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Work-in-Progress: A Multidisciplinary Hands-on Course to Guide Engineering Students Toward Becoming Blended Digital Professionals

Dr. Jaskirat Sodhi, New Jersey Institute of Technology

Dr. Jaskirat Sodhi is interested in first-year engineering curriculum design and recruitment, retention and success of engineering students. He is the coordinator of ENGR101, an application-oriented course for engineering students placed in pre-calculus courses. He has also developed and co-teaches the Fundamentals of Engineering Design course that includes a wide spectra of activities to teach general engineering students the basics of engineering design using a hands-on approach which is also engaging and fun. He is an Institute for Teaching Excellence Fellow at NJIT and the recipient of NJIT's 2022 Excellence in Teaching Award - Lower Division Undergraduate Instruction, 2022 Newark College of Engineering Excellence in Teaching Award, and 2018 Saul K. Fenster Innovation in Engineering Education Award

Dr. Ashish D. Borgaonkar, New Jersey Institute of Technology

Dr. Ashish Borgaonkar works as Asst. Professor of Engineering Education at the New Jersey Institute of Technology's (NJIT) Newark College of Engineering (NCE) located in Newark, New Jersey. He has developed and taught several engineering courses primarily in first-year engineering, civil and environmental engineering, and general engineering. He has won several awards for excellence in instruction; most recently the Saul K. Fenster Award for Innovation in Engineering Education. His research focuses on increasing diversity in STEM education and the STEM workforce. He has received multiple grants to run workforce development training programs as well as undergraduate research experience programs to train underrepresented minority and first-generation students. He is the Founding Director of NJIT's Grand Challenges Scholars Program. He also has worked on several research projects, programs, and initiatives to help students bridge the gap between high school and college as well as to prepare students for the rigors of mathematics. He is also involved in various engineering education initiatives focusing on the integration of novel technologies into the engineering classroom, and excellence in instruction. His additional research interests include water, and wastewater treatment, civil engineering infrastructure, and transportation engineering.

Teresa L. Keeler, New Jersey Institute of Technology

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Abstract

The boundaries between different engineering majors are thinning and there is a strong need for all engineering students to work toward becoming blended digital professionals in order to succeed as future engineers. This work-in-progress paper will introduce readers to an interdisciplinary, upper-level course that has been recently developed at the New Jersey Institute of Technology located in Newark, NJ, USA. This course familiarizes students with microcontrollers, an integral part of many modern, technological devices, and their exciting applications in the fields of the Internet of Things (IoT) and Robotics. Using a project-based, hands-on approach, microcontrollers are included as a component part of a broader design activity to introduce students to coding, logic, and automation in the wider context of engineering design. Students from different majors collaborate to work on multiple mini-projects to integrate a programmable system into a working prototype, such as a step counter, automatic plant watering system, and a home security alarm system. Overall, this course provides a foundational understanding of software design and coding, and microcontroller interfacing with sensors, actuators, motors, etc. Students also develop 3D modeling and prototyping skills and are encouraged to use the makerspace. The course further exposes students to the interesting field of data science, as students gather real-life data from sensors and then clean, analyze and create visualizations from the data set using common Python-based libraries. Preliminary feedback from students has been very positive. Students have expressed satisfaction in being industry-ready, especially as they were introduced to Python programming and data science while maintaining an engineering, hands-on context. This paper will discuss why this course was developed, its various components, and its preliminary outcomes. The goal is to enable readers to offer a similar course at their universities or integrate some of these modules into an already existing course that they are teaching.

Keywords: college teaching, pedagogies, project-based learning, software design, microcontrollers, data science, educational assessment, engineering design

Introduction, and Literature Review

Engineers live and work in a connected world, yet engineering students often study in isolated departments. This paper will examine the benefits to students for participating in a multidisciplinary engineering course. The course will give students insight into the collaborative approach used in professional settings and familiarize them with a critical piece of today's technology. In multidisciplinary teams, students will design and test numerous projects involving microcontrollers throughout a semester-long course. The rationale for and the structure of the course will be explained in more detail in the sections below.

The boundaries between different engineering disciplines are blurring with a significant focus being placed on interdisciplinary coursework. Gone are the days of masters of only one trade. For example, a computer and electrical engineer has as much to contribute to car production as a mechanical engineer. Any major engineering project requires engineers from different disciplines to work together and to understand the role and importance of each and every contribution to make the project a success. Engineering education is following these professional changes and more and more interdisciplinary courses are being added to the engineering and engineering technology curriculum. However, a majority of these courses focus on one to two engineering disciplines, and few courses are able to offer something to students from several different majors.

Engineering Boundaries Blurring

The intellectual components of engineering must be connected holistically to avoid "fractionated knowledge" (Hotaling, Fasse, Bost Hermann, & Forest, 2012). This is not how knowledge is created or the profession operates. With significant advances in computing power and emerging technologies, students need to become blended digital professionals in order to be successful in the modern engineering world. ABET (2010) stresses the need to cross and mesh disciplinary boundaries because new knowledge is increasingly created at disciplinary interfaces and new problems are best solved by multidisciplinary teams. Hotaling et al. (2012) also showed that multidisciplinary teams are more innovative, have greater proof of concept, demonstrate greater utility, produce stronger analysis and have better communication skills than monodisciplinary teams.

Importance of Computing in Engineering

The need to learn computer programming is well understood in some engineering disciplines; for others, the application of programming is less evident (Arjmandi, Woo, Mankelow, Loho, Shahbaz, Auckaili, & Thambyah, 2023). Coding builds independence, computational thinking, and the ability to reflect on and critique one's efforts (Siu, 2022). For example, when students learn to debug code, they are learning the process of finding solutions to their errors and being able to view things through a critical problem-solving lens (Siu, 2022) … just the things that engineers need to know how to do. Therefore, this course familiarizes students with microcontrollers, an integral part of many modern, technological devices, with a range of applications in the fields of the Internet of Things (IoT) and Robotics. By designing projects using microcontrollers, students learn coding, logic, and automation in the wider context of engineering design.

Approaches to Learning in Engineering

Much of the literature describes engineering curriculum as oriented toward the retention of facts and analytical skills (Stump, Hilbert, Husman, Chung, & Kim, 2011) As such, engineering education is often highly structured and driven by knowledge attributes, course outcomes, and program goals with responsibility for learning placed on the students (Chilukuri, 2020). However, research in the general education and engineering education realms confirms that learning occurs most readily in settings where the teacher transforms from a preparer of course content to a facilitator of student success (Chilukuri, 2020). Facilitation can occur through the design and implementation of various learning strategies, including project-based learning and collaborative learning. Each approach will be described below in further detail.

Project-Based Learning: For over twenty years, the concept of "project-based learning" (PBL) has woven its way into the education arena. As PBL gained in popularity, researchers at the Buck Institute for Education (BIE) created a comprehensive, research-based model for PBL to maintain the quality of this approach. Their "gold standard" for PBL includes seven essential project design elements: 1) a meaningful problem or question, 2) sustained student inquiry, 3) authentic context and application, 4) student voice and choice, 5) student reflection, 6) project critique and revision, and 7) public demonstration (Buck Institute for Education, 2020). Incorporating these elements ensures a successful project that maximizes student learning and engagement and aligns with Next Generation Science Standards (NGSS) and engineering practices (Larmer, Mergendoller, & Boss, 2015).

Typically, a culminating major engineering design project occurs at the end of a program of studies and is based on the knowledge and skills acquired in earlier coursework. A "capstone project" aligns with ABET accreditation standards (ABET, 2023). However, research has demonstrated the positive effects of incorporating project-based learning activities earlier into the curriculum. Ruiz-Ortega, Gallardo-Rodriguez, Navarro-Lopez, and Ceron-Garcia (2019) showed how incorporating even partial aspects of PBL into first-year engineering courses increased student motivation and understanding of course content. Students in our course will engage in active and collaborative learning to complete a multidisciplinary project.

Collaborative Learning: Engineers today need to be innovative and flexible to solve complex societal problems, or "Grand Challenges" as identified by the National Academy of Engineering (NAE, 2023). Therefore, engineering education should incorporate collaborative learning in the curriculum as a means of preparing students for future practice. Additionally, educational experiences that are active, social, contextual, engaging, and student-owned lead to deeper learning. The benefits of collaborative learning include the development of higher-level thinking, oral communication, self-management, and leadership skills; increase in student retention, self-esteem, and responsibility; exposure to and an increase in understanding of diverse perspectives; and preparation for real-life social and employment situations (Center for Teaching Innovation, 2023; Stump et al., 2011).

Integrated Curriculum: Individuals live and work in a connected world. An integrated curriculum can simply be described as "making connections" (Drake and Burns, 2004). Connected learning is brain-building (NE DOE, 2017). The more connections made by the brain, the greater the opportunity for making high-level inferences … that wonderful process of gathering and sorting information to draw conclusions. Inferences are the ultimate example of a "21st Century Skill" (Fadel, 2008) that helps students to more easily move from concrete to abstract thinking.

Vega (2013) goes further to say that "integrated studies involve the combination of two or more subjects in a lesson, project, classroom, or curriculum." A report from the Nebraska Department of Education (2017) described an integrated curriculum as "learning that is synthesized across traditional subject areas and learning experiences that are designed to be mutually reinforcing." In other words, an integrated curriculum develops a student's ability to connect and transfer learning to other settings. The more connections that can be made, the more knowledge that can be built.

Objectives

The goals of an integrated curriculum are quite similar to the goals of engineering education - "to develop the student's capabilities to integrate, analyze, innovate, synthesize, and understand contextually" (Hotaling, Fasse, Bost Hermann, & Forest, 2012). Effective strategies for developing these capabilities include active and collaborative learning through the use of student projects. This course is an attempt to utilize these strategies in a multidisciplinary course in an effort to increase student engagement and learning. The primary motivation to develop and run this course is to achieve the following two objectives:

Objective 1: Provide students with transferable skills that are useful across engineering disciplines.

Objective 2: Invigorate passion for engineering in students using a project-based, collaborative learning approach that is exciting for students.

Course Structure

This course builds on the research around learning strategies while purposely engaging microcontrollers to analyze and solve an engineering problem. This course stresses upon students understanding sensors, both in-built on the microcontroller as well sensors that can be used as an add-on. Additionally, students are taught to work on these microcontrollers using the most sought-after programming language in the current age- Python. The course consists of multiple mini-projects and a final project (as shown in Table 1) that utilizes concepts and skills learned throughout the semester. The microcontroller that is used for this course is BBC Micro:bit which was chosen due to its ease of use (which works well with the multidisciplinary population of this course), its compatibility to being programmed with Python, and finally because of its accessories' low cost. The various inbuilt sensors such as temperature, accelerometer, compass, light, etc. as well as the input/output such as Bluetooth connectivity, onboard speaker, etc. make the Micro:bit stand out from the other microcontrollers.

As the course progresses students are exposed to programming concepts such as lists, loops, functions, dictionaries, etc. in an application-based environment where they are able to see their code take shape on the Micro:bit. Another aspect of this course is to expose students to the Makerspace on campus and get them to actively use the facility to design and make working prototypes. This is done by running multiple pieces of training such as 3D Printing, Introduction to Computer-Aided Design (CAD), Laser Engraving, and Cutting during class time in the Makerspace. Another important facet of this course is introducing students to data analysis and data visualization applied to real-world datasets using Python, specifically Python libraries such as Numpy, Matplotlib, and Pandas. This helps students gain hands-on experience in

implementing and utilizing data science tools and eventually moving them forward on their path to becoming blended digital professionals. As an example, Mini-Project III requires students to find a real-world dataset of their own choice (with at least 3 columns and 150 rows) and then use Numpy and Pandas to parse, clean and analyze data, use Matplotlib and Pandas to create visualizations. As an example, a student chose to look at Soccer English Premier League (EPL) data from 1993-2018 to ask questions such as:
How many teams have played or are still playing in the League?
Which team has won the most EPL titles?
How many titles have certain teams such as Manchester United or Arsenal won in this time period?
The student was able to extract important information from the raw data file using Python and the aforementioned Python libraries. They were then able to analyze this data to find answers to the above questions. If you are curious to know- From 1993-2018, 50 teams have played or are still playing in the EPL. Manchester United has won the maximum number of EPL titles (12). Arsenal has won 4 EPL titles. Figure 1 below shows a visualization that the student-generated using Python and its auxiliary libraries.

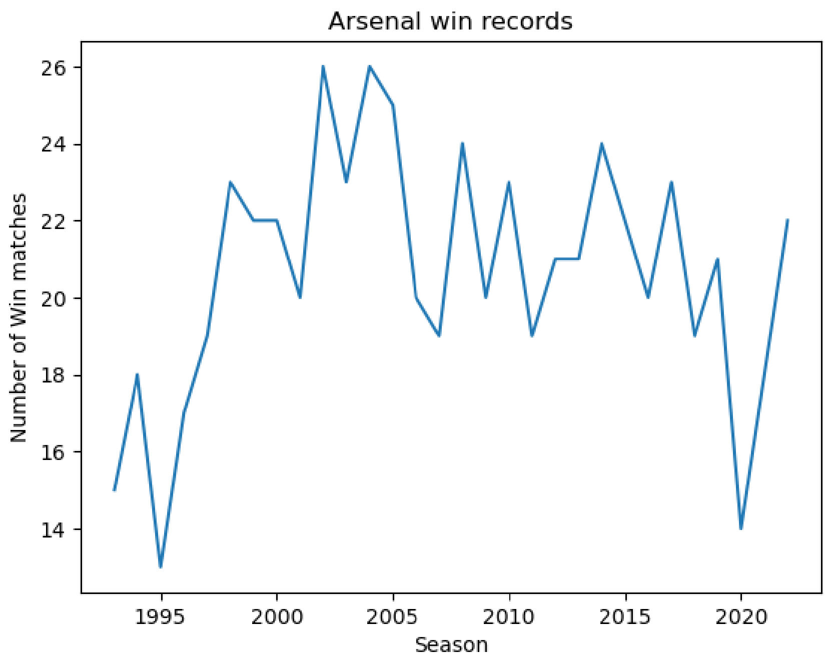
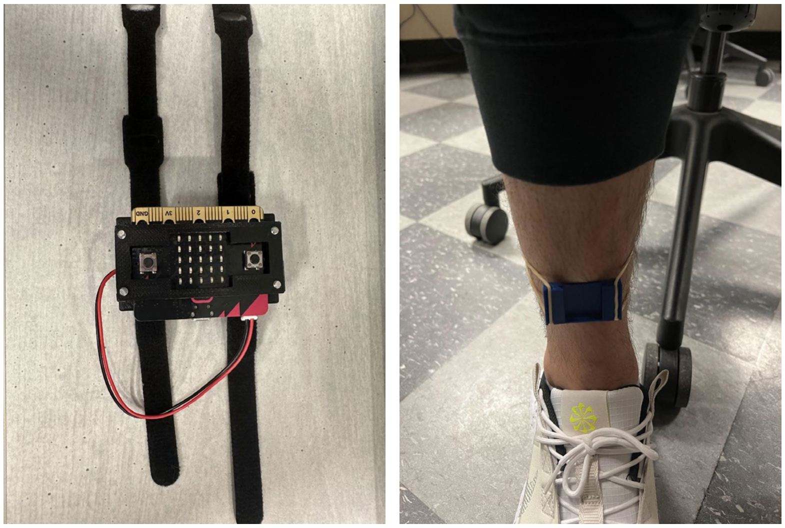


Figure 1 : Example of a student project showcasing data visualization. The plot shows the number of matches won by Arsenal from 1993-2018.

To provide some more context, a few more projects and assignments are shown in the figures below. Figures 2a and 2b show student designs of a pedometer design using the Micro:bit and a 3D-printed wearable device to mount the Micro:bit and the battery pack. Figure 3 shows a team-designed student project for a two-traffic light intersection with a left turn signal as well as a laser cut board to keep the lights in place as well as provide a perspective of how the lights will look in real life. For the take-home midterm, students were tasked to design a Micro:bit powered Halloween theme prototype with Python being used as the programming language and another constraint being that the project had to involve some aspect of making, which can be 3D printing, laser cutting, wood or metal work, etc. Figure 4 shows a student-designed Halloween-themed candy dispenser using a Micro:bit. The box is protected with a passcode, which when entered using the buttons on the Micro:bit, provides access to the valuable candy inside. The idea of showcasing these projects is to stress the hands-on aspect of the course as well as exhibit how the projects were made close to real-life engineering applications to keep students engaged and motivated.

Table 1: Course Schedule

Week	Topic
1	Basics of Microcontrollers, Sensors, and Actuators Introduction to the Internet of Things, Embedded Systems and Physical Computing
2	Python Programming: Variables, Lists, Loops. Micro:bit Buttons
3	Micro:bit Sensors: Accelerometer, Thermometer and Light Sensors, Compass, Speaker, I/O Pins
4	Python Programming: Functions, Lists, Dictionaries. Micro:bit: Radio Communication.
5	Makerspace Trainings, Mini Project I
6	Python Programming: Modules and Classes. Stop:bit Traffic Light. Mini-Project II
7	**MIDTERM EXAM**
8	Python Programming: Tuples, Slicing, and Dictionaries.
9	Data Analysis using Python Libraries – Numpy, Matplotlib
10	Data Visualization using Python using Pandas, Mini-Project III
11	Micro:bit: Soil Moisture Sensor. Collecting and Analyzing Data. Relays. Mini Project – IV
12	Micro:bit: Data Collection and Analysis using Accelerometer. Mini Project – V
13	Microbit: Programmable LEDs, Ultrasonic Sensors, Servo Motors.
14	**FINAL PROJECT PRESENTATIONS**



Figures 2a and 2b: Two Student Designed Pedometers using Micro:bit.

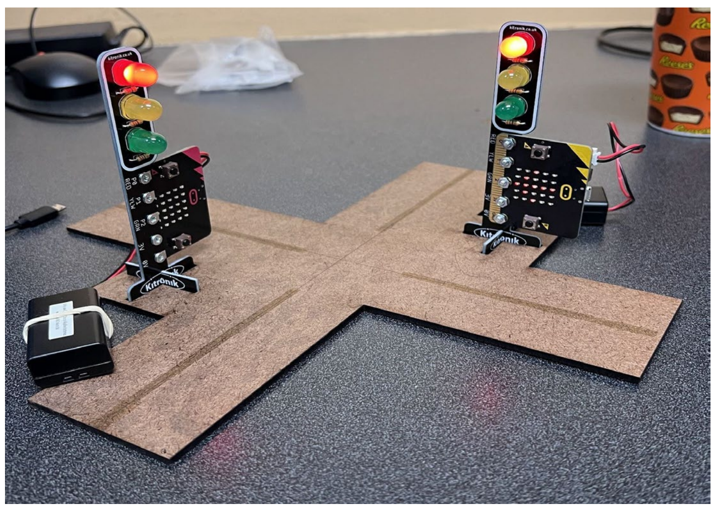


Figure 3: Student team designed traffic light project using Micro:bits

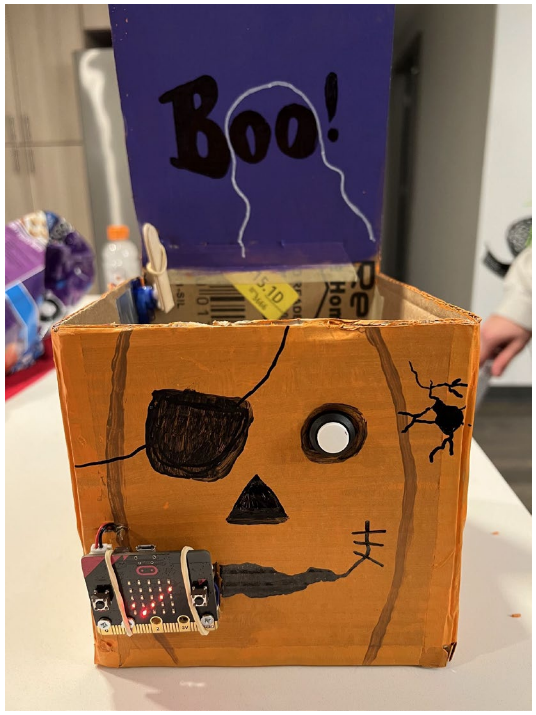


Figure 4: Student-designed Halloween-themed prototype for take-home midterm

Course Details

The course is a junior-level general engineering course offered under the umbrella of the engineering college rather than any specific department. It counts as a technical elective for all engineering and engineering technology majors except electrical and computer engineering students (as they already have a more detailed microcontrollers course). There are no prerequisites to this course to remove any barriers as well as encourage non-engineering majors at the host institution to also register for the course if they are interested. The first iteration of this course ran in the Fall of 2022 with 11 students. The students were from engineering (1 biomedical, 1 chemical, and 3 mechanical) and engineering technology majors (1 mechanical engineering technology and 5 electrical and computer engineering technology). The course is being planned to run on a yearly basis.

Preliminary Feedback

A mid-semester one-question feedback survey was run asking students what is the most important/valuable thing they have learned in this course so far. Table 2 below summarizes the results. There were three themes observed, namely Python programming, 3D modeling, and designing prototypes and making which match with the learning outcomes the instructor wanted students to take away. Another theme that came out from a few comments provided in the comments section was exposure to Makerspace. An example of such a comment is – "In addition to codifying hardware, my favorite part of the course so far is how interconnected it is with the Makerspace. It has pushed me to use the laser cutter in our Makerspace for the first time, as well as provided me the opportunity to learn a little bit of CAD to create a 3D design".

Table 2: Summary of mid-semester feedback

Themes	Number of times observed
Python Programming	6
3D Modeling	5
Designing Prototypes and Making	4

Feedback was also collected at the end of the semester using the course evaluations. Similar themes addressing the integration of Makerspace and engaging and enjoyable projects were observed. A student comment that summarizes this well is – "Every project and assignment felt purposeful and never painstaking. Even the non–Micro:bit assignments were thoroughly enjoyable despite the difficulty. I have never felt bored when working on an assignment, as they were always engaging and fun. I will certainly carry everything I have learned into the future." Another favorable student comment said – "The coursework and what is learned is different and very applicable. Gives me ideas for future projects." These two specific comments and the overall feedback speak directly to the two main objectives in designing the course were – 1. to make the course hands-on and application-based and 2. to inspire students to create similar projects armed with the basic tools needed to do that.

Summary/Conclusion

To summarize, this paper discusses a multidisciplinary project-based course that uses microcontrollers to enhance engineering and engineering technology students' skills in Python programming and Data Science. It also exposes students to the hands-on and making aspect of engineering as students work on creating multiple working prototypes. The feedback collected has been positive, but the course has only been taught once so far and the data collected is from a small population of students and thus not enough to make any statistically significant inferences. Future research on this project will collect more data and also work on doing a comparative analysis to see the impact of this course on our student population.

The repeated calls to expand the number of students completing STEM-related bachelor's degrees have been well-documented over the past two decades. Yet, only small progress has been made in advancing those numbers. The multi-disciplinary engineering courses such as the one covered in this paper are based on research findings that active, collaborative instructional methods combined with an integrative curriculum can increase student learning. Therefore, programs are encouraged to continue moving away from traditional lecturing in isolated classes in favor of active learning to improve overall student performance and build the pipeline of students receiving STEM degrees.

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