Motors, Sensors, and Robotics for Physics 202 Labs

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Executive Summary

This application for the Fine Teaching Award is a request for a course release to enable development of new labs for Physics 202, Introduction to Electricity & Magnetism. The driving motivation behind this work is that the traditional physics labs for this course tend to be procedure-based and have focused on basic circuit elements like resistors and capacitors. The content of this course could become much more relevant to the digital age by including labs that make contact with devices and sensors that are similar to systems that students will encounter in their careers. Through the lens of sensor and computer-oriented circuits, the new pedagogy will make important contributions to both students' technical knowledge and their general education as we enable them to better understand the digital world.

The specific plan for these new curricular developments is to transform the existing set of labs that are of a procedural nature to include more inquiry-based learning tasks, and to develop and integrate an entirely new set of labs that are based around Arduino development boards. The Arduino is a small computer that emerged from the DIY/hobbyist world and can be used as a generic development platform for a wide range of projects. Auxiliary boards can extend the functionality of the device to control motors, communicate over Wi-Fi networks, and control visual displays, for example. A wide range of sensing devices such as thermal, light, and range sensors can be easily integrated with the Arduino to construct devices from motion sensors, to weather gauges, to autonomous robots.

It is expected that these changes will have significant impacts on student learning, perhaps with auxiliary benefits including enhanced recruitment of physics majors. The use of basic computer programming is an important component of a contemporary general education for students in STEM fields and will be a central component of these labs. For many students majoring in something other than a physics discipline this may be their only formal exposure to computer programming during their education at SUNY Cortland. The Arduino platform that students will work with can also serve as a template for future teachers who will be looking to bring creative STEM activities to their classrooms.

Problem Definition

The long-standing tradition of physics labs for introductory focuses on the process of measurement in simple experiments. Perhaps foremost among these, and ones that we all likely experienced, were measurement of the acceleration of a block on a slope (in intro mechanics) and measurement of the RC time constant for DC circuits (in intro electricity and magnetism). While such experiments, having been stripped of all excess complications, reveal fundamental relationships and provide a training ground for application of statistics, they are dreadfully boring and disembodied from real-world experience.

My focus in Physics 201 labs (Introduction to Mechanics) has been to move away from the model of block-on-slope labs and move toward labs that involve both inquiry-based learning and applied learning pedagogy. These are distinct pedagogical concepts that warrant a brief description. Inquiry-based laboratory exercises lead students with a general goal or problem statement, in contrast to procedure-based exercises that require students to follow a specified protocol to achieve a specified set of measurements. Two benefits of this method are that it requires that students understand concepts and equipment at a deeper level, and it requires that broad interpretive and critical thinking skills be applied to the problem. Applied learning nicely dovetails with inquiry-based learning because its goal is to immerse students in simulations in problems that are inspired by real-world situations, possibly to the extent of becoming a simulation of a real-world environment. The suspension of disbelief that accompanies these situations, somewhat similar to our experience when watching a science-fiction movie or a play, enhances the experience through enhancing the willingness to engage.

While it has been fairly straightforward to integrate new labs of the inquiry-applied style into Physics 201 because of the relatively simple tools required for those lab experiences, I see substantially more difficulty in incorporating similar ideas into Physics 202 labs given that the focus there is on analysis of circuits and is largely defined by the available equipment to conduct such measurements. Three primary issues make modification of the existing curriculum an important and high-priority task.

First, and most importantly, Physics 202 is the only appropriate place in the curriculum for students from across the sciences to develop a working knowledge of sensors, computers, electro-mechanical systems like robots. While some foundational knowledge in the basics of circuit design and measurements process is important, it is also essential that we prepare students to better understand the world they will actually encounter. The proposed transformations are in this way unique across the SUNY Cortland campus.

Second, the existing labs feel particularly old and dry to me, so I can only imagine how they feel to the current generation of students. The existing equipment for Physics 202 labs includes analog oscilloscopes that lack even a basic trigger function, circuits that are wired using knife switches one would expect to see in a 1940's science-fiction movie, and marginally adequate function generators. The new Arduino kits will be a huge makeover for these courses and will provide a refreshing and modern appeal to the course. Given that this is the second-semester course in the intro series, my hope is that once word of the interesting labs in Physics 202 gets around, that the focus on robotics provides further incentive to students to buy-in to Physics 201 as a stepping stone to this course.

Third, there currently exists a large deficit in the laboratory material for Physics 202. We are currently operating with a set of 8 full labs for Physics 202. This deficit of labs should be viewed as an opportunity for us to expand the range of experiences of this course in a very meaningful way while keeping some of the fundamental (and important) elements of DC and AC circuit analysis.

Proposed Solution

The new labs will use the "Arduino Engineering Kit" that was designed for college engineering courses. These kits come with hardware to build autonomous robots, and also includes things like range sensors, motors, gears and wheels.

The rough plan for the full curriculum redesign, assuming that a Fine Teaching Award will support this work, is to incorporate the former lab exercises into the new labs to create a set of approximately eight labs. Each major lab will be conducted over multiple weeks, and the series of labs will build to a capstone project where students develop a working robotic device designed to complete a specific challenge. A series of scaffolded labs will be developed to introduce students to the Arduino hardware and the basics of computer programming. Intermediate projects will incorporate elements of the former traditional labs, including things like voltage dividers and high/low-pass filters, as building blocks in support of the larger goals.

The SUNY Cortland administration has expressed an interest in this project and it is possible that funding for the purchase of 25 kits could be acquired for Fall 2019. The success of this curricular development project does not require that a full set of kits be available for Fall 2019.

Anticipated Benefits

There are four clear and important benefits that will arise from the proposed curricular changes. These are:

- The new curriculum will be far more relevant to the future careers of our students, and therefore is a significant addition to their technical general-education.
- We will more effectively use the time dedicated to Physics 202 labs by expanding the number laboratory activities.
- The new activities will include inquiry-based and applied-learning components that will make the overall experience far more engaging for students.
- All students will be required to learn the fundamentals of computer programming.

The incorporation of computer programming into the new curriculum is both a necessity and an added benefit. A majority of the students who take Physics 202 likely get no formal exposure to programming elsewhere in their studies. A series of scaffolded labs will introduce students to programming, building up to more complex tasks on a weekly basis. As an example, we will start Day 1 of lab with the "blink" program where we get an LED to blink on for half a second and off for half a second, which requires only the following lines of code.

```
void setup() {
        pinMODE(LED_BUILTIN, OUTPUT);
}

void loop() {
        digitalWRITE(LED_BUILTIN, HIGH);
        delay(500);
        digitalWRITE(LED_BUILTIN, LOW);
        delay(500);
}
```