
AC 2011-2642: USING ARDUINO AS A PLATFORM FOR PROGRAMMING, DESIGN AND MEASUREMENT IN A FRESHMAN ENGINEERING COURSE

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Abstract

Arduino is a compact, inexpensive, open-source electronics prototyping platform built around an Atmel AVR microcontroller. The features, cost, and small size makes Arduino a potent tool teaching as well as practical device use in engineering projects. This paper reports on adapting the *Living with the Lab* (LWTL) curriculum to the Arduino platform. LWTL was developed with the Boe-Bot mobile robotics platform and the Basic Stamp microcontroller. The Arduino is more modern and has better technical capabilities, but there are fewer educational resources for the Arduino than there are for the Boe-Bot. The updated curriculum was successfully implemented at two universities. End-of-term surveys indicate that students had a positive experience of the course, especially the hands-on exercises. However, students were not as positive about the current state of instructional support for Arduino programming. The Arduino remains a viable and preferable platform. Recommendations for improvement of curricular materials for the Arduino are made.

Introduction

Engineering classes for freshman have traditionally focused on problem solving, engineering graphics, and computer programming. These subjects require no prerequisites other than an interest in some type of engineering. The traditional freshman engineering classes are now recognized as being un-inspiring to incoming students, even though the skills taught in the class are considered useful. Furthermore, in limiting course content to only the basic skills, students are not exposed to the more creative and applied aspects of engineering practice. There is now broad agreement that engagement of freshman engineering students is important for retention and motivation¹.

Many universities have developed freshman year courses with substantial hands-on experiences designed to expose students to the application of engineering principles²⁻¹⁰. Hands-on, project-based courses attempt to resolve the tension between providing training in the fundamentals of programming, graphics and problem solving, with the need for motivating and engaging students. Active learning in freshman year courses is also believed to improve retention and appeal to more diverse population of students.

The *Living with the Lab* curriculum uses design and fabrication projects involving DC electrical circuits, computer programming, solid modeling, machining, rapid-prototyping, working with hand tools, testing, data analysis and plotting^{5, 11-13}. Students assemble their own set of hand tools. They purchase a robotics kit that is used throughout the curriculum. The “Living with” in the title of the curriculum refers to student ownership of critical components of the laboratory hardware. Students complete homework exercises with this hardware at home, and then demonstrate their skills and working hardware in class.

Robots and or microelectronics kits are popular features in hands-on courses for first year students^{2, 5, 14-19}. The equipment is chosen because it is compact, portable and relatively inexpensive. Students kits contain sensors, a programmable controller, actuators, light emitting diodes (LEDs), and other components that can be assembled and reassembled into a variety of systems. Playful experimentation can be incorporated into coursework and students are often given wide latitude to do something interesting, even in those cases where the class work involves a competition between student teams.

This paper is a report on freshman engineering courses using the *Living with the Lab* (LWTL) curriculum and the Arduino platform to teach programming, sensing, and control. LWTL was developed with the Boe-Bot mobile robotics platform and the Basic Stamp microcontroller²⁰. The Boe-Bot has a large community of practitioners and high quality educational materials. The Arduino is a robust and easy-to-use platform with a strong community of developers and users. The Arduino uses a modern microcontroller architecture and has better support for sensor input than the Basic Stamp. Although there are many examples of using Arduino in simple projects, the breadth and quality of the educational materials for the Arduino does not currently match that of the Boe-Bot/Basic Stamp platform. The goal of the paper is to provide a case study in successful introduction of the Arduino into the LWTL curriculum.

Arduino is a compact, inexpensive, open-source electronics prototyping platform built around an Atmel AVR microcontroller. Arduino is a single board system that is programmed via USB connection to a host computer. It has regulated and unregulated DC power, digital inputs and outputs, and analog inputs. The features, cost, and compact form factor makes Arduino a potent tool for introducing a large range of engineering concepts. Although it would seem that microcontrollers are of interest only to computer, electrical and mechanical engineering students, the LWTL curriculum is used in freshman courses taken by many disciplines, including biomedical engineering, chemical engineering, civil engineering, computer science, industrial engineering, and nano-systems engineering.

The Arduino is part of a larger trend toward open source hardware fostered by a diverse mix of private tinkerers and profit-making companies selling electronics kits²¹⁻²⁴. The broad interest and commercial viability of this platform makes it easy for academics to focus on the development of instructional materials, not on the design, fabrication, and support of the hardware platform. Consistent with the LWTL philosophy, each student gets his or her own kit with an Arduino and electronic parts for less than \$100. Students are also required to purchase a kit of basic hand tools, which costs no more than \$75 (in 2010). The educational exercises begin with using the parts in the commercial kit, and then expand to include hardware developed exclusively for LWTL.

Two different introductions of the Arduino platform into LWTL are described in this paper. At Louisiana Tech University, an Arduino board was used to replace the Basic Stamp microcontroller on a mobile robot platform. The curriculum closely follows the original LWTL curriculum developed for the Boe-Bot mobile robot by faculty at Louisiana Tech. At Portland State University, the Arduino was used as the power supply and for control of a student-designed desktop fan instead of a mobile robot. This paper describes a work in progress as the Arduino implementation is happening for the first time in 2010 – 2011 academic year. The Arduino

instructional materials and projects developed for the LWTL curriculum could be used selectively in other courses without needing to implement the full LWTL curriculum.

Method and Research Questions

This paper is a progress report on the introduction of the Arduino microcontroller platform into an established Freshman Engineering curriculum. The faculty at Louisiana Tech developed and has used the curriculum for several years. The faculty at Portland State University has just adopted the curriculum. The transition to the Arduino platform is motivated by the improved features and cost as described in the preceding section. The introduction of the new technology is expected to improve the class, but it also introduces complications because the lecture materials and laboratory exercises need to be modified. Thus, we are using formative assessment to monitor the effect of changes in curriculum. Another research goal is to determine the degree to which changes in curriculum are effective at motivating student interest in engineering in general, and interest in specific skills such as working with basic electronics, computer programming, solid modeling, fabrication, testing, data analysis and plotting.

The popularity of the Arduino platform amongst hobbyists and professionals working with microcontrollers does not mean that students will respond positively. Instructors used the “buzz” about the Arduino to motivate students, by indicating that the students were using a new and popular technology. Instructor observations of student reaction showed that students were not universally inspired by or interested in the technology. This makes sense because the definition of “cool” is not uniform for engineering students.

Assessment was performed with an end-of-term survey of student attitudes toward the course and how it affected their career plans. Students were asked whether the use of the Arduino platform changed their attitude toward computer programming and electromechanical systems. The complete survey is included in Appendix B. Results from the survey are discussed in a later section. First we provide background on the LWTL curriculum and the changes made to incorporate the Arduino.

Living with the Lab

Living with the Lab (LWTL) is a project-based, hands-on curriculum for first year engineering students. Over one academic year, LWTL exposes students to programming, electronics, sensors, basic integrated circuits, controls, robotics, mass and energy balances, statics and dynamics, engineering design, teamwork, technology and society^{5, 11-13}.

LWTL involves classes of 20 to 40 students who meet twice a week for 110 minutes over a 30-week period. Both Louisiana Tech University and Portland State University use a quarter calendar with 10-week terms. Consequently, the LWTL curriculum is divided into three distinct courses. Louisiana Tech University awards six semester hours of credit (two per quarter) for the three courses, while Portland State University awards six quarter hours (two per quarter) for the three courses (equivalent to four semester hours). The content breadth and depth is ambitious for the course credit awarded. Note that on average the students spend a substantial part of each class period engaged in hands-on activities that might include building and testing circuits on

breadboards, manufacturing parts with milling machines, or measuring performance of components and systems that they have fabricated and assembled.

The first LWTL course uses the robotics platform as a tool for introducing basic DC circuits and includes a major project; the major project at Louisiana Tech University is a robot navigation challenge while the major project at Portland State University is the design, fabrication and control of a small oscillating fan. Students also fabricate and test a small centrifugal pump as part of the first course at both universities. In the second LWTL course, student teams develop a system that provides closed-loop control of the temperature and salinity of a small volume of water. Students fabricate and calibrate conductivity and temperature sensors and use transistors and relays to control solenoid valves and a heater. In the third LWTL course, student teams develop a prototype of their own innovative product using the hardware, knowledge and skills acquired in the first two courses. The third course focuses on sensors and design strategies for product development. All three LWTL courses include a strong focus on fundamental engineering topics.

Homework typically consists of worked-out problems covering engineering fundamentals, problems requiring the use of the robot and sensors, and activities related to course projects. Students also deliver oral presentations detailing their projects, locate and specify parts and supplies from online retailers, complete solid modeling assignments, and use Excel and Mathcad to solve course-related problems. The broad aim of LWTL is to immerse students in a dynamic, project-focused environment. Both universities stress individual accountability for learning course materials while also encouraging teamwork and providing exciting open-ended challenges. The combination of homework, fabrication, programming, design, problem solving, and communication provide a strong foundation and context for later engineering courses.

While students provide most of their own tools and equipment, both universities provide project parts and supplies and fixed equipment to facilitate projects. The preparation and management of these is consuming less faculty/staff time as the LWTL effort matures. Both universities have developed dedicated classrooms that allow instructors to seamlessly transition between lecture, laboratory and shop activities. For example, the large LWTL classroom at Louisiana Tech University serves 40 students and includes 10 round tables to encourage collaborative learning, 10 milling machines for fabricating project parts, 10 sets of tools at each milling station, two sheet metal shear/brake combinations, two lathes, and a rapid prototyping machine to render 3D parts for projects. Portland State University has a lab classroom that serves 32 students with 8 tables of four, 8 milling machines and tool sets, and a laser cutter.

To keep costs down, the LWTL experience does not require students to purchase an engineering textbook. Instead, all of the course materials are available online for free download. The major challenge in moving from the Boe-Bot to the Arduino has been to modify the large collection of online documents that were specific to the Boe-Bot. The transition effort has resulted in the development of a significant number of new homework problems and the revision of the notes with Boe-Bot specific content; about half of the content has been significantly revised. The transition has also resulted in the rescheduling of course topics in some cases. Incorporating the analog input capabilities of the Arduino caused the biggest change in course structure. The Boe-Bot does not have a built-in analog-to-digital converter.

Low Cost Microcontroller Technology

Microcontrollers are single-chip, integrated circuit devices that can be programmed to read electrical signals (input) and send electrical signals (output). Microcontrollers are designed for embedded control applications, and are pervasive in consumer and industrial products. Electrical and computer engineering are professions most commonly associated with the design and use of microcontrollers. However, as microcontrollers have become inexpensive and ubiquitous, the systems for programming and deploying them have become easier to use. These trends have made microcontrollers accessible for many types of engineers, as well as curious hobbyists, artists, and other “non-technical” people. The Arduino platform was “intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments”²².

Arduino is an open-source hardware and software platform. The electrical design, programming software, and a large set of tutorials and examples are freely available. There is an energetic and idealistic community of open-source hardware participants who contribute to improvements in the platform, the creation of add-on circuits and components, and in providing instructional materials. This leads to rapid innovation and diffusion of innovation.

The Arduino has several features that make it useful as a platform for an introduction to engineering. It is inexpensive: a bare Arduino costs about \$30 (US dollars in 2010). For less than \$90 (US) students at Portland State University bought a copy of the Arduino Inventor’s Kit that includes an Arduino and a variety of electrical components and sensors sufficient for much of the curriculum described in this paper²⁴. Figure 1 shows the 2009 version of the Arduino called the Duemilanove (“2009” in Italian). Features identified in the Figure 1 are described in Table 1.

The Arduino platform has excellent technical performance, especially considering its low cost. The A/D components can read up to 7 channels of data at speeds sufficient for a broad range of applications. It has 14 channels for digital input or output, which enables control of logic (on/off) signals. Five of the digital output channels can be configured for pulse-width modulation (PWM), which provides emulation of analog (variable level) output. The AVR microcontroller has sufficient memory for writing complex programs for data acquisition and control. The Arduino platform includes a program editor and cross compiler. Programs are written on a host computer — typically a student’s laptop — where they are compiled and then downloaded to the Arduino’s microcontroller via a USB cable.

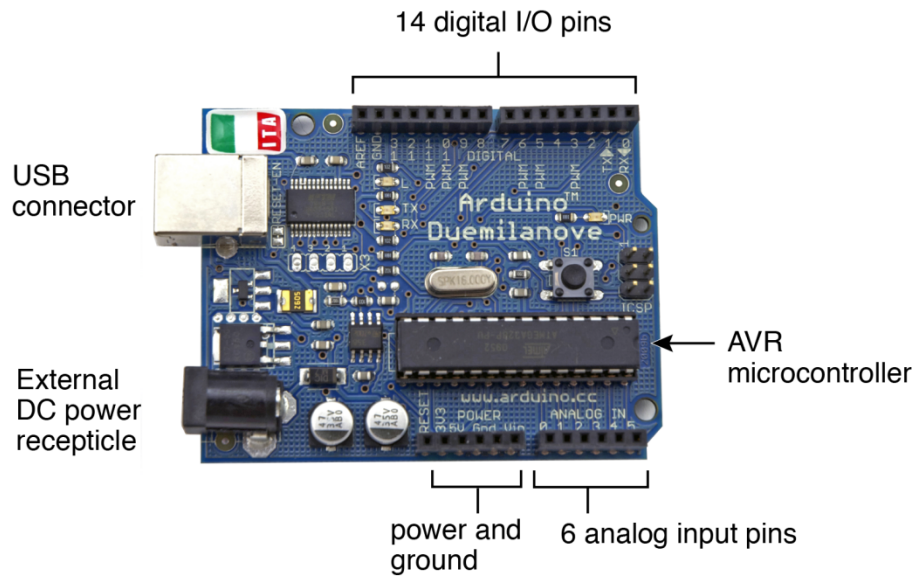


Figure 1 Arduino Duemilleneuva: actual size 7.6 cm long by 5.1 cm wide.

Table 1 Functional components of the Arduino microcontroller in Figure 1. See also Appendix A for a glossary of terms.

Functional block	Purpose
AVR microcontroller	The ATMEL AVR328 is the computational brain with on-board analog to digital conversion (ADC) and pulse-width modulation (PWM) output
DC Power jack	Supply power: required when the USB cable is not connected or when current supplied by the USB is insufficient for a control task.
USB port	Download programs from the host PC Upload data from the microcontroller
Digital I/O pins	Electrical connection points used to send voltage signals to external components
Analog input pins	Electrical connection points for measuring voltage signals from external components (e.g. sensors)
Power and ground	Electrical connections to supply DC voltages (5V, 3.3V or V_{in}) and the ground plane for the microcontroller

Learning to Program with a Microcontroller

In a traditional freshman engineering course, students are introduced to a computer programming language. Historically, that language was Fortran. Depending on the discipline, the first language learned today might be Java, C, C++, python, MATLAB or Visual Basic. Typical programming exercises involve automation of engineering analysis by evaluating and printing and/or plotting values from a design formula. This is a valuable skill, but it can be challenging to convince students of the need for that skill when they can do most of their elementary computations on a spreadsheet.

A microcontroller platform provides the context and motivation for students to learn computer programming. Instead of evaluating and printing results from an engineering formula, students write programs to blink lights, read sensor data, and control servo motors, DC motors, or other actuators. The outcome of these programs is tangible and evident to anyone, regardless of their familiarity with programming. Since it is not (yet) possible to write microcontroller code with a spreadsheet, students working with an Arduino see that learning to program has provides important capabilities not attainable with business-oriented software.

A substantial part of the first LWTL course involves learning to program by controlling a small robot. The Boe-Bot platform is a mobile robot with a well-developed supporting curriculum provided in textbook format by the manufacturer, Parallax, Inc ²⁵. In the original LWTL curriculum students learn to program by completing a number of exercises in the book, which includes visual guides to assembling circuits and the hardware for the robotics platform.

Switching to Arduino meant that large amounts of documentation for the courses had to be re-developed. The technical capabilities, the physical dimensions, and the programming language for the Arduino is distinctly different from the Boe-Bot. The Arduino is very popular, and it is easy to find Arduino tutorials and sample projects on the Internet. Unfortunately, little of the on-line material could be used as-is in the LWTL courses.

Another major hurdle for switching from Boe-Bot to Arduino is that there is no standard mobile robotics platform for the Arduino. Therefore, we had a choice: either find or develop a mobile robotics platform for the Arduino, or change the emphasis of the programming assignments from mobility robots to something else. Faculty at Louisiana Tech University took the former approach: adapting the Arduino to the Boe-Bot chassis without the Basic Stamp microcontroller. Faculty at Portland State University took a different approach: developing a new exercise that required students to learn how to program and fabricate hardware for the microcontroller to manipulate.

The Mobile Robot at Louisiana Tech University

The mobile robot adopted by Louisiana Tech University is shown in Figure 2. The chassis was purchased from Parallax and includes the same basic parts as the Boe-Bot. That is, the chassis kit includes the aluminum chassis, two Parallax servos, a 4-AA battery holder, and various electrical components. An Arduino Duemilanove was purchased to serve as the

microcontroller. Additional parts that were purchased include two microswitches to serve as whiskers (touch sensors), a 6-AA batter holder (the Arduino needs a supply of at least 7VDC), a 4 inch x 6 inch aluminum plate 1/16 inch thick, a 400 tie point solderless breadboard with adhesive backing, and a USB cable.

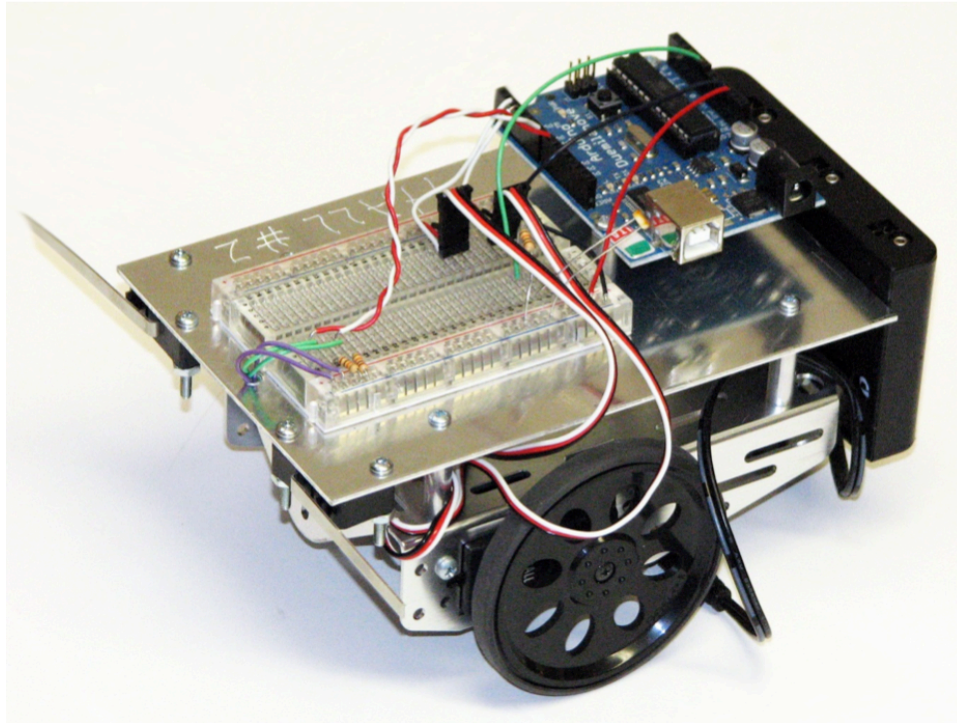


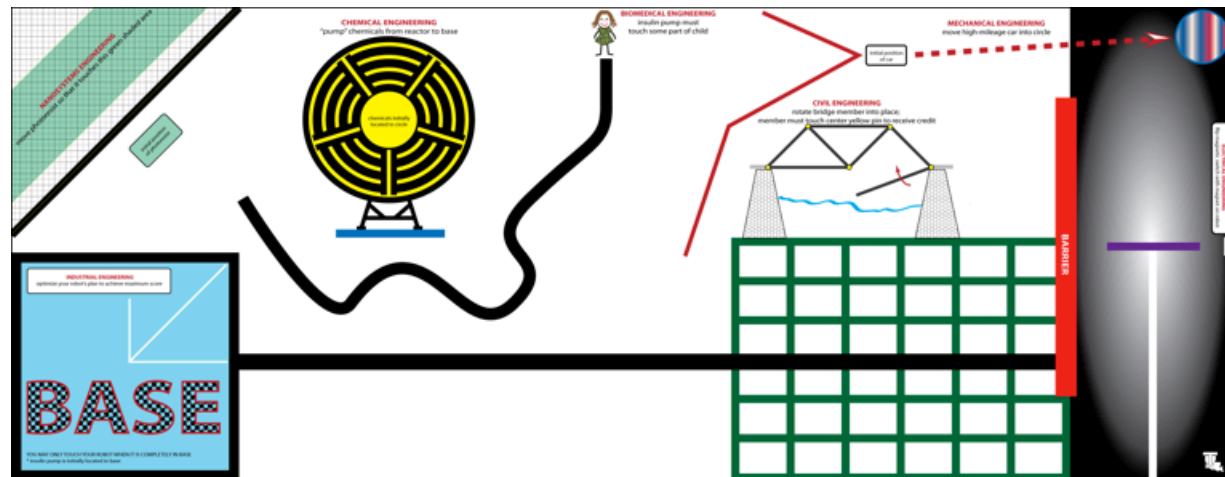
Figure 2: Arduino microcontroller mounted on a Boe-Bot chassis.

Students assembled the robot and completed homework exercises that required developing programs to move the robot and have it respond to sensor inputs. The culminating project for the class was the “Navigating the Engineering Disciplines” robot challenge shown in Figure 3. Student teams configured and programmed their robot to achieve the maximum number of points by completing seven missions. The challenge involved moving rubber ducks around on the mat, activating an electronic switch, and pushing a hinged bar into a specified location. All students attached some sort of plow to the front of their robot to push the ducks around. Some students implemented line following programming using the photoresistor available in the Parallax kit, some used the whiskers as touch sensors, some implemented infrared sensors, and some just relied on dead reckoning to direct their robot. Figure 4 shows some photos taken at the competition. Four students achieved perfect scores.

The robot challenge provided an opportunity for students to practice programming; earlier versions of the LWTL curriculum did not include this sort of open-ended programming challenge. The challenge allowed the students who loved to program to take their skills to another level. The challenge was also designed to allow students who were not as interested in the electromechanical aspects of the course to have some success with a limited amount of effort.

It is important to point out that the LWTL curriculum covers a wide range of content; not all of the content centers around robots and programming. Early engineering majors need to be frequently reminded of how the current projects fit into the scope of the engineering field; that is, graduating engineers perform daily jobs ranging from sales to detailed design to control to management.

This challenge involves programming your robot to “navigate the engineering disciplines” by completing six individual missions. Your robot will operate autonomously on an 84 in. x 32.5 in. playing field.



The missions and their point values are provided below. All students, regardless of major, should attempt to successfully complete as many challenges as possible. The difficulty of a given mission is not related to the difficulty of the corresponding major. ☺

Biomedical Engineering (40 points) – deliver an insulin pump (developed by a biomedical engineer) to a child:

move insulin pump from base to child

Chemical Engineering (30 points) – pump chemicals from a reactor (designed by a chemical engineer) into base:

move object on field into base

Civil Engineering (40 points) – install an I-Beam on a bridge designed by a civil engineer: *push a hinged beam into place*

Electrical Engineering (60 points) – use a magnet to activate a switch for a process control system implemented by an electrical engineer: *mount magnet to robot, maneuver robot to bring magnet close to switch, switch turns on an LED*

Industrial Engineering (40 points) – optimize your robot’s plan to achieve the maximum score: *points awarded if four or more missions are successfully completed; strategy is important*

Mechanical Engineering (70 points) – roll a high-mileage car (designed by a team of engineers, including mechanical engineers) to vehicle test area: *car must touch some part of the circle*

Nanosystems Engineering (20 points) – deliver photoresist to photolithography station to fabricate a microdevice developed by a nanosystems engineer: *push object already on field into designated area*

A perfect score is 300 points.

Figure 3 The Navigating the Engineering Disciplines robot challenge.

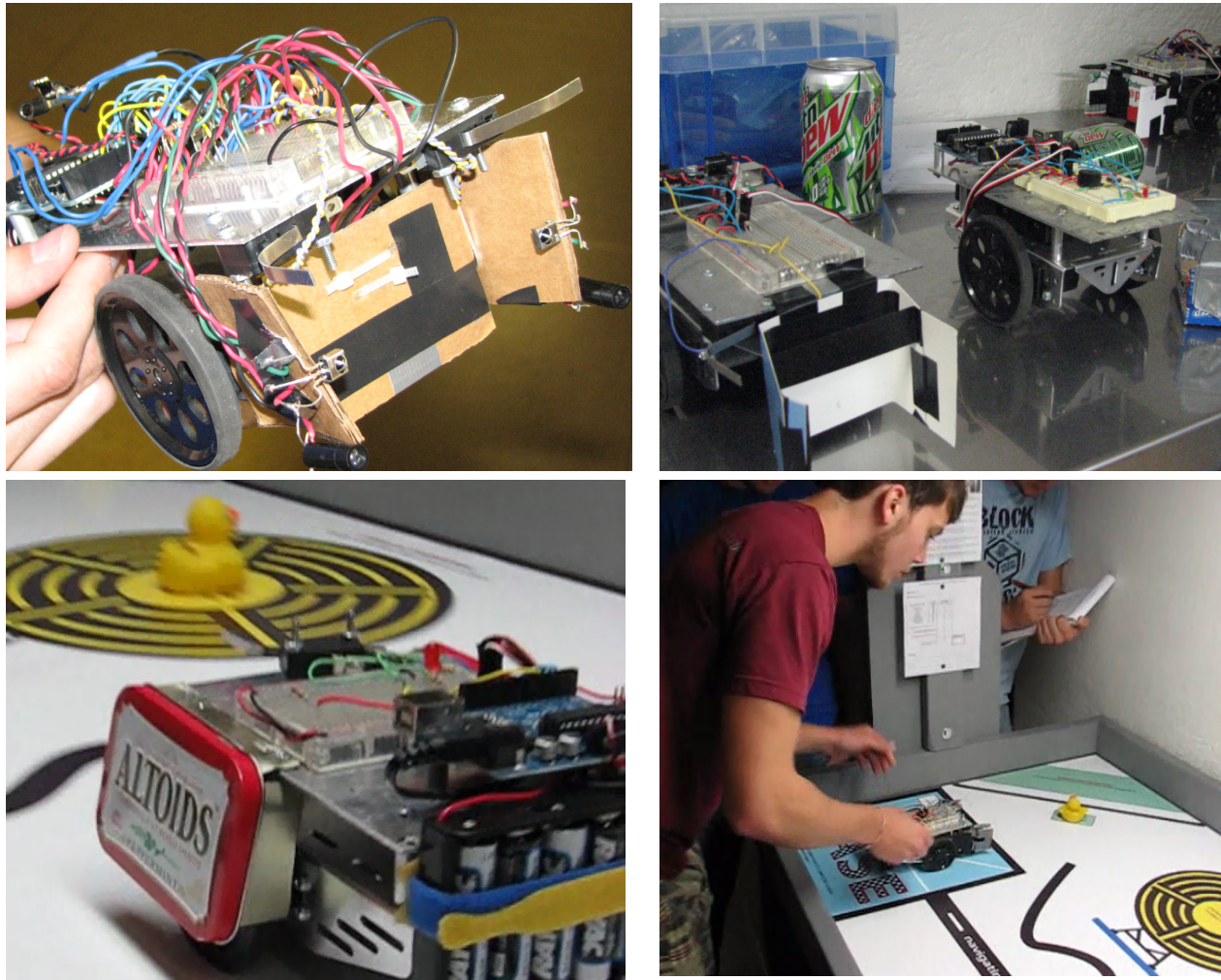


Figure 4 Photos taken during the robot challenge.

The Desktop Fan Project at Portland State University

The desktop fan project is a substitute for the mobile robot exercises in the conventional implementation of LWTL. The desktop fan project requires students to learn elementary use of a solid-modeling package, basic measurement techniques involving calipers, soldering, building circuits on a breadboard, and Arduino programming. Students are exposed to transistors, and pulse-width modulation (PWM) for speed control of a DC motor. Programming required the use of loops, analog input, and PWM output. The primary goals of the project are to provide a simple design-and-build experience, to require students to work in teams of two, to show what kinds of parts can be fabricated from acrylic with a laser cutter and acrylic bender, and to provide practical motivation for Arduino programming.



Components

Arduino
 DC motor
 Servo motor
 Propeller
 NPN Transistor
 Resistors, potentiometer
 Breadboard and jumper wires
 Acrylic for structure

Figure 5: Reference design for the structure, and list of components for the desktop fan. The Arduino Inventor's Kit contained all components except for the propeller and the acrylic used for structural support.

Figure 5 shows the primary components for the desktop fan and a reference design for the structural components. Students were shown this picture at the start of the project, but they were encouraged to develop the physical design of their own structure. A YouTube video was created to demonstrate the operation of laser cutter and acrylic bender, and to show a sample fan in operation. Creating a design for the fan structure provided an exercise in spatial visualization. The three-dimensional modeling capabilities of Solidworks were of little use because the laser cutter needs a two dimensional drawing.

Pulse-width modulation (PWM) power control was used to adjust the speed of the DC motor that drives the fan. A potentiometer wired to one of the analog inputs on the Arduino provided a way for the user to adjust the fan speed. Figure 6 shows the PWM circuit. An NPN transistor switched the current to the motor, using the PWM output as a control signal.

Most of the parts needed to complete the desktop fan projects are included in the Arduino Inventor's Kit that students are required to buy for the course. Model airplane propellers were purchased in bulk from a hobby shop for less than 75 cents (US) each. A sheet of 1/8 inch thick acrylic was purchased and students were allowed to use rectangles of either 12 inch by 1 inch, or 6 inch by 3 inches. The 18 square inch limit was imposed to keep material construction modest, and to force students to deal with a material constraint in their design.

The assignment was spread over three weeks of class. Performance milestones, such as submission of two-dimensional drawings for the laser cut parts, and trial motion of the servo

motor, were assigned as homework before the final deadline for the completed fan. Learning objectives for the desktop fan project are that students will be able to

- Use a caliper to measure the physical dimensions of the servo motor in the Arduino Experimenter's Kit, and from those measurements, design a support structure to hold the servo in place.
- Design structural members to connect the servo the DC motor that drives the propeller such that servo oscillation causes the air stream from the fan to change direction.
- Develop two-dimensional drawings of structural parts (using Solidworks) so that those parts can be cut from acrylic sheet with a laser cutter.
- As necessary, use a strip heater to bend the acrylic parts into their final shape. Assemble the structure that forms the base of the desktop fan.
- Solder extension wire leads to the DC motor from the Arduino Inventors kit.
- Use basic Arduino programming structures: variables, loops, analog input, and digital output.
- Build a transistor-controlled circuit to run the DC motor using power from the Arduino.
- Complete the circuit and structural assembly. Write the Arduino code to control the system. Demonstrate the system in class.

At the end of the project, all teams had working fans. Some were more capable and robust than others. Figure 7 shows the solution created by the instructor.

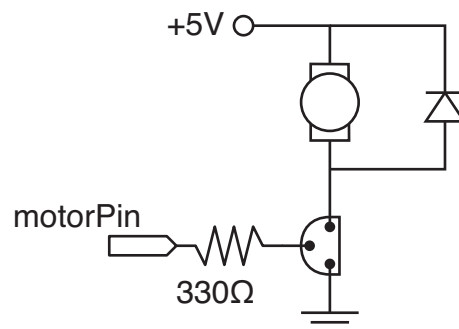


Figure 6: Control circuit for the DC motor that drives the fan propeller.

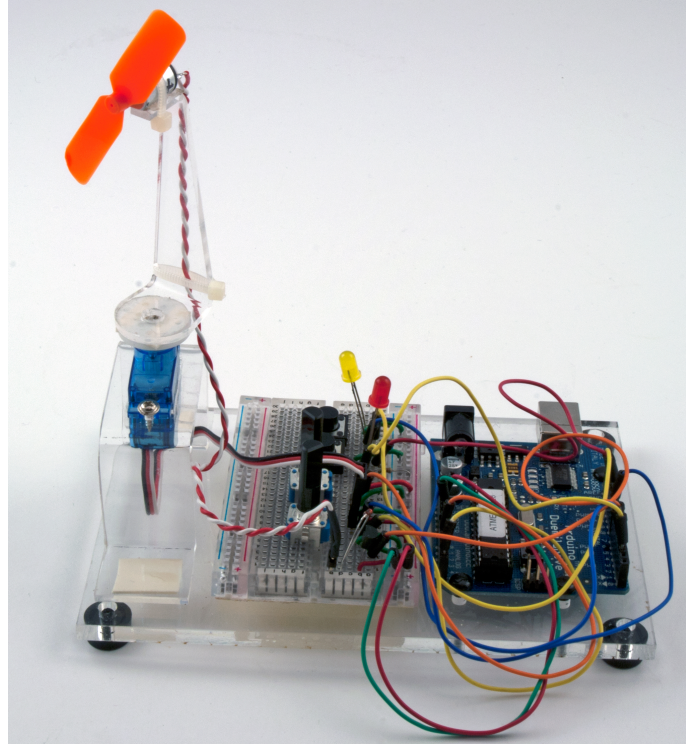


Figure 7 Instructor's solution to the desktop fan design project.

Assessment

In this section we present results of an end-of-term survey of students at Portland State University. A comparable instrument was not used at Louisiana Tech University. The survey has eleven statements (11 items) with a five level, Likert scale response. In addition, there are three open-ended questions. The survey is included in Appendix A.

The Likert scale items use two different sets of responses listed in Table 2. The first two items of the survey use the standard response scale to indicate agreement or disagreement with the stem. The remaining items have a stem and corresponding response scale for indicating a self-assessed degree of change experienced by the students. In all cases, higher ordinal positions are associated with a positive outcome for the course. This leaves the survey results open to potential acquiescence bias²⁶. No attempt to correct for acquiescence bias was made. The potential problem of acquiescence bias was realized after the survey was administered.

The Cronbach alpha for the 11-item survey was 0.790 with 95 percent confidence intervals of (0.698, 0.881). Calculations were performed with the *rela* package for *R*, written by Michael Chajewski²⁷. Since the Cronbach alpha exceeds the threshold of 0.7 that is typically used to indicate reliability of a multiple-choice instrument, we conclude that the survey questions and responses are internally consistent.

Table 3 lists the text of the statements and the aggregate responses for the survey. The mean response is computed by assuming the Likert responses are an interval scale. In the last

three columns, the five-level Likert scale responses are grouped into “negative”, “neutral” and “positive” categories. Referring to row numbers in the first column of Table 2, the negative responses are ordinal positions 1 and 2, neutral responses are ordinal position 3, and positive responses are ordinal position 4 and 5.

Table 2 Ordinal position and text of responses to Likert scale survey questions. The *Change response* in the last column is used for questions that asked students to rate how the course caused the students to change their attitude toward their professional direction, or their interest in the subject matter, or confidence in their abilities to be successful.

	Standard response	Change response
1	Strongly disagree	Decrease a lot
2	Disagree	Decrease
3	Neutral	No[t] change
4	Agree	Increase
5	Strongly agree	Increase a lot

Survey Results

In general, the survey responses indicate a strong positive attitude toward the course. The least positive scores were on items 7 and 8, which are related to the Arduino.

Items 1 through 4 indicate student interest in engineering and computer science as academic disciplines. For each of these questions, the majority of responses were positive: the positive fraction was close to 65 percent for items 2 and 3; the positive fraction was 86 percent for items 1 and 4. Thus, the survey indicates that the course had a positive influence on student interest in engineering and computer science.

Responses to item 5 indicate that almost 70 percent of the students taking the survey are more confident that they will be successful because they took this class. One student wrote this response to the open-ended question (item 14) on the survey:

“This class was very enjoyable. I was impressed with my own abilities as a result of what I did in this class.”

Of course, not all students had confidence-boosting experiences. Over seventy students attended the first day of class. Enrollment was limited to 64 students because of the layout of the tables in the lab – there were two sections, and enrollment in each section was limited to 32 students who could fit at eight tables with four chairs per table. Enrollment dropped to sixty-two students by the second week of class. By then the pace was evident, the first quiz was given, and the first assignments were collected. 52 students completed the course. Despite the drop-off in attendance, the survey responses show that the course increased the confidence of a large fraction of students who remained in the class.

Table 3: Summary of responses to end-of-term survey questions for LWTL classes at Portland State University. Row data may not add to 100 due to rounding of individual items in the row. Likert scale responses are listed in Table 2. Sample size is 44 responses out of 52 students who completed the course.

		Mean response	Negative (%)	Neutral (%)	Positive (%)
1	Overall, this class has increased my interest in engineering or computer science.	4.16	6.8	6.8	86.4
2	Because of my experience in this class, I am more likely to continue taking courses toward a degree in engineering or computer science.	3.80	9.1	25	65.9
3	Because of my experience in this class, my interest in Mechanical Engineering has ...	3.73	6.8	29.6	63.6
4	The hands-on experience in this class has caused my interest in engineering or computer science to ...	4.16	0	13.6	86.4
5	The hands-on experience in this class has caused my confidence in my ability to succeed in engineering or computer science to ...	3.84	9.3	20.9	69.8
6	This class has caused my understanding of engineering design to ...	4.06	0	13.6	86.4
7	Working with the Arduino microcontroller has caused my interest in programming to ...	3.28	23.1	30.8	46.2
8	Working with the Arduino microcontroller has caused my interest in electromechanical systems to ...	3.51	17.9	20.5	61.5
9	The manufacturing and fabrication experience in this class has caused my motivation for school work to ...	4.00	2.6	17.9	79.5
10	The manufacturing and fabrication experience in this class has caused my practical knowledge of the engineering profession to ...	4.08	0	10.3	89.7
11	The in-class exercises, such as programming, working with breadboard circuits, fabrication has caused my motivation to study math, physics and chemistry to...	3.59	2.6	41.0	56.4

Item 6 reflects students' self-assessed knowledge of engineering design. A large majority (86 percent) felt that the class increased their understanding of design. No student felt that the class decreased their understanding of design.

Items 7 and 8 measure the change in student attitude that can be attributed to using the Arduino platform. These two questions had the largest fraction of negative responses, 23 and 18 percent, respectively. Almost a quarter of the respondents reported a decrease in their interest in programming. In the open-ended comments, many students wrote that the course could be improved by providing more instruction on programming. We believe this reflects two predominant shortcomings of working with Arduino.

First, there are no in-depth resources that use Arduino as the platform for a *first course* in programming. There are many on-line tutorials, YouTube videos, and some books that aim to help users get started with Arduino²⁸⁻³⁰. These resources tend to focus on project case studies that help users replicate the project. This is very valuable and was helpful to us in preparing course material. While project tutorials help learners be successful on projects that are the same or very similar to the tutorial, they do not provide more systematic instruction. Students tend to copy and paste code from tutorials without really understanding how to write that code from scratch. There is a lack of resources that teach the fundamentals of programming. For the next offering of the class, we need to prepare better notes on programming, as well as a variety of exercises that give student practice in small and large programming tasks.

The second shortcoming of using the Arduino to learn programming is that the programming language is C, which has a terse, and unforgiving syntax. There is no easy solution to the difficulty of learning C as a first programming language. However, the survey responses to item 8 (discussed next) suggest that students may have a more positive programming experience if the connection to electromechanical systems is strengthened. This is purely speculative, but deserves consideration during the next revision of the course material.

Scores on item 8 indicate the change in student interest in electromechanical systems attributed to working with the Arduino. Survey responses to this item were positive for over 61 percent of the respondents, and negative for 18 percent of the respondents. The difference in responses between item 7 and item 8 suggest that despite the difficulty of programming the Arduino, students enjoyed the physical effects (flashing lights, spinning motors) that are obtained from successful completion of an Arduino programming assignment.

Responses to items 9 and 10 show that hands-on manufacturing experiences had an overwhelmingly positive impact on student motivation and knowledge. The open-ended comments in response to items 13 and 14 reinforced this observation. Here are un-edited samples of positive open-ended comments:

"Hands-on portions are superb. I was not expecting this level of involvement from a freshman, first term course" (item 13)

"The hands-on activities allow one to immediately see results from his efforts. This also promotes greater understand of the material as one can actually see how things relate to one another."(item 13)

"Manufacturing parts was very fun" (item 13)

"Projects are manageable yet challenging" (item 13)

"That we got to experience a bit of all types of mechanical engineering from programming to manufacturing. Keep the fan and pump project" (item 13)

"I loved this class!" (item 14)

"Wish there was a sophomore level class!" (item 14)

"Excellent course overall and good introduction to engineering" (item 14)

"Keep the class fun. Background on design and design process should be emphasized more" (item 14)

Item 11 is an attempt to measure whether the course increased student motivation for the math and science courses that are required for engineering. A large fraction (41 percent) of the survey respondents felt that the class had no effect on their interest in math and science. A slight majority (56 percent) felt that the class increased their motivation to study math and science. During the course we did not stress the explicit connection between engineering and math and science. It is not surprising, therefore, that the attitude toward those subjects did not change for a large fraction of the students.

There are aspects of the course that did not improve student motivation or confidence. Direct feedback from students and responses to the open-ended questions made it clear that many students thought the class was too much work for the two credits that students earned. The instructors at Portland State University agree, and we will address this in future offerings of this class. Another common theme in student criticism is the pace of the class. Here are some samples of responses to item 12, *what one change would improve the course*:

“To go slower and cover the things in class more thoroughly”

“Slow down. Too much material crammed into too little time”

“Slow it down”

“More time (class is a lot of work)”

This view of the pace of class was not universal, however. One student wrote as a response to item 12:

“I felt that even though things were fast paced, any difficulty was my own fault, but it would be good to meet more often than twice per week”

Opinions on the pace of material may also reflect the lack of academic experience of many students in the class.

Conclusion

The LWTL curriculum has been successfully implemented with the Arduino platform replacing the Boe-Bot and Basic Stamp. That was the hope during the spring term of 2010 when the transition to Arduino was first contemplated. Now that the transition for the first course has been completed, and formative assessment results have been obtained, it is clear that more work is necessary. Additional lecture notes were developed and used for remedial teaching during the second course in the sequence. Those notes will be incorporated into the first course in the next academic year. More examples of code, and self-study aides are under development.

As the final draft of this paper is being written, faculty at Louisiana Tech University and Portland State University have completed the second course in the LWTL curriculum during Winter 2011 using the Arduino platform. The third course will also use Arduino in Spring 2011. Readers interested in the course details can visit the web sites for the two courses discussed in this paper:

<http://www2.latech.edu/~dehall/LWTL/ENGR120honors/main.html>

<http://web.cecs.pdx.edu/~gerry/class/EAS199A>

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Appendix A: Glossary

- PWM** *Pulse-width modulation.* PWM is a method of using a digital (0 to 5V, say) pulses of varying width to control electrical loads having a slow response relative to the frequency of the pulses. Typically, the pulses are sent a fixed frequency. As the width of the non-zero pulses increases, the effective voltage level experienced by the load increases.
- ADC** *Analog to digital conversion or analog to digital converter,* also abbreviated A/D. A continuous (analog) signal is digitized by storing the discrete values of the signal at a fixed time interval.
- Analog input** A continuous (and therefore analog) electrical signal received by an ADC converter. The signal from a sensor is a typical analog input.
- Digital output** An electrical signal sent as a signal from one device to another device such that the voltage level is interpreted as either a 1 or a zero, i.e. as a binary value.
- Microcontroller** A single-chip, integrated circuit devices that can be programmed to read electrical signals (input) and send electrical signals (output).
- GND** *Electrical ground* corresponding to zero volts. Voltages are always relative. The ground voltage (or ground plane) is a shared reference level for all components in an interconnected circuit.
- USB** *Universal serial bus.* USB is a widely used means of communication between digital devices. For example, most computer keyboards and mice are connected to our computer via USB cables.

Appendix B: End-of-term survey at Portland State University

This survey designed to measure your confidence, career interest, and attitude toward the material covered in EAS 199A. Your answers to these questions will not affect your grade, and will not be associated with you personally in any way. This information will be used to help us improve the class and to share what we have learned from this class with our colleagues at Portland State University and other universities.

- ☐ I understand that my choice to complete this survey will not affect my grade in EAS 199A.
- ☐ I am voluntarily participating in this survey.
-

Please circle the word or phrase that best completes the opening statement, or that expresses your agreement with the opening statement.

1. Overall, this class has increased my interest in engineering or computer science.

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree
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2. Because of my experience in this class, I am more likely to continue taking courses toward a degree in engineering or computer science.

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree
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3. Because of my experience in this class, my interest in Mechanical Engineering has

decreased a lot	decreased	not changed	increased	increased a lot
--------------------	-----------	-------------	-----------	--------------------

4. The hands-on experience in this class has caused my interest in engineering or computer science to

decrease a lot	decrease	not change	increase	increase a lot
-------------------	----------	------------	----------	-------------------

5. The hands-on experience in this class has caused my confidence in my ability to succeed in engineering or computer science to

decrease a lot	decrease	not change	increase	increase a lot
-------------------	----------	------------	----------	-------------------

6. This class has caused my understanding of engineering design to

decrease a lot	decrease	not change	increase	increase a lot
-------------------	----------	------------	----------	-------------------

7. Working with the Arduino microcontroller has caused my interest in programming to
- | | | | | |
|-------------------|----------|------------|----------|-------------------|
| decrease
a lot | decrease | not change | increase | increase
a lot |
|-------------------|----------|------------|----------|-------------------|
8. Working with the Arduino microcontroller has caused my interest in electromechanical systems to
- | | | | | |
|-------------------|----------|------------|----------|-------------------|
| decrease
a lot | decrease | not change | increase | increase
a lot |
|-------------------|----------|------------|----------|-------------------|
9. The manufacturing and fabrication experience in this class has caused my motivation for school work to
- | | | | | |
|-------------------|----------|------------|----------|-------------------|
| decrease
a lot | decrease | not change | increase | increase
a lot |
|-------------------|----------|------------|----------|-------------------|
10. The manufacturing and fabrication experience in this class has caused my practical knowledge of the engineering profession to
- | | | | | |
|-------------------|----------|------------|----------|-------------------|
| decrease
a lot | decrease | not change | increase | increase
a lot |
|-------------------|----------|------------|----------|-------------------|
11. The in-class exercises, such as programming, working with breadboard circuits, fabrication has caused my motivation to study math, physics and chemistry to
- | | | | | |
|-------------------|----------|------------|----------|-------------------|
| decrease
a lot | decrease | not change | increase | increase
a lot |
|-------------------|----------|------------|----------|-------------------|
12. If the instructor were going to change one thing to improve the course, what would that be?
13. What is the best aspect of the course – the one thing that should not be changed?
14. Other comments