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Work In Progress: Interfacing with microcontrollers: an online laboratory learning experience

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WORK IN PROGRESS: INTERFACING WITH MICROCONTROLLERS: AN ONLINE LEARNING EXPERIENCE

An online learning experience for resident students entitled “Interfacing with Microcontrollers” has been designed and implemented. This is a 2-credit laboratory course offered in online format using the Blackboard LMS. This course, offered within the Department of Biomedical Engineering and crosslisted as a multidisciplinary course in the School of Arts, Science, and Engineering at the University of Rochester instructs on how to interface sensors and actuators with microcontrollers in order to make measurements and control objects in the real world.

While learning objectives for this course center around teaching students to properly interface microcontrollers with sensors and actuators, the course was designed with a number of meta-objectives in mind. One such goal is the desire to enhance the employability of our engineering students by providing them with more and earlier opportunities to acquire and demonstrate technical knowledge and skills, which have been shown to be very important to engineering employers [1] Second, this initiative sought to use an online learning environment to overcome obstacles to increased enrollment in such skills courses, such as crowded student schedules and increasingly limited facilities for educational laboratories for large classes. Lastly, this course sought to provide early engineering students with a rewarding hands-on experience that can demonstrate the power of an engineering skill set, perhaps encouraging students, especially those who might require extra coursework preparation to facilitate success in engineering curricula, to remain in engineering programs. The latter goal precludes the expectation of any engineering experience, thus there are no prerequisites.

This course has been fielded in two consecutive Spring Semesters, with final enrollments of 10 and 36 students, respectively. Initial enrollments are somewhat larger, with a subset of students dropping after the organizational meeting in which the details of the online format are introduced. Course evaluation results are similar to those of traditional courses offering similar material. It is anticipated that this course can scale up to accommodate 100 students without difficulty.

INTRODUCTION

Efforts toward continuing improvement in our department have fostered a desire to enhance the employability of our engineering students by providing them with more and earlier opportunities to acquire and demonstrate technical knowledge and skills, which have been shown to be very important to engineering employers [1] and our students have expressed similar opinions. There are, however, obstacles to fulfilling this curricular goal. Full semesters, busy students with high time commitments, fairly rigid degree requirements that involve high course counts, and finite instructional laboratory resources that are already highly in demand are all issues that need to be contended with. Lastly, we are exploring the possibility that early access to zero-prerequisite hands-on technical courses that can demonstrate the power inherent to an education in engineering might be of value for retention purposes, especially for non-traditional at-risk students that might find their early engineering coursework to be overly challenging.

Microcontroller development is an obvious target for a skills course. The need to learn embedded development comes up repeatedly in the context of our capstone senior design experience, and has resulted in the individual instruction of many students at our institution, over many years, often in the form of guided tutorials. While effective enough to support the capstone course, this approach does not expose every student that wants to acquire this skill set with the opportunity to do so; such instruction is limited to those students that need to learn the skills to support a project. It also lacks the efficiency of a classroom approach.

Microcontroller skills can be acquired today without formal instruction. Students can learn much of this material on their own through the “Maker Movement” [2], in which makers learn through the rigorous use of publicly available example programs. Personal observation suggests that such methods do indeed enable students to reach some facility with programming techniques, becoming more facile with each project undertaken, but students seem less successful in learning the hardware skills necessary to support embedded system design using such techniques. Perhaps this shortcoming lies in the lack of basic circuits skills sufficient to enable understanding of the circuits copied in the maker environment, and thus techniques might not generalize from project to project.

While the Maker environment seems to come up short in this respect, the lessons of the Maker Community should not be ignored: using modern communication techniques, highly technical skills can be learned outside of the traditional classroom environment, even if the skills require fairly advanced laboratory setups. Such an approach might prove useful in overcoming obstacles we've encountered in trying to offer more laboratory-based courses meant to develop technical skills. Indeed, if such techniques can be taught in an online learning environment, there is no need to reserve instructional laboratory space, which is a commodity that our faculty find increasingly challenging to acquire. Further, the flexibility afforded by the asynchronous aspects of online learning might make it easier for busy students to find the time necessary to take electives such as this course.

With this in mind, we developed a largely asynchronous online 2-credit offering of "Interfacing with Microcontrollers" (IWM). This offering makes extensive use of the Arduino system popular within the Maker Community, supplementing the typical Maker approach of learning-by-example with extra instruction and support in basic circuits skills. The course places less emphasis on programming skills than might be encountered in Makerspaces, focusing instead on why sensors, indicators, and actuators are interfaced with microcontrollers in certain ways.

Course learning objectives are:

- to use microcontrollers to measure and to manipulate the environment;
- to program microcontrollers using an Integrated Development Environment;
- to interface analog and digital sensors and switches to microcontrollers;
- to acquire and use the data thus generated; to interface microcontrollers to analog and digital actuators and other electronic devices to cause actions in the physical world; and to interface microcontrollers to other computational devices.

To accomplish these objectives, the major components of the course were:

- review of written material with associated video walk-throughs;
- completion of laboratory exercises, with students submitting videos of functioning assignments;
- presentation of laboratory exercises in journal form;
- module discussion groups;
- module quizzes;
- a Final Project, in which students were expected to incorporate tools learned in each module.

COURSE ORGANIZATION

IWM is a laboratory course hosted entirely within our Blackboard LMS. Students do laboratory exercises remotely and asynchronously, precluding immediate feedback. Scaffolding is provided by detailed video walkthroughs of the laboratory exercises, along with detailed drawings and photographs of exactly what the setups should look like. In these videos, the instructor can highlight details and provide insight to circuit functionality by using bench equipment, such as oscilloscopes and logic probes, that are not available to individual students. Instructor interaction is facilitated through scheduled video-conferenced "office hours" in which the instructor uses a video camera designed to image the physical apparatus in real time, and can view images of students' lab setups taken with cell phone cameras if necessary. Individual appointments for video conferencing are also available. Help can also be sought through class participants in module discussion forums, which students must participate in, either to ask questions or to offer help to students that need it. The instructor monitors these forums to offer assistance if required, or to recommend an individual video conference. Lastly, there is a weekly in-lab office hours made use of by roughly 10% of students in the class, with many using this opportunity simply as a set aside time in which to do the exercises, rather than as a source of supplemental or individualized instruction.

The successful participation of this course requires each student to purchase an Arduino kit from a reliable Amazon vendor (Elegoo, Inc., Shenzhen, China), and an additional small custom course kit containing some sensors and a digital multimeter from a large electronics distributor (Jameco Electronics, Belmont, CA). Students must also install the Arduino Integrated Development Environment (IDE). Indeed, the ease of installation and use of the IDE is a key facilitator of this course. There would be no way of running this course if the environment were not remarkably robust, as supporting the development system on every students' personal computers is simply not a possibility.

The very first assignment is used to verify that the student turning in the assignment has purchased the necessary kits, and can run the IDE, upload a program to the Arduino, generate a video of the working setup, and can submit a video -- in other words, the completion of the students' toolkit for taking the course is verified. Following this "getting started" exercise, the course proceeds in a series of five modules:

- Getting Ready to Use Microcontrollers – in this module, the students are introduced to very basic programming principles, as well as circuits fundamentals. More advanced circuits techniques are introduced in other modules, as needed.
- Reading Information from the Environment – students are taught to interface analog (resistive) sensors and tactile switches to the microcontroller.
- Controlling Things in the Environment – students are taught to control LED indicators, DC motors, and model aircraft servomotors with the microcontroller.
- Communicating with Other Devices -- students are introduced to serial communication techniques, including UART, SPI, and I2C busses.
- Putting it all together – this is the final project, in which students are asked to use a combination of concepts taught in earlier modules in the form of a modest project.

ASSESSMENTS

The assessments for the learning objectives include online quizzes, written assignments, class participation in the form of discussion forums, informal reports on laboratory assignments, and a final project. The informal laboratory reports minimally contain diagrams of the experimental setup, a brief description of the laboratory exercises, and answers to any questions asked in the laboratory assignments. Lastly, to complete the informal report, students must upload a video of the working laboratory setup for a given exercise.

The final project constitutes a strong assessment of the learning objectives. To complete this project, students must minimally measure an analog or digital signal, and manipulate the state of some indicator or actuator based upon the input signal. This goes beyond earlier exercises by simultaneously requiring the handling of both inputs and outputs. In a discussion forum, students define their final project, which is reviewed for acceptability. Guidance and modifications may be offered at this point. Students then implement their design, and submit their results in the form of an informal lab report and video. Successful completion of the final project indicates that the students have generalized concepts learned in earlier modules, and can use sensors, indicators, and actuators on a microcontroller when not given step by step instructions, thus demonstrating synthesis of ideas taught in earlier modules. The project is introduced in a staged manner, involving proposals and reviews before completion. A process-oriented assessment encourages honest academic practices [3] and students' insufficient grasp of any material are fairly easy to identify and (though less easily!) remediate during this process. The enhancement of the process-oriented nature of this project constituted a major change between the first iteration of the course and the second.

The demonstration of synthesis of the course material taught suggests that this course is meeting one of its primary goals: a course that typically makes extensive use of instructional laboratory space has been taught using a rather different resource model that eliminates the need for such a facility. While traditional courses can certainly make use of course kits to allow asynchronous completion of laboratory exercises, the online format also affords other advantages, such as flexibility for student scheduling purposes. Further, initial experiences suggest that with ample TA help, the course can accommodate many more students than it currently hosts, and more than we would be able to host in instructional laboratory space.

The meta-objectives, such as enhanced employability of engineering graduates and the retention of at-risk young engineers, are more difficult to assess. Certainly, we shall seek the opinion of our Advisory Board, which contains many decision-makers in the medical device industry, on the inclusion of early experiences to develop technical skills, and its impact on employability. Student enrollment has included young engineering students, including first year students. Non-engineering majors have also enrolled in this course. Almost all students in the first two instances of this course have passed, with only one student failing. Future efforts will be made to track the retention of students in our engineering programs. Future offerings of this course will contain detailed analysis of course evaluations, and evaluation questions will be added to specifically assess student opinions about the online format. Efforts will be made to compare the evaluations to those of similar courses taught by more traditional means. We will also investigate retention statistics for students with and without early technical skills courses, with some focus on at-risk students.

References

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