WIP: Varying the Design Experience in First-Year Engineering

Dr. Kathleen A Harper, Case Western Reserve University

Kathleen A. Harper is an associate professor and the assistant director of the Roger E. Susi First-year Engineering Experience at Case Western Reserve University. She received her M. S. in physics and B. S. in electrical engineering and applied physics from CWRU and her Ph. D. in physics, specializing in physics education research, from The Ohio State University.

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Introduction: Course Goals, Structure, and Approach

Case Western Reserve University's first-year engineering experience is a one-semester required course. It introduces students to a breadth of engineering disciplines while developing their skills in programming, teamwork, and design. A series of two-week modules introduces students to cooperative engineering problem solving using a variety of tools and techniques. There are two 75-minute lab meetings per week and one common 75-minute lecture a week. In the lectures, programming concepts are presented and guest lecturers introduce the engineering majors. During lab, students combine programming with basic electronics to control devices, take data from sensors, and analyze that data. Each module, inspired by one of the engineering majors available on campus, culminates with a small design project. Each project lends itself to highlighting different aspects of the design process, as well as different ways of sharing prototypes.

Most modules take four laboratory periods, and the basic structure of each module is similar. During the first three lab periods students work in teams of four to build a physical device or object. The procedures for these first three periods are fairly prescriptive and introduce students to new tools, components, techniques, and concepts. As the module progresses, students start considering elements of a design challenge that applies their new knowledge. During the final lab period, students build, test, refine, and share the design with their classmates. Each design project has multiple unique features. To illustrate the scope of skills the projects entail, we describe the first two rapid design projects of the semester: a water filter from the environmental engineering module and a spy gadget from the materials science module.

Two Modules

Environmental Engineering Design: Water Filters

After several class periods of introduction to MATLAB coding and a brief introduction to engineering design, the first module where students integrate software with electronics focuses on water quality. During the first 2.5 class periods of the module, students create a prototype turbidity sensor using an Arduino, breadboards, LEDs, resistors, and a sensor from a dishwasher. In the second half of the third class, they are encouraged to read through some basic information about water filtration, along with the specifications for a water filter they will build, test, refine, and demonstrate in the fourth period. Each team is given a small plastic funnel for their filter and then may choose to arrange any combination of cheesecloth, cotton balls, sand, and small gravel inside of it. The filters are assessed based on how quickly and how effectively they filter muddy water. They are encouraged to research and sketch as they brainstorm. Each team is to arrive for the fourth class with an initial design ready to build.

At the beginning of the class, the testing procedure for the water filters is described in more detail. Particular attention is given to the criteria, how they will be measured, and how the best water filter will be determined. Teams then have 45 minutes to build, test, and modify their filters. When development and testing time is over, teams deliver their final designs to the testing area, where samples of dirty water prepared by the instructional staff await them. A representative from each team briefly describes their filter and some of the reasoning behind their design. At a signal, all teams begin pouring the dirty water through their filter, stopping when they have filtered one ounce of water. (One ounce was chosen because it is about the minimum amount to easily measure turbidity with our sensors.) A TA records the order of finish. As the filtering phase is completed, students present their filtered samples to a TA who measures the turbidity of each in nephelometric turbidity units (NTUs). The two criteria are combined to determine the best filter, using Equation 1, with the lowest score being the winner:

$$Score = NTUs * \left(1 + \ 0.2 * (time\ rank)\right) \qquad (1)$$

Teams go through multiple design iterations in the time provided. Most tend to focus on effective filtration more than the speed, but there are some exceptions. A typical final design includes layers of each available material, though students aiming for a fast filter tend to omit the cotton.

Materials Science and Engineering Design: Spy Gadgets

In the first three sessions of the materials science module, students work with a piezoelectric film, oscilloscope, Arduino, breadboard, and basic electrical components to write MATLAB code that detects how many times someone has knocked on the piezoelectric film. (This is not trivial, as different people's knocks generate different signals, and one knock contains multiple local maxima.) During the third class, teams are prompted to read the specifications for the design of a secret agent gadget that incorporates knock sensing. As before, they are to arrive at the fourth class with an initial design.

Students then construct their spy gadget using their piezoelectric film and their choice of a provided array of electrical components. The options include several components they have not used before, such as buzzers, haptic motors, and multi-color LEDs. Brief documentation is provided for these components. When the devices are complete, teams share their creations poster-style. Students are provided with a one-slide PowerPoint template with space for the name of their device and a one-sentence description of why spies would find their device useful. Students are given about an hour to build and test prototypes of their gadgets and create their slides. Each lab station has an LCD screen that the slides are displayed on during the sharing. As students, TAs, and instructors circulate around the room, they leave feedback regarding the creativity and strengths of each design. The professor shares these comments with each team.

Summary of the Rapid Design Projects

These rapid design projects serve multiple purposes in the curriculum, some of which are summarized in Table 1. In addition to these features, both projects are substantial enough that teams must work effectively to be successful in the time provided. The spy gadget project also introduces students to the concept of designing with the needs of a client in mind.

Table 1. Key details of the described rapid design projects

Characteristic	Water Filter	Spy Gadget
Research	Methods of water filtration	How to wire and work with new electronic components
Communication	Presenting the water filter design to the whole class (typically one student)	Presenting the gadget design and purpose during the "poster" session, asking other teams questions, leaving feedback for other teams
Iteration	Opportunities to test several iterations of the filter	Minor opportunities to adjust some aspects of the design (software and hardware)

Informal Assessment

The filter project has undergone no changes in the past several years, other than some minor adjustments to the formula used in judging. One common issue is that most class sections have at least one filter that takes more than ten minutes to filter enough water to measure turbidity, which makes it challenging to determine a winner before class ends.

In the most recent version of the spy gadget challenge, about 75% of the teams had a working prototype to share with their classmates. Those who did not achieve their desired functionality still had made enough progress that they could convey their intentions. Most of the teams without a working prototype either did not arrive to class with a plan or had a plan that was overly complex. Students greatly enjoy the interactions in the poster format and leave positive feedback for their classmates.

Even with room for improvement (discussed below), the faculty's informal observations indicate that students are learning about multiple facets of engineering. In addition to seeing students apply new technical knowledge to novel designs, we see that both projects foster fruitful interactions within and between teams. Students also take advantage of opportunities to be creative in both projects, but particularly when creating their spy gadget slides. On average, students have rated both of these modules in the top three of their most favorite modules in an end-of-course survey.

Future Work

Possible improvements and variations for future offerings of the water filter project include using different materials, adding a cost component to the criteria, and stipulating a minimum filtration speed. Modifications being discussed for the spy gadget include expanding the inventory of available electrical components and changing the intended client of the device.

In the future, we will more formally assess the success of each design experience using the following criteria: 1) percentage of teams that complete successful prototypes, 2) number of students in each team contributing to work (as measured by peer review), 3) student satisfaction (self-reported), and 4) quality of student feedback to other teams. We will also perform a qualitative analysis of the responses to reflective questions teams will answer about the design experience as part of the lab write-ups.