Design, Build, and Program a Thermostat for a Tiny House

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Abstract

This paper describes a multi-objective teaching module developed for the second semester of the first-year experience at the Department of Engineering at James Madison University. During the course, students explore the complexities of engineering decision making through fundamentals integrated with the semester theme of tiny houses. The objective of the module is to design, build, and program a thermostat for a tiny house using an Arduino UNO platform. Necessary skills were developed through an independent preparation assignment, followed by an in-class self-directed learning session where students built the Arduino "Love-O-Meter." Students were intrigued by the project and were asked to use their new knowledge to create more complex control systems to alter the Love-O-Meter into a thermostat for a tiny house. Among many standard learning outcomes, students experienced a real life application as many had not considered how or why thermostat controls works, and independent learning skills were honed. Multiple modes of learning were implemented and students completed the project empowered.

Keywords

Circuits, control system, programming, tiny house, first-year engineering experience

Introduction and Background

The ABET accredited Engineering program at James Madison University has a mission to nurture engaged engineers as a community of conscientious and adaptable learners who develop solutions for the betterment of society. As an undergraduate-only program located within a large public liberal arts university, the Madison Engineering (MadE) program is uniquely positioned to integrate the technical rigors of engineering fundamentals with the socio-cultural engagement provided by a strong liberal arts general education to develop the engineer versatilist[1,2]. These goals are consistent with the described "Engineer of 2020" by the National Academy of Engineering[3]. In light of these goals and the fact that JMU Engineer of 2020 has enrolled this year, there exists an urgency to implement integrated, multi-dimensional project-based learning. The development of such a program for the JMU engineering first year experience, as described by Gipson et al.[4], encourages such complex problem based learning. Specifically, the second of two first year courses, ENGR 112, focuses on knowledge, skills, and attitudes required to make engineering decisions[5].

This paper describes a multi-objective teaching module developed for the second semester of the recently reimagined first-year experience at Madison Engineering program. During the course, students explore the complexities of engineering decision making through fundamentals integrated with a semester design project. Two sections of ENGR 112 Introduction to Engineering Decision Making adopted the strategy of centering all independent topics back into a semester long theme of Tiny Houses. Tiny Houses are residential structures, generally less than

500 ft^2, designed for sustainable living including reduced cost, energy demand, space and general lifestyle downsizing. Tiny Houses are complex systems that integrate the engineering fundamentals of heat transfer, circuits and energy, statics, engineering economics, with a real world design challenges of building codes, construction materials, and the needs of real clients. Every topic of learning was tied back to the Tiny House theme through homework, group work, in class projects and discussions. In addition, the module (as contributing to the larger project) provided an opportunity to demonstrate course themes of integrate many of the course learning objectives which were:

1. Learn independently using a variety of commonly available resources;
2. Apply a methodical approach to understand and analyze problems;
3. Apply fundamental physical principles, mathematical relationships, dimensional analysis, and calculations to enhance engineering decision-making skills;
4. Accurately and appropriately use analytical and physical prototyping to evaluate trade-offs and make informed engineering decisions;
5. Use common engineering tools and software to solve engineering problems; and
6. Communicate and justify decisions to a broad audience in a professional manner.

Specific Objectives

The objective of the module was to design, build, and program a thermostat for a tiny house using an Arduino UNO platform. The learning outcomes included fundamental skills in basic circuits, computer programming, and control systems within a real-life application. Independent learning skills were honed in the context of intimate teamwork with one partner, while providing adequate scaffolding and excitement to motivate students to complete the hands-on design, build and programming of a real product. The Arduino platform has been used as a way to teach introductory computer science concepts[6,7,8] and provide context to computer science classes[9]. Given the ubiquity of sensors in everyday life and modern engineering applications, this learning activity provided a relevant and realistic way to introduce engineering students to programming sensors and algorithmic thinking.

Why a Thermostat?

The prompt for the Arduino mini-project was directly related to the tiny house clients' desire to reduce their environmental impact while providing for efficient heating and cooling of their new house. The prompt is as follows: "To be energy efficient, the temperature inside your Tiny House needs to be monitored closely with signals to turn the heating system on and off at specified temperatures. The goal of this assignment is to design and build a thermostat using an Arduino Uno."

A thermostat provides a real life application, as many students have not considered how or why a thermostat works (concept of controllers), turning HVAC systems on and off to regulate ambient temperature. Within the context of the Tiny House theme, a thermostat as a controller provided an immediately relatable practice with programming and sensors and a launch point for deeper conversations regarding design for social, environmental, and economic sustainability.

Arduino

The Arduino UNO platform is an inexpensive, versatile, open-source platform that includes company-developed modules and projects for learning programming and circuits. The instructions are available by printed book or online. The Arduino "kit" provided to students consisted of the UNO board, bread board, LEDs, temperature sensor, and the appropriate wiring, and resistors.

Independent Learning

In preparation for class, the students practiced independent learning by completing self-paced online learning modules on circuits using Lynda.com and on the Arduino system using the Arduino company-created modules. During the preparatory assignments, students built a circuit, connected the UNO board to a computer, and programed the controller using the Arduino programming language, which is based on C++. Students came to class with completion certificates to demonstrate the preliminary work had been completed. After completion of the prep assignments, students had a basic but functional understanding of circuits, building a circuit, and enough programming to demonstrate that the UNO light was functional.

Self-Directed Learning

Students learned the basics of circuits and computer programming through independent learning modules in preparation for in-class work. Fundamentals of computer programming were covered during self-directed activities in class. Students were provided additional temperature sensors and instructed to complete a module building the Arduino "Love-O-Meter." The Love-O-Meter utilizes a temperature sensor to measure the heat from a person's hand and lights up increasing numbers of LEDs with increasing temperature. Finally, students were asked to redirect their new knowledge of control systems to alter the Love-O-Meter and adapt it into a thermostat for a tiny house which performed as follows:

"The thermostat will continuously measure and regulate the ambient room temperature by turning the heating system on and off at specified temperatures. When the temperature drops below 68 degrees F, the thermostat will turn on the heating system (indicated by turning on a green LED) (green is for GO!). When the ambient room temperature reaches 71 degrees F, the thermostat will turn off the heating system (as indicated by turning off the green LED and turning on a red LED) (red is for STOP!)."

Simulating a thermostat could be accomplished by modifying the circuit and code from the Love-O-Meter in multiple ways and so students needed to demonstrate basic computational thinking in order to complete a working design. Students were intrigued by the project and created a more complex circuit and programming controls with additional sensors. Several upper class students with extensive knowledge of Arduinos were available to float and help students during the activity with troubleshooting and iteration. Multiple modes of learning were implemented and students completed the project empowered to design their own sensor systems for the course project and future courses.

Anecdotally, student experiences with the Arduino module were more positive and memorable than prior students' experiences with introductory circuits modules that utilized a theory and lab experiment approach.

Extension of Work and Success Story

After initial success with the tiny house Arduino learning module in Spring 2016, the activities were incorporated into one section of the course in Spring 2017. The course project changed for the second iteration of the module but addressed the same learning outcomes. For the Arduino module, the "tiny house" theme was replaced by a more generalized "energy efficient home" context, which was deemed to be relatable to the first year students. At the conclusion of the module, students were encouraged to incorporate sensor technology into their design project which focused on a local greenway and park development. Multiple groups explored potential solutions to challenges like safety, low-power lighting, and water collection/irrigation which would utilize sensors and control systems. Ultimately, one group (out of six) built their design solution with an Arduino sensor that could detect changes in ambient light in order to trigger trail lighting and considered options for how a user's motion could trigger lights further down the path. The group proposed a sensor-based system as a way to minimize power draw for lighting but still provide a safe environment. The group successfully built on their independent learning modules and self-directed learning activity to create a new system for a very different project context, and is promising for future work to incorporate programming and sensors into first-year project-based courses.

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Dr. Elise Barrella is an Assistant Professor of Engineering and Founding Faculty member at Wake Forest University. Prior to launching the new department at Wake Forest, she was a faculty member at James Madison University for five years and was recognized with the university's Junior Scholar Award in 2016. Dr. Barrella completed her Ph.D. in Civil Engineering at the Georgia Institute of Technology as part of the Infrastructure Research Group. She is an active member of Transportation Research Board and American Society of Engineering Education, among other organizations. Her scholarly interests focus on two areas: community-based design and urban planning, including the use of sustainability rating systems, and engineering education for sustainability. In addition to teaching and student mentoring, Dr. Barrella is engaged in research projects sponsored by National Science Foundation investigating engineering students' application of sustainability concepts across courses and project contexts.