later in their studies in the 3rd and 4th year projects, when a more complex design is required, they have used the tools and know the areas where they need to focus to obtain faster results and come up with more sophisticated solutions.

During the lectures, students are frequently encouraged to do scientific research at all stages and participate in professional organizations or societies. For this reason, they have access to different scientific journals and conferences via the institution, which they can use at any time. They should cite and reference all their sources in any document (paper, poster, video or presentation). Sources should be technical documents as datasheets and scientific papers in order to avoid half-delivered information from online sites.

This is a challenging course because students only have one semester to experience the complete product development cycle, they must determine which components must be used and how to integrate them into a functional prototype using embedded systems and communication protocols. At the end of the semester, students again meet with the ECE faculty and peers to present their results, discuss further work and answer some questions from the audience. The last deliverable is not a report but a poster prepared for a conference that includes the discussion of the experiments and results.

Projects and results from the students

The team projects are designed and built separately by each team. The principal goal is to produce an embedded device that can interact with the environment through both sensors and actuators. Plug-in breadboards are not acceptable for the final device, so they must have a designed PCB or solder board instead of it. For some of the parts they can make use of components with breakout boards. The students are also required to design a solution fulfilling five of the following constraints: utilize a communication protocol, operate with the use of batteries, use wireless communication, teleoperation (wired connection possible), integrate a relative or absolute positioning system, interact with the other team(s) devices, use more than one microcontroller, self-charging, include text display or multiple copies of function blocks. Students use TM4C123G LaunchPad Tiva board as its primary microcontroller which has a Cortex M4-ARM 32-bit microprocessor (80- 120 MHz) and 40 I/O ports, 8 UART, 6 I2C, 4 SPI, USB and 2 CAN modules, ADC, PWM, and power. Nevertheless, they can use more than one microcontroller and not all of them need to be the TM4C123G. Figure 1 shows examples of the final PCB boards designed and built by the students.

In the 2nd year project course, students are supposed to face and struggle with some of the basic implementation obstacles of product development and design. Nevertheless, starting from Fall 2016 students took the Embedded Systems course in parallel. In this manner, they do research at the beginning of their projects and then through the semester they learn if their solution was the best option and still have time to re-design and upgrade their system.

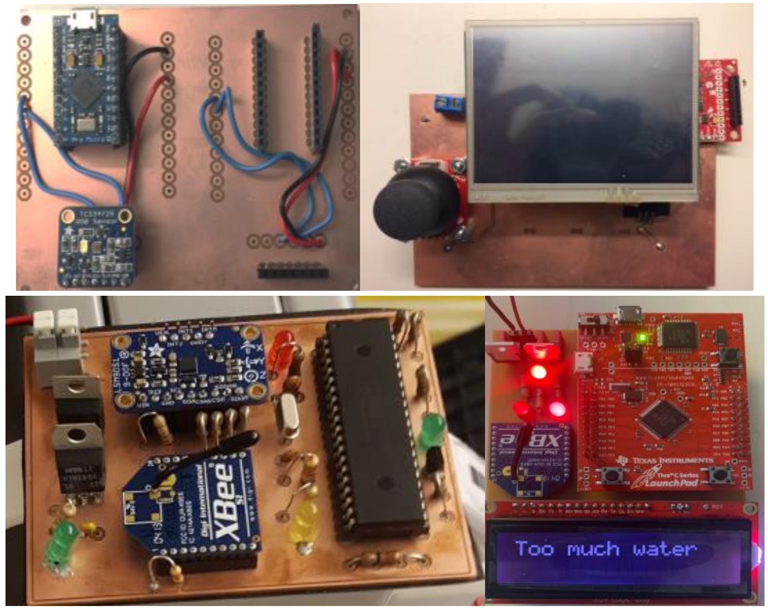

Figure 1. Examples of the final PCB boards

At the beginning they propose both, a real engineering problem and a solution based on the use model and course requirements. Then, by the second week, students start working directly with the design which includes the selection of the components. In this stage, they find out the importance of physics and math theory to start a new design. They are guided to calculate power requirements according to their own prototype specifications, size and portability of their solution and the correct integration of all the components. The principal difficulties encountered at this stage are finding the correct motors, sensors, breakout boards and batteries to complete the design. Figure 2 shows an example of a block diagram designed during Fall 2016. Some project examples are described next.

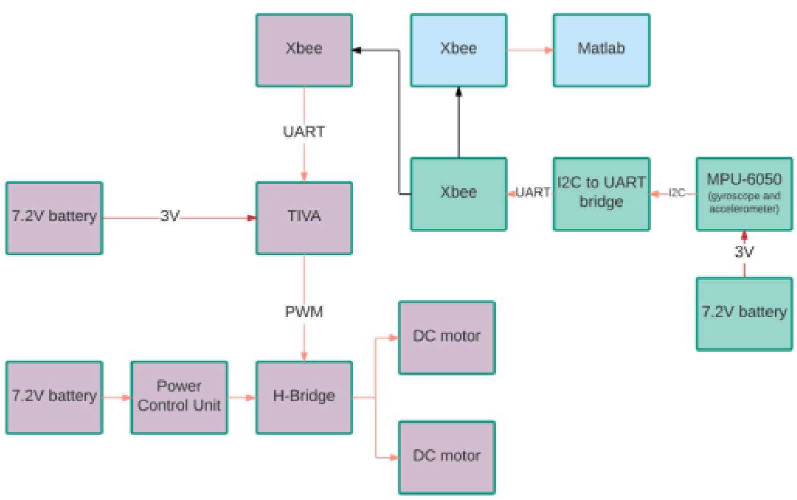

Figure 2. Block diagram of Project TIRCC (Tilt Interactive Remote Controlled Car)

Remote controlled tank radar visualization

In this project, students reutilized an already equipped mobile robotic platform (tank) used in a 1st year course and equipped it with an infrared radar to send the distance between obstacles and the robot via wireless (radio frequency) to a controller with a 2D screen. They designed the 360° radar, the controller, the pattern and algorithm shown on the screen to facilitate visual feedback from the robot to the user, allowing a user to control the tank without clear line of sight. Figure 3 shows the schematic diagram they have designed for the controller board and the implementation. They used four IR sensors mounted into a servo motor that rotated 180° in both directions. By means of one long distance sensor and one short distance sensor per each side of the radar, students were able to display on the controller's screen a bird's eye view of the layout surrounding the tank (360°) where the obstacles were represented by painted pixels. Navigation was achieved due to a joystick on the controller.

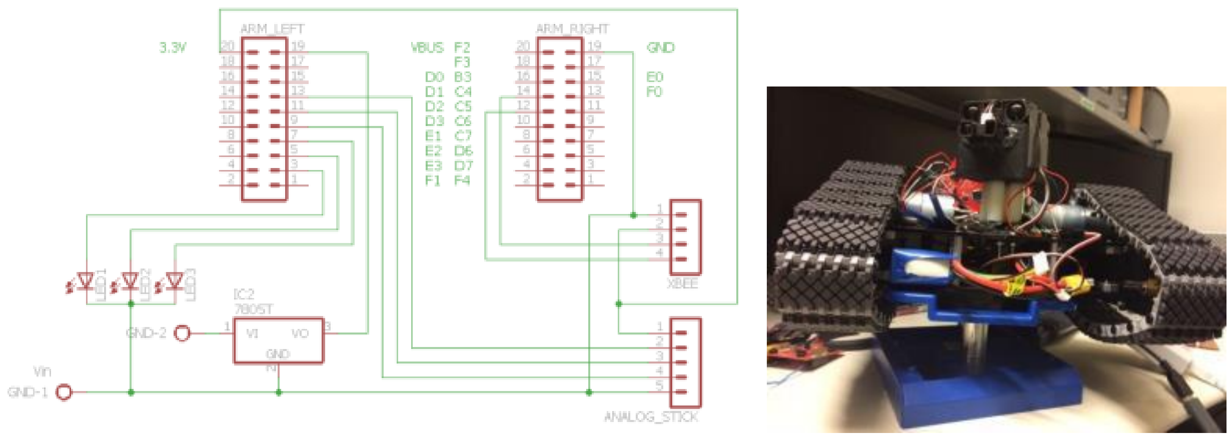

Figure 3. Schematic for the controller of "Remote controlled tank with radar visualization"

Project guide robot

Students in this project created a robot able to autonomously navigate its way through a predetermined course (line follower) to guide visitors on a tour through our campus. The robot uses Omni wheels and DC motors connected on a slave MCU that receives the instructions for movement and decides the direction of the motors. Another slave MCU is connected to the ultrasonic sensor that sends the signal when an obstacle is present which triggers an avoidance algorithm as a safety measure in case there is an object or a person in front of it. IR color sensors on the bottom of the robot detect the following path and if it has reached a specific spot that require a guided explanation, (laboratories, classrooms, showrooms, etc.). The robot was supposed to be big enough so that tourist and people on the area could easily see it or follow it. This was one of their biggest challenges because considering a weight of 2 kg they needed to find the correct motors, drivers and batteries that could manage this restriction.

Project Mobile Relay Beacons

Students worked on a deployable communication network, consisting of relay beacons, a base station, and handsets. This network was to be deployed in a post disaster situation, in which other communication networks had failed, and to be used by emergency services to talk to victims of the disaster. Figure 4 shows the implementation of their final prototype.

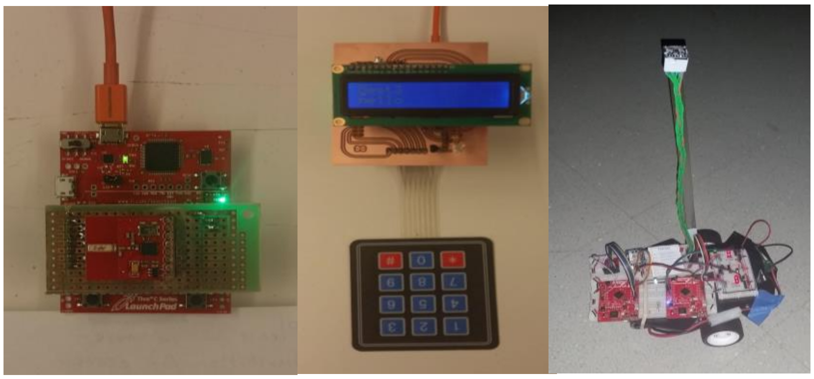

Figure 4. Final “Mobile relay beacons” prototype.

Other examples include an electric wheelchair controlled through a remote helmet with an on board IMU, a robotic hand wirelessly controlled by a glove worn by a user, a robotic tank that carries a plant around a room, searching for sunlight and informs the user on the current state of the plant. Some of these final protypes are shown in Figure 5.

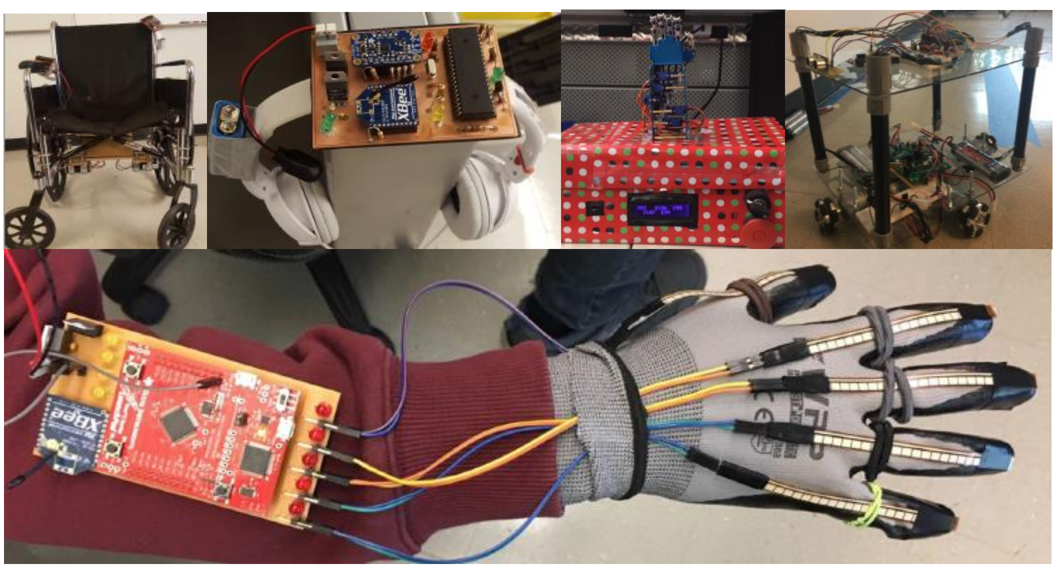

Figure 5. Examples of students final prototypes.

Analysis of student outcomes obtained

As mentioned before, the principal student outcomes of the course are based on the ones promoted by ABET. Students should develop and/or mature an ability to: apply mathematics, science and engineering, design experiments, analyze and interpret data, design a system considering the impact and constraints involved and communicate ideas. They should also get engaged in long-term learning, understand the context of their project and raise awareness of the ethical and professional responsibility they have. All these abilities are grounded in the use of techniques, skills, and modern tools necessary for engineering practices.

The rubrics used to evaluate the students are shown in Appendix C. These have been directly correlated with the specific student outcomes we expect from the course. This means that the final grade of the student is a representative metric of how much have the students practiced and reinforced these abilities and skills.

During the proposal and final presentations, every attending faculty evalutes the corresponding rubric and then an average of every result is obtained. That way the perception of more faculty members is involved to grade the students during presentations. The final grade of the course is calculated using the weighted average from assigments, quizess, reports, poster and presentations. The grading policy of the course is presented in Appendix A.

Additionally, we are not only interested in how the professor perceives these results, but also the way students feel about it and how confident they are about their knowledge in the related fields at the end of the project. For this reason, the students participate in two different surveys in the semester, (1) the knowledege survey which is applied at the beginning and at the end of the semester, and (2) the ABET survey which is applied only at the end of the semester. Next, we will describe the goals and results of both surveys.

The purpose of the knowledge survey is to assess the current relative level of knowledge of topics related to the course before and after the students take the course. They are required to answer only the questions that they know, they should not try to guess an answer. In our analysis these are called "attempted questions". The survey consist of thirty "true or false" statements about the tools, theory and technical concepts that are related with embedded systems. The students should confirm if the sentence is true or false. Nevertheless, they have the option to answer "I do not know". The list of questions used in this survey is shown in Appendix D. It is important to mention that the survey has no grade value, and should not be considered as a study guide for this or other courses.

Even though the amount of confidence that students have related to embedded system topics is a subjective variable, we are able to measure it by making the students aware that the test is not graded and that they can explicitly say that they do not know the answer, if that is the case. This way, we can obtain the rate between the number of attempted questions and the total number of questions on the survey as a representative metric of how confident the students are as shown in equation 1.

$$sureness\ rate = \frac{attempted\ questions}{total\ amount\ of\ questions} \quad (1)$$

The "sureness rate" can vary from 0 to 1. The results obtained from the survey applied on Fall 2018 are shown on Table 1.

The average sureness rate of the students increased from 0.63 to 0.89 which means that students were able to answer more questions and that they were confident they knew the answer. Moreover, the average grade increased from 52% to 78.33% because they not only answered more questions but they increased their knowledge. We can confirm this by looking at the compensated grade where it can be noticed that the amount of correct answers remains similar. It means that at the end of the semester, the students were correct in the same proportion that at the beginning of the semester.

Table 1: Summary of results from Knowledge survey applied in Fall 2018

	First week results			Last week results		
	Sureness rate	Actual Grade*	Compensated Grade**	Sureness rate	Actual Grade*	Compensated Grade **
Student 1	0.73	66.67	90.91	0.93	90.00	96.43
Student 2	0.67	66.67	100.00	0.93	93.33	100.00
Student 3	0.20	20.00	100.00	1.00	83.33	83.33
Student 4	0.60	43.33	72.22	0.73	63.33	86.36
Student 5	0.77	50.00	65.22	0.93	83.33	89.29
Student 6	0.90	60.00	66.67	0.93	63.33	67.86
Student 7	0.37	33.33	90.91	0.73	60.00	81.82
Student 8	0.83	76.67	92.00	0.93	90.00	96.43
Average	0.63	52.08	84.74	0.89	78.33	87.69
Standard deviation	0.24	19.10	14.44	0.10	13.80	10.39

*Actual grade is the percentage between the amount of correct answers over amount of total questions (30)
**Compensated grade is the percentage between the amount of correct answers over the amount of questions answered only as true or false.

Figure 6 shows the normally distributed curves for the sureness rate and the actual grades, where it can be observed that in average the students had a better performance at the end of the semester and they felt more confident. The same can be observed by analyzing the median. The sureness rate median increased from 0.70 to 0.93. In the other hand, the actual grades median increased from 55 to 83.33.

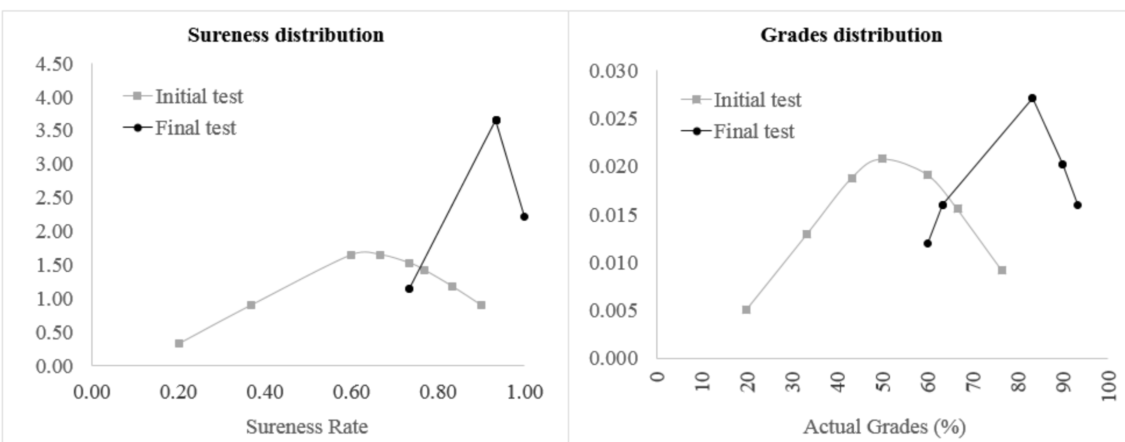

Figure 6. Normal distribution of the knowledge survey results before and after the project course.

Additionally, at the end of the semester, students receive a second survey related to ABET outcomes. This survey is not used to grade the students but to measure the confidence of the students in the specific skills and abilities that they must practice along the semester. In this survey, each ABET student outcome is divided into more specific indicators so that students are able to self-assess how well the course prepared them for being able to demostrate these abilities to colleagues, pears or potential employers.

Students were asked to evaluate on a scale of 1 – 5 (1 = Strongly Disagree, 5 = Strongly Agree) how well these indicators were promoted by the course. The four students in the 2015 cohort, nine of the students in the 2016 and 2017 cohorts and the eight students in the 2018 cohort were asked to complete the survey, (full survey criterions and specific indicators are shown in Appendix B).

Although this project course has always been a requirement in the CE curriculum, until Fall 2015, students were not required to enroll at the same time in the embedded systems theoretical course. This was the reason why we used to receive significant comments from the students asking us for more information at the beginning of the semester about all the technologies and boards they would be using. That introduced several problems to the course since the faculty was responsible to connect the dots through lectures and office hours with an increasing workload. Students are not used to implementing a project on a “learn as you go” basis. Nevertheless, this is one of the principal objectives of Project Based learning, where they must find answers by themselves and do research because they must be prepared for the professional engineering environment, where constant learning is a fact. In industry, research and learning is even often built into the project plans. As a response, during Fall 2016 class sessions, we included more technical lectures about general topics like the fundamentals of PWM, control systems, sensors and actuators, and some tools including Matlab. Additionally, students are now required to enroll the embedded systems course in parallel, which resulted in a better implementation of the “learn as you go” basis. We can see the difference of opinion as an increment in the results of the Survey for Fall 2016-2018. Figure 7 show the difference between 2015 and 2016-2018 in terms of average.

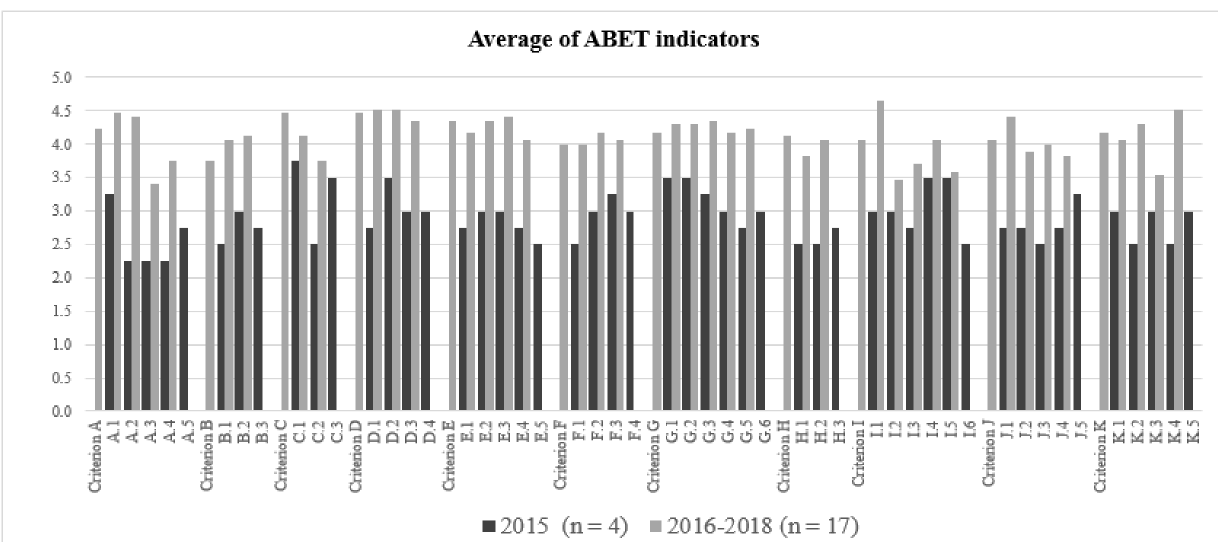

Figure 7. Results of average in ABET survey from 2015 to 2018 for each one of the criterions of Table 2. Note that 1=Strongly Disagree, 3= Neutral, and 5= Strongly agree.

Considering the results of all the indicators in 2015, the total average value was 2.84 and the median was 3. In the other hand, considering all the data of all the indicators starting from 2016, the total average was 4.1 and the median was 4. It means that to implement the course without any theory behind is not preferred by students and partially promote confidence in their abilities because the results showed a neutral attitude to the survey. Contrary, the results from 2016 to 2018 support the idea that students can learn by themselves through "hands-on" projects but need to have a proper guidance in a "learn as you go" basis where they do the research first and later reinforce their new knowledge obtained in a parallel course that covers similar topics. This initiative promotes more confidence in the students in how well prepared they are getting.

With this new model, the overall average and median from 2016 to 2018 show that students partially agree that they are practicing the ABET student outcomes and improving their skills. This can be observed when we calculate the number of indicators that obtained a value less than, equal than or more than 3 which is the neutral value. With the overall results we got that 3.48% of the specific indicators obtained a value between 1 and 2, 15.84% a value of 3 and 80.67% a value between 4 or 5. This also shows that the students feel that this course helped them to mature the ABET outcomes of their program. Moreover, 35.20 % of the indicators obtained the maximum value of 5.

When we grade each one of the indicators as a percentage, the results show a value between 68% and 93% in every one of the outcomes. So, students also agree that each one of the outcomes are being covered and trained along the semester. Figure 8 shows these results. They were obtained by grading each one of the indicators as an average using n=17 as the sample size (n is the number of enrolled students that took the survey).

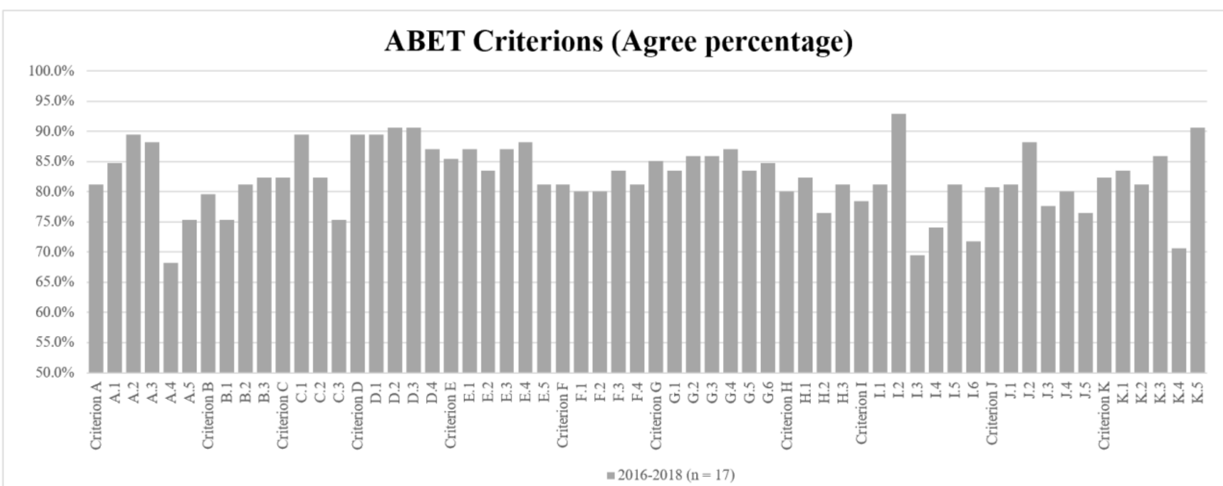

Figure 8. Results (agree percentage) of surveys applied during 2015, 2016, and 2017 for each one of the criterions of Table 1.

By their 3rd semester, students already agree they are applying math and sciences (81.2%), are able to work in teams (89.4%), could apply their knowledge to design and implement a project (82.4%), the skill to communicate effectively (85.1%) and to solve engineering problems (85.41%), which shows confidence in their field. The indicators that obtained the best results were the application of knowledge from previous courses, the ability to use lab equipment, perform tasks in satisfactory fashion and the ability to explain ideas to team members.

In the other hand, the worst results but above an average of 3 were the ability to apply discrete mathematics and the ability to participate in professional organizations and societies. In the former, we expected a low result because students have only learned fundamentals about digital electronics in previous courses. We will consider eliminating this indicator in further surveys since it is not an important outcome for this course. For the latter, we are evaluating the idea of including the participation in professional organizations as part of the requirements for the course because right now we are only recommending students to join a club.

Students perception was also that they needed to understand more contemporary issues and the impact and context for their projects, and how to relate they work with the professional environment. We should make a better effort to help students see all the possible applications their solutions can have. In the case of the impact that their solution has in any context (ethical, environmental, global, economic and societal), we are considering adding more options for the design requirements, for example, the use of lead-free components, analysis of power efficiency and analysis of reliability.

Currently, students must create their own code and make sure they are not violating any intellectual property rights, they have lectures and analyze study cases about ethical problems that could arise in the professional environment; however, we can reinforce this by including it into the rubrics as well as the ability to keep the expenses under the budget.

We also found through the results and student presentations that it is necessary to increase the research ability from the students and help them to reach different audiences and participate in professional organizations. These objectives are even more encouraged during 3rd and 4th year project courses of the CE program.

After few years we could also notice a tendency between the grades obtained during the 2nd year course and the grades obtained in the electric circuits course at 4th semester. Figure 9 shows that there is a relation between both courses showing and upward tendency, but due to the limited sample size (n = 13) we will continue to get data in subsequent years to confirm the results. However, it did not happen in the course offered on 2015 where the embedded systems theoretical course was not required. In that case, students obtained an average grade of 85% in the project course and 77% in electric circuits.

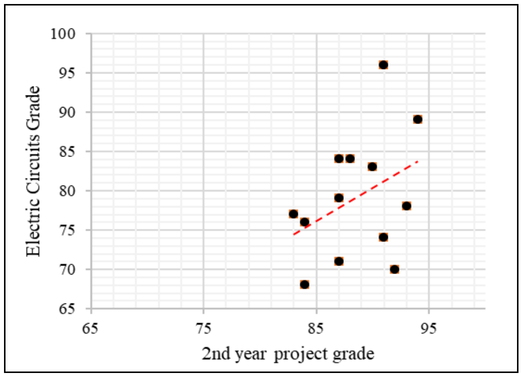

Figure 9. Trend between 2nd year course and electric circuits course.

Discussion of successes and limitations

At the beginning of the 2nd year project course, students received some examples of projects from previous semesters. Their first reaction is to feel overwhelmed because they would have to learn everything too quickly and some students even express a lack of confidence because they are conscious of their limitations. It is important to emphasize that they will discover theory through practice and it is also a priority make them aware that they already have the required knowledge about programming, logics, math, and physics, acquired from previous and on-going courses. If students are not engaged from the beginning of the semester the learning curve can be slower than expected. Students set their own project objectives and limitations for their own comfort. Through the semester they find out that re-design is a fact in real engineering projects as well as research.

There are a lot of factors that might influence the achievement or failure of a project, for example, lack of supplies or equipment due to paperwork or shipping, project costs (students are not expected to pay for their project supplies), and faculty workload, which are not directly related to the student. This is why, even when the course has very high expectations, they must remain reasonable. Students are involved in all the processes as well as faculty. Moreover, all ECE faculty are available to support students, not only the class instructor. Through this exercise, students perceive the faculty not as the one who tells them exactly what to do, but as an advisor and evaluator of a project of their own. This is similar to the professional environment where the manager or team leader decides about requirements, costs and limitations but the engineer is the one that solves, design, test and implement. Through the course experience, students gain exposure to all these abilities, including how to conduct background research using journal papers and patents.

Another challenge is that students need time to understand the technological limitations faced in their projects. It is difficult to design a system that fulfills all the requirements of power, size, cost, availability, etc., without any iteration. Students can find information about which component to use and how to use it but at the beginning they do not consider the need of physical concepts and proper calculus. If students are not properly guided, this work will become just a vain attempt that used a lot of their time and energy. Students must know from the beginning that every component or their system is connected at different levels and everything must match in the final design.

For faculty, it is difficult to give feedback in the proper level because there must be a balance between too difficult (given the early stage of the student curricula where they might not understand some terms), and too simple (where the students might feel that they don't need to learn any more). At the end of the semester, students must want to learn more because they are not yet engineers, and the instructor must be sure they know it.

Another success that we could notice about the 2nd year project course is when students at the end of Spring 2017 started asking to participate in ECE faculty research summer projects. During this period, at least 8 of those students were engaged in projects that improved their hands-on experience and allowed some of them to do an internship by the beginning of the 5th semester in industry. This happened again in the next year, several students participated at research summer projects and more students were able to get internships at 5th, 6th and 7th semester. We are expecting to obtain the same results this year.

We have anecdotal evidence that the 2nd year embedded systems projects helps prepare students for their 3rd and 4th year projects. In most of these projects, students are using either a PSoC or a FPGA in combination with microcontrollers. Examples of upper level projects include a device for real-time HDMI colorblind correction, an embedded camera system that recognizes hand gestures using neural networks, numerous advanced robotics projects, a fully working game console, and a co-processor for detecting moving targets sensed by a portable radar system. Many of these projects could be considered as advanced at the undergraduate level, and synthesized students prior experience in designing, implementing, and testing with more advanced topics like control systems, digital signal processing, and machine learning.

Conclusions

This paper describes a 2nd year project-based course offered in the 3rd semester of a Computer Engineering program. One objective of this course is to involve the CE students as soon as possible into real engineering problems in such a way that at the beginning of their second year they had have a full experience on the development of a product, from the formulation stage to prototype testing.

According to our results, we have found out that all these "hands-on" practices gives the students confidence in the field and they agree that are applying previous math and science knowledge in the design of a system. Given the difficulties present in their projects and the bottlenecks that they had to figure out, they now understand the importance of the analysis of a design based on proper calculus. This also accelerates the student process of understanding the theory on the following semesters because they already have worked with the components.

Students also agree that they are already solving engineering problems in the same way they would do it in the professional environment. Students are now aware of all the possible limitations and how to select every component and re-design their systems until all the restrictions, limitations and solutions match in the final prototype. Moreover, later in the curriculum in the 3rd and 4th year projects, when a more complex design is required, they will know how to use the tools and know the areas where they need to focus to obtain faster results.

By the end of the semester, the results show that students have gained more confidence in their own skills, they feel more technical competent that at the beginning of the course, their ability to work in teams has been improved and we were also able to notice that they are motivated because they get more involved in research and engineering projects in the following semesters. In this course, students also learn how to discover new knowledge and how to do reliable research. All these abilities enable a more effective and lasting learning.

Future work

We will continue to survey students as they proceed through the program on their experiences in ECE220L, and how the course influences later courses. We will continually update and improve the knowledge and ABET surveys and add them in other courses.

As ABET criteria is constantly being improved, we will adapt our surveys and outcomes to fulfill the new requirements. The Engineering Accreditation Commission include in their 2019-2020 Criteria: the ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics; the ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors; the ability to communicate effectively with a range of audiences; the ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts; the ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives; the ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions; the ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

All the specific indicators that we have defined for the project course can be mapped to these new requirements. However, we plan to redefine the surveys using the data and results obtained from this work as well as include new indicators that fulfill the requirements. We plan to continue to offer revised versions of the document in each Fall term.

Our future work studying project-based learning will include results comparing 2nd year and upper level project performance, for example applying this methodology to 3rd and 4th year project-based courses.

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Appendix A: Course Syllabus

Course name: ECE220L CE 2nd year project, (3 credits)

Prerequisites
ECE110 or GAM150

Course Description
In this course, students are expected to design and build a device using components such as integrated circuits and embedded microprocessors, usually taking the form of a robot or electronic toy. The device interacts with people or the environment, and it demonstrates digital communication. This course introduces concepts of software engineering and process documentation, and emphasizes system-level design. Students are expected to learn the process of creating a device from documenting their concept to building an initial prototype.

Course Objectives and Outcomes
Students are expected work on a team to design and produce a functional device. The device must be well documented and meet certain guidelines as regards to its functionality and cost. Over the course of the semester students should be creating a design, researching components that can be used to implement that design, implementing the design, and testing the design. The process must be documented at every step and formal presentations will be given to provide updates on the students' progress as well as to present their work to the institution. In this manner students should experience the complete cycle of product development.

Through the semester the successful student should practice and demonstrate the ability to a) apply knowledge of mathematics, science and engineering, b) design and conduct experiments, as well as to analyze and interpret data, c) design a system, component or process to meet desired needs within realistic constraints, d) function on multidisciplinary teams, e) identify, formulate and solve engineering problems, f) understand professional and ethical responsibility, g) communicate effectively, h) understand the impact of engineering solutions, i) engage in life-long learning, j) understand contemporary issues and k) use the techniques, skills, and modern engineering tools necessary for engineering practice.

Textbook (recommended)
Arnold S. Berger *Embedded systems design: An introduction to processes, tools, & techniques,* CRC press, 2011, ISBN 978-1-57820-073-3 (Reference copies are available in the library)

Optional recommended textbooks
- Jack Ganssle. The Art of Designing Embedded Systems, Second Edition; ISBN: 978-0-75068-644-0

Supplemental materials may appear on the course Moodle site.

Grading Policy

- 30% Assignments and quizzes
- 5% Written proposal
- 5% Proposal presentation
- 5% milestone presentation
- 15% Final presentation
- 15% Final Poster
- 10% Final device evaluation
- 10% Weekly report/ Minute
- 5% Attendance & Work

Attendance

Attendance and weekly report is mandatory. Each student's final grade will be modified based on the percentage of class periods missed due to **unexcused** absences. Students receive 5 points at the beginning of the semester and lose a point each time they miss class or a significant portion thereof. For an absence/tardy to be excused, documentation must be provided regarding the reason why (doctor's note, etc.) It should be noted that attendance requires your presence for the entire class period unless otherwise dismissed early. If you simply sign the attendance sheet and then leave, you will be marked as absent for grading purposes.

I should point out that the intent of this policy is not to be punitive, but to make sure you are successful in your project. There is a direct correlation between students' attendance and their success at DigiPen.

I would also highly discourage you from being tempted to use the class period to do assignments for other courses. This time is set aside to work with your teammates and have instructors available to assist you. If you use this time instead to do your other homework, this is a wasted opportunity.

Course Outline

To support course outcomes lecture material will be pulled from the following topics:

- Introduction to academic research
- Sensors and Actuators
- The electronics development cycle
- Common development tools used in industry
- Basics of control systems and signals
- Testing and Statistical methods.
- Project topics (Robotics)
- Academia/Industry/Market Environment
- Presentation preparation
- Professional ethics

Other topics of interest as time permits

Project

The team projects will be designed and built separately by each team. Each project must interact with the environment, that is, the device will have one or more types of sensors and react in some way to the sensor data. The final device must use a designed PCB or a solder board with permanent soldered connections. Plug in breadboards are not acceptable for the final device.

Each project should also include at least five of the following (more will cause a project to be evaluated more highly):

- Utilize a standardized communication protocol (e.g., USB, I^2C, SPI, etc.) to control the device, send data back to a PC, or communicate with a peripheral that is part of the device. Note that programming your device's flash memory does not count.
- Operate autonomously (on batteries/solar power and without any connection to a computer).
- Use wireless capability somehow (Bluetooth, Zigbee, etc.).
- Capable of being operated remotely (this can be via a wired connection).
- Robust relative or absolute positioning system.
- Interact with the other team(s) devices.
- If microcontrollers are used, the device uses more than one. Each controller has specific, unique tasks and shares information somehow with the other(s).
- If battery-operated, the device is capable of charging itself if plugged in (to USB, AC outlet, bench supply, etc.).
- The device includes a text display used to provide debugging or other information. The display may consist of any number of characters (even one character is fine).
- The team produced multiple copies of the same device which are all equally functional.

It is expected that each project will consist of a robot of some kind, but this is not a requirement if a team feels they have another kind of device that will largely meet the above criteria. **Documentation will consist of** a user manual, bill of materials, schematics, background literature research, flow charts, measured results and test plan. These documentation components will be submitted throughout the course of the semester and may have to be submitted more than once for grading. Proper documentation is the cornerstone of any project, and a necessary method for improving the efficiency of large team projects. The completion score will be based on if your finished device actually works and how many of the design criteria (autonomy, communications, etc.) are both implemented and functional. You will have a score based on the final presentation you give for your project at the end of the semester. A rubric will be provided in advance of the final presentation so that students are aware of exactly how they will be judged. The last portion consists of my review of your personal contribution to the project over the course of the semester.

Platforms and IDEs for projects

Platform	***IDE***	***Characteristics***
Launchpad	KEIL	ARM Cortex M4; production style chip; uses TI's TIVA ware support code; USB 2.0

This entire syllabus may be adjusted or changed at any time by the instructor.

Appendix B: ECE220L ABET criteria for student survey from Fall 2015 to Fall 2018

Criterion A (an ability to apply knowledge of mathematics, science, and engineering)
A.1 Identify the engineering trade-offs in implementing a solution
A.2 Ability to convert the theoretical solution into a hardware implementation
A.3 Ability to convert the theoretical solution into a software implementation
A.4 Ability to apply knowledge of discrete mathematics in computer science and computer engineering
A.5 Ability to apply knowledge of physics (mechanics, waves, electricity and magnetism)
Criterion B (an ability to design and conduct experiments, as well as to analyze and interpret data)
B.1 Demonstrate a clear understanding of the Scientific Method and how to test hypotheses
B.2 Identify and collect data from performance metrics
B.3 Demonstrate ability to determine and report factors which influence the outcome of the experiment such as errors, accuracy, and uncertainty
Criterion C (an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability)
C.1 Students are prepared to discuss how various project restrictions influenced their design choices
C.2 Students are prepared to discuss how their project affects the world at large, such as through societal or environmental impacts
C.3 Demonstrate awareness of the ethical practices of product development
Criterion D (an ability to function on multidisciplinary teams)
D.1 Proactive participation in the process of task assignment to team members
D.2 Perform the tasks assigned in satisfactory fashion
D.3 Able to explain ideas and concepts to team members in an effective fashion
D.4 Ability to lead the development effort for the given cycle
Criterion E (an ability to identify, formulate, and solve engineering problems)
E.1 Identify the problem and its constraints
E.2 Survey existing approaches to the same problem
E.3 Propose a solution and model it using appropriate methods and algorithms
3.4 Implement the solution to solve the problem
E.5 Validate the solution for correctness and efficiency
Criterion F (an understanding of professional and ethical responsibility)
F.1 Understand the importance of ethics in the workplace environment, including issues like gender/racial discrimination, respect for intellectual property rights, personal responsibility, etc.
F.2 Understand the importance of respecting intellectual property rights
F.3 Work proactively to avoid plagiarism, and know when to properly attribute the work of others
F.4 Demonstrate professional responsibility in areas such as (but not limited to) punctuality, dress, reliability, respect, fairness, etc.
Criterion G (an ability to communicate effectively)
G.1 Communicate an understanding of the underlying theoretical methods
G.2 Document processes related to solving engineering problems
G.3 Present projects before an audience of peers and faculty
G.4 Demonstrate professional communication skills (email, phone, written, workplace best practices)
G.5Demonstrate ability to describe, narrate, analyze and argue persuasively
G.6 Demonstrate ability to present research results in a coherent manner
Criterion H (the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context)

H.1 Understand the broader impact of the engineering methods in related fields
H.2 Understand the economic and environmental impacts of engineering
H.3 Understand the global and societal impacts of engineering
Criterion I (a recognition of the need for, and an ability to engage in life-long learning)
I.1 Understand the theoretical concepts well enough to extend them if necessary
I.2 Student demonstrates the solution by using knowledge from multiple courses preceding the current course
I.3 Participate in professional organization and societies
I.4 Read journal articles and web blogs related to field of study; interact with peers
I.5 Demonstrate ability to do in-depth, multimedia-based research
I.6 Demonstrate ability to communicate with diverse audiences
Criterion J (a knowledge of contemporary issues)
J.1 Understand the relative tradeoffs in engineering solutions
J.2 Ability to tailor the solution to fit a practical scenario
J.3 Understand the optimization processes, if necessary, to implement a better solution
J.4 Ability to choose from a variety of similar approaches to solve the current problem
J.5 Read journal articles and web blogs related to field of study
Criterion K (an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice)
K.1 Understand the analytical techniques required to solve the problem
K.2 Understand the computational techniques required to solve the problem
K.3 Identify and demonstrate the ability to use the development tools (compilers, libraries) correctly
K.4 Use benchmarking tools to analyze the implemented code
K.5 Demonstrate ability to use lab equipment such as oscilloscope, functional generator, power supplies, etc.

**In the study responses to survey, note that 1=Strongly Disagree, 3= Neutral, and 5=Strongly agree*

Appendix C: Course Rubrics

DigiPen Institute of Technology, CE 2nd Year Project
Project Proposal Rubric (revision August 2018)

Team: ABET Criterion D

	Unsatisfactory	Developing	Satisfactory	Exemplary	ABET Criterion	Weight
Use Model	Does not describe how the device works.	Describes how the device works, but not why or how it will be used.	Gives motivations and describes how the device can be used, but does not define success in operational terms.	Gives motivation for the project, describes how the device will be used and operationally defines success in terms that can be experimentally verified.	C, H	10%
Background and Literature	No background; no references or relevance of references unclear.	Provides some references or links, but does not adequately describe or summarize them.	Describes previous similar designs or relevant technologies and provides references to related papers.	Describes relevant previous work by student or others and provides references to papers describing them in detail.	B, F, J	15%
Technical content	No design, design incorrect or missing major components	Presents global design but function and/or use model remain unclear	Presents overall design and explains function and use model.	Presents structural and functional design and motivates design choices based on functional requirements and use model.	A, E, K	20%
Planning	Schedule lacking specific dates or timeframes or missing major tasks to be completed.	Overly optimistic schedule or difficult to determine what will be done when; (for teams: no division of tasks)	schedule with clear steps and dates or timeframes	Realistic schedule with detailed measurable steps and specific dates or timeframes (for teams: clear division of tasks)	A, D	25%
English	Generally poor English	Avoidable spelling errors & grammatical errors, overly convoluted compound sentences with unnecessarily lengthy or redundant words.	Few spelling and grammatical errors, but style issues such as overly long sentences, redundant words, inconsistent point of view, inconsistent use of tenses.	Correct English with sentences of modest length and complexity, logical flow and few unnecessary words.	G	10%
Presentation	Report does	Subjective does	Generally follows	Objective. Follows	G	10%

	not follow guidelines	not consistently follow guidelines	guidelines, but viewpoint is not consistently objective.	formatting, section titles, captions, references, charts & figures.		
Organization	Unclear sectional organization, missing sections, inconsistent section headings.	Sections in wrong order, term use before definition, haphazard use of formatting, fonts, blank lines and indents.	Good use of sections, but inconsistent use of paragraphs, subsections, footnotes, cross references etc.	Good sections and section titles, abstract, conclusions and bibliography. Appropriate breakdown in subsections and paragraphs. Proper use of footnotes and cross references. Definitions before use.	G	10%

DigiPen Institute of Technology, CE 2nd Year Project
Project Proposal Presentation Rubric (revision August 2018)

Team: ABET Criterion D

Reviewer: ____

Rubric	**ABET Criterion**	**Points**	**Grade**
Explains function and scope	E	10	
Motivation for the project	C, J	10	
Explains use model	C, J, H	10	
Review of relevant technology used	A, E, F, J, K	15	
Shows block diagram	E, K	10	
Breakdown in tasks with time estimates	D	10	
Understandable, volume, enunciation, enthousiasm and engagement	G	10	
Structure and organization of talk	G	5	
Clarity of slides, font size, clutter, use of images, diagrams or charts	G	10	
Individual participation balance	F	10	
Total		**100**	

DigiPen Institute of Technology, 2nd Year Project
Final Presentation Rubric (revision August 2018)

Team Name: ABET Criterion D

Rubric	ABET Criterion	Points	Grade
Explains use model	C, H	5	
Motivation for the project	C, F, H	5	
Explains previous similar work by others	B, E, F, J, I	5	
Review of relevant technology used	A, J, K	5	
Explains function of the system	E, J, K	5	
shows block diagrams or schematics	E, K	5	
Presents measurements, experiments or tests	A, B, K	5	
Debugging and problems encountered	B	5	
Demonstration either live or on video	E	10	
Structure and organization of talk	G	5	
Clarity of slides, not too cluttered	G	5	
Not too few or too many slides,	G	5	
Use of images, diagrams or charts	G	5	
SUBTOTAL		**70**	

Individual		**Initials**			
Understandable, volume, enunciation,		5			
English and grammar		5			
Confident demeanor		5			
Eye contact with audience		5			
Enthusiasm		5			
Dress and appearance		5			
SUBTOTAL		**30**			

Name: ____________________________ Grade: ______________________

Name: ____________________________ Grade: ______________________

Appendix D: Second Year Project Knowledge survey

This survey is to determine your current relative level of knowledge of topics related to the course. Please answer truthfully, do not try to guess. If you don't know the answer, simply mark the appropriate option. ***This survey has no grade value, and should not be considered as a study guide for this or other courses.***

Name: ____

Answer the following questions with **T** (for True), **F** (for False) or **DK** (for Don't know):

1. A serial communications protocol transmit data several bits at the same time: _____
2. Bluetooth is a wired communication protocol: _____
3. A microcontroller has a microprocessor embedded: _____
4. Electrical current is measured in Amperes: _____
5. Ohm is the measurement unit for Voltage: _____
6. Traces in a Printed Circuit Board have zero resistance: _____
7. The amount of internal RAM in a typical microcontroller is more than 50GB: _____
8. WiFi has more range than Bluetooth: _____
9. A microcontroller can have digital and analog I/O: _____
10. PWM is a form of control commonly used to control the speed of a motor: _____
11. Copper density of a PCB clad has no effect on the final traces resistance: _____
12. Power traces in a PCB can normally have the same width of digital I/O traces: _____
13. In a device with 10 Ohm, supplied with 5V, there are 0.5A: _____
14. A solar panel of 5V and 100mA can provide 5W: _____
15. A PCB can only have 2 layers: _____
16. If we connect 24V to a 12V regulator and draw 1A from it, then the regulator is dissipating 6W: _____
17. How many Amperes we draw from a DC regulator has no effect on its temperature: _____
18. Through-hole devices are typically smaller than SMDs: _____
19. SMDs can typically dissipate less power than Through-hole devices: _____
20. Inside a microprocessor, accessing a register is faster than RAM memory: _____
21. A device that needs 5W on 5V, needs a battery of 500mAh to operate half hour(approx.):___
22. The higher the frequency of a communications protocol, the more power it needs: _____
23. Localization through odometry is known to accumulate errors: _____
24. A stepper motor can only rotate in one direction: _____
25. The direction of rotation of a DC motor can be controlled with a H-Bridge: _____
26. The direction of rotation of a Servomotor must be controlled through an H-Bridge: _____
27. A photoresistor's value can be read with an analog input in a microcontroller: _____
28. An open-loop controller does not sense the current state of the plant: _____
29. Traces can have the same width if they are in an external or internal layer, for the same application: _____
30. USB, I^2C, SPI are examples of serial communications protocols: _____

Appendix E: ECE220L Fabrication facilities

Overview: This document lists items that should be considered common to an electronics lab and required for executing courses such as ECE220L CE 2nd year project.

General purpose lab equipment:

- Oscilloscope, 4-channel, running at least 100MHz with ability to take screen captures.
- Analog Discovery 2: 100MS/s USB Oscilloscope, Logic Analyzer and Variable Power Supply
- Function generator, runs 1 – 5MHz, sine, triangle, square wave outputs, adjustable duty cycle, DC output level, and DC offset, TTL –compatible output, arbitrary waveform generation.
- Frequency counter, 0 – 5V @ 0 – 100MHz input signal range
- Logic analyzer, 8-channel, 100MHz with ability to decode SPI and I2C signals, among others.
- Power supply, variable 0 – 10V, either two variable outputs or one variable output and one fixed output @ 5V, at least one output running @ 3A.
- Desktop PCB Milling Machine for double-sided PCBs with 6 mil trace and space. Working volume: 5.5 × 4.5 × 1.35 in. Max XYZ Traverse speed: 100 in/min
- 3D Printer. Dual extruder. Build volume: 230x270x600 mm
- Multimeter, digital.
- Computer workstation.
- Project storage. Students need the ability to put away their electronics work when not working in the lab.
- Work lamp, swing-arm, adjustable
- Tools:
    - IC Extractor.
    - Wire stripper & cutter, used for 22AWG
    - Small shears.
    - Long-nose pliers.
    - Screwdriver
    - Cable, BNC to Alligator, 36”
    - Cable, Banana to Alligator
    - Cable, Banana to banana
    - Alligator test leads
    - Resistor lead forming tool
    - IC Pin Straightener.
    - Solderless breadboard, large
    - Solderless breadboard, small
    - Soldering iron.
    - Heat-resistant, flame-resistant glove
    - Solder, lead-free
    - Flux, resin.
    - Heat gun, 1200W, 2-temperature settings
    - “Helping hand”, magnifying glass with clips.
    - Brass shavings tip cleaner.
    - Tip Tinner, lead-free
    - Solder wick, lead-free.
    - Desolder pump
    - Soldering aide, picks, clamps, etc.
    - Fume extractor.
    - Small circuit board holder.
    - Large circuit board holder.
    - Heat shrink tubing, 1/8” – 1/2" diameters, assorted colors.
    - Tweezers.