AC 2011-2062: SPIRAL LABORATORIES IN THE FIRST-YEAR MECHANICAL ENGINEERING CURRICULUM

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SPIRAL Design-Oriented Laboratories in the First-Year Mechanical Engineering Curriculum

Abstract

As a primary part of realizing a Student-driven Pedagogy of Integrated, Reinforced, Active Learning (SPIRAL) throughout our Mechanical Engineering curriculum, we are implementing new laboratory experiences in the first and second years of our program. This paper will focus on the laboratories for our new, required first-year course sequence, in which the traditional topics of design methodology and computer programming are taught in the context of robotic and mechatronic systems. The laboratories encompass engineering software, mechanical and electrical hardware, and manufacturing, with content driven by the semester-long team-based robotic/mechatronic design projects. We expect that the integrated laboratory experiences in our first-year mechanical engineering classes will improve the students' understanding and retention of fundamental engineering principles through the coupling of hands-on laboratory learning with design-based learning. We will assess this outcome by comparing final exam scores across semesters (i.e., before and after the curricular changes). We also anticipate increased student retention, which will be assessed by tracking which students eventually register for the Mechatronics course in the junior year of the program.

1. Introduction

Our overall curriculum has a very strong "hands-on" component at all levels with semester-long design projects in both semesters of the freshman year and year-long design projects in the three subsequent years as outlined in Table 1. These hands-on competitive (years 1-3) or capstone (year 4) design experiences help the students comprehend the practical aspects of their theoretical learning and give them an opportunity to creatively apply course material. In years 1-3, the design projects are closely integrated with the course content, and involve "spiraling" of concepts in successive semesters and years. Weekly laboratory experiences provide additional hands-on learning and prepare the students to achieve the various design project milestones.

Table 1: Design courses in the four-year Mechanical Engineering curriculum.

Year	Semester	Class	Design Experience
1	Fall	ME EN 1000: Introduction to the Design of Robotic Systems I: Mechanical Systems	Design Competition
1	Spring	ME EN 1010: Introduction to the Design of Robotic Systems II: Sensors and Actuators	Design Competition
2	Fall/Spring	ME EN 2500/2510: Introduction to the Design of Sustainable Energy Systems I/II	Design Competition
3	Fall/Spring	ME EN 3200/3210: Mechatronics I/II	Design Competition
4	Fall/Spring	ME EN 4000/4010: Senior Design	Capstone Design

This paper will report on the development and implementation of a series of laboratory experiences that expand on lecture material and support the design projects in our new first-year course sequence, ME EN 1000/1010: Introduction to the Design of Robotic Systems I and II.

These courses replace a stand-alone freshman design course titled “Engineering Design and Visualization” that introduced students to various aspects of Mechanical Engineering, and a separate Computer Science programming course. In the development process, it is our intention to design active-learning experiences – both traditional labs and in-class “mini-labs” – that can be modularized in an inexpensive manner for large classes. With state and national budgets facing a bleak outlook, large classes will become more prevalent, and public institutions will need to provide a better education (versus narrowly-focused, knowledge-based web learning) to more students with fewer resources. We believe that active-learning activities like those presented here will not only improve student learning but also enhance student recruitment and retention, especially when class sizes are large. Our typical enrollment for fall semester of the freshman year is 150 students, which translates to eight lab sections of 16-20 students and approximately 40 four-person design teams.

The general format of the laboratory meetings in our first-year course sequence is a one-hour software tutorial followed by a two-hour lesson on either software or hardware. During the hour-long Excel® (fall) or MATLAB® (spring) tutorials, students complete introductory problems with the help of their teaching assistant, and then start working on their more in-depth homework assignment if time remains. In the fall, the two-hour lessons cover hand drawing, computer-aided design using SolidWorks®, engineering topics including springs, pulleys, gears, friction and traction, and manufacturing topics including safety, hand tools, waterjet cutting and sheet metal bending. Some lab time is also dedicated to engineering communication instruction, where students give presentations and meet with graduate communication instructors to discuss writing, oral presentations and teamwork. In the spring, the two-hour lessons include an introduction to electronics and programming using the Arduino® microcontroller platform, mechanical and electromechanical hardware topics including fourbar linkages, motors, solenoids and sensors, and advanced SolidWorks® and communication instruction.

In both semesters, the laboratory content is driven by the required team-based design project. For example, the fall project involves the design and construction of a mechanically-powered autonomous machine or vehicle. In manufacturing-themed labs, students learn to design and manufacture sheet metal parts that are cut out on the waterjet cutter. In labs focused on engineering physics and mechanical hardware, students experimentally determine the static and rolling friction of their vehicles and characterize the spring constants of extension, compression and torsion springs that can be used, e.g., to propel a vehicle or launch an object as required by the design project. In spring semester, the students design an electro-mechanically actuated machine/vehicle. Electromagnetic hardware labs have the students build and test solenoids and characterize torque-speed curves of provided motors. Students also synthesize, model (in SolidWorks®), prototype and manufacture (using the waterjet cutter) a fourbar linkage that is a required element of their device. The manufacturing focus in the spring is fused deposition modeling (FDM), and the students design (in SolidWorks®) and “print” a 3D version of their team logo. Finally, the spring-semester electronics and Arduino® labs teach students about simple circuits and components, how to solder wires and printed circuit boards, how to construct connectors, and how to program an Arduino® microcontroller for use in the design project.

2. Metrology and Manufacturing Labs

Manufacturing labs are incorporated early in the first-year curriculum to teach the students basic skills that they can use to manufacture their competition devices. Although some students enter the program with advanced machining skills, the students are limited to the use of hand tools and the manufacturing techniques that are taught in the first-year labs (waterjet cutting, sheet metal bending and fused deposition modeling) in order to promote a fair competition. Safety is emphasized as students are first introduced to basic hand tools and practice drilling and tapping holes. In addition, the students are expected to develop essential metrology skills that will prepare them for learning more advanced machining skills (e.g., milling machine and lathe) in the sophomore curriculum.

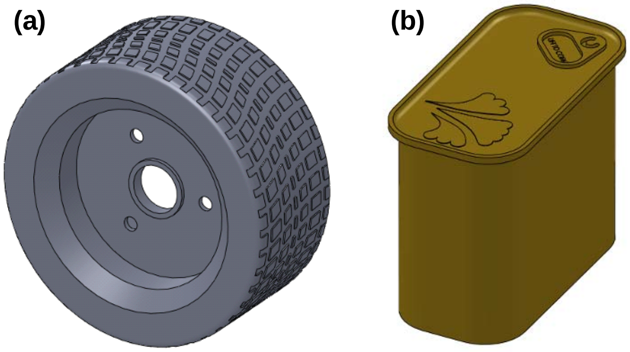

Figure 1: Example SolidWorks® models of (a) a tire and (b) a SPAM® can, generated as part of the metrology lab.

2.1 Metrology Lab

The metrology lab gives students experience taking measurements with both a caliper (digital) and micrometer (vernier). This prepares them for instruction in advanced manufacturing skills (e.g., mill and lathe), which occurs during the sophomore year. The metrology lab is integrated with the fifth in a series of eight SolidWorks® tutorials, which focuses on planning and lets students practice the SolidWorks® tools they have learned in the previous four labs. After measuring several common objects (washer, wing nut, wheel, pulley, etc.) for the metrology part of the lab, each student is asked to write out two plans for modeling each object in SolidWorks®. After choosing what he determines to be the best of the two plans, the student proceeds to follow that plan to create a model of the object in SolidWorks®. Example SolidWorks® models are shown in Figure 1. Ideally, the objects to be measured and modeled are relevant to the design project and might be incorporated into SolidWorks® models of a team's design competition device. For example, tires (Figure 1a) and SPAM® cans (Figure 1b) were chosen as objects when the design project involved designing and building SPAM®-powered vehicles.

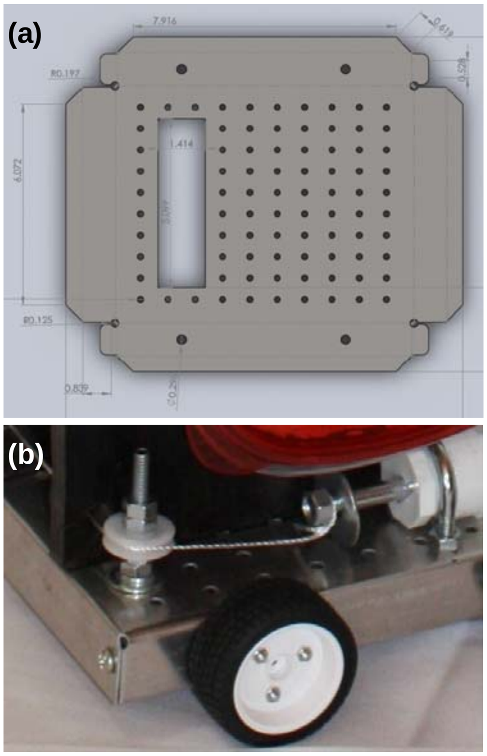

Figure 2: (a) SolidWorks® drawing of sheet metal chassis. (b) Completed sheet metal chassis on assembled design competition vehicle.

2.2 Manufacturing Labs

During the freshman year, students are introduced to three manufacturing techniques: waterjet cutting, sheet metal bending and fused deposition modeling. During fall semester, the students first see a demonstration of both the waterjet cutter and sheet metal bending. For a subsequent project assignment, they are required to design the chassis of their design competition vehicle out of sheet metal (Figure 2). Following a SolidWorks® tutorial in which the students learn to use the SolidWorks® sheet metal tools, each team prepares drawings of the parts (the vehicle chassis plus any other parts that can be cut from a specified size sheet of sheet aluminum) to be cut on the waterjet cutter (Figure 2a). The actual waterjet cutting is done by the lab TAs (although students can eventually be trained to use the waterjet cutter themselves), so along with their CAD files the students submit a transmittal memo with instructions for the TAs as well as a paper prototype to demonstrate the feasibility and manufacturability of their design. After the parts are cut on the waterjet cutter, the students use a sheet metal bender and various hand tools to complete the chassis fabrication. A sample chassis is shown in Figure 2b.

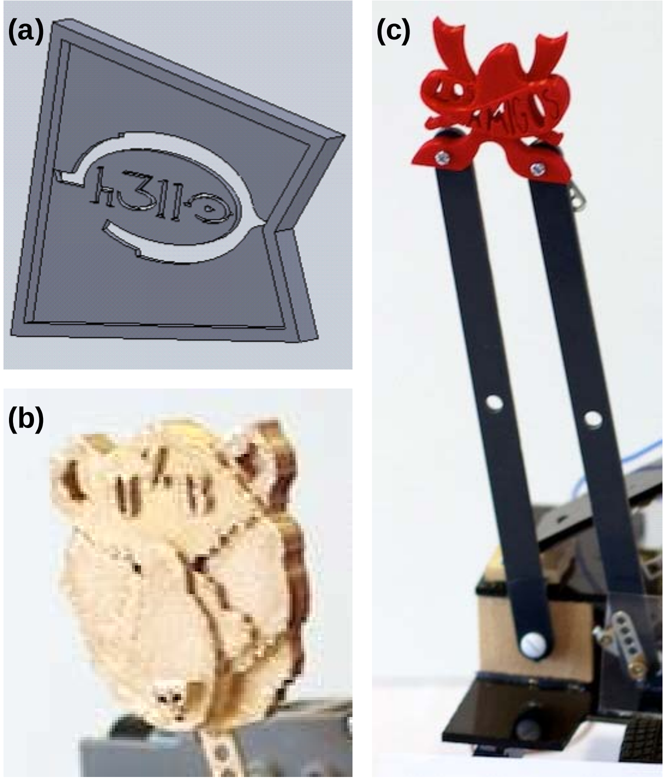

Figure 3: Flags representing team logos for the spring semester design project. (a) SolidWorks® model. (b) Fused deposition model of Team Bear's logo. (c) Team Amigos' flag mounted in a fourbar linkage, with links cut on the waterjet cutter.

In spring semester, each design team is required to use the waterjet cutter to fabricate a fourbar linkage (typically out of plastic) and use fused deposition modeling to fabricate a flag representing their team's logo. The fourbar must be used to perform an essential function on their design competition device, and the flag must be "waved" in some fashion at the end of each competition run. Again, the students use SolidWorks® to prepare the files needed by the waterjet cutter and the fused deposition tool, which are operated by the lab TAs. A SolidWorks® model of a team flag is shown in Figure 3a, while a sample flag is shown in Figure 3b. Figure 3c shows a fourbar linkage used to wave a team's flag. In addition to the required fourbars, students can use additional (limited) waterjet cutting time to fabricate other parts for use on their competition device.

3. Engineering Physics and Mechanical Hardware Labs

The fall semester design project focuses on the mechanical aspects of mechatronic/robotic systems and the utilization of mechanical energy. For example, students might be asked to design a vehicle that drives and shoots an object using only the gravitational potential energy stored in the equivalent of 2 SPAM® cans suspended at a height of one meter and the spring potential energy stored in three springs (one extension, one compression and one torsion). As such, several mechanical hardware labs are conducted in the fall semester to help students make design decisions and model the performance of their devices. In addition, a gears lab is conducted late in the fall semester in preparation for using motors with gearboxes in the spring semester competition. Fourbar linkages are the mechanical hardware focus in the spring semester, with each team required to incorporate a fourbar into their competition device.

3.1 Spring Lab (or In-Class Activity)

In the fall semester design project, students use mechanical energy – either spring potential energy or gravitational potential energy – to perform a task or tasks, e.g., propelling a vehicle and launching an object. As such, a good understanding of spring behavior is essential. The spring lab (performed either in lab or as an in-class activity) teaches students how to experimentally determine the spring constant of a spring. An inexpensive homemade mounting apparatus that attaches to the back of a lecture hall chair, shown in Figure 4, facilitates the in-class activity in our large class (~150 students). Students measure the spring displacement as a function of the number of marbles in a bag hanging from the spring. As part of a follow-on Excel® homework assignment, the students plot and fit their experimental data to calculate the spring constants, which the students then use to make design decisions and model their spring-powered devices.

Figure 4: In-class setup for characterizing the spring constants of compression (left) and extension (right) springs using bags of marbles to displace the springs.

3.2 Friction Lab

The purpose of the friction lab is for students to become familiar with static friction and rolling resistance by calculating the coefficients of static friction and rolling resistance for three different surfaces. These experiments are done during the fall semester to help students obtain the parameters needed to model the distance traveled by their SPAM®- or spring-powered vehicles.

In the static friction portion of the lab, students determine the coefficient of static friction between an object and three surfaces: carpet, sandpaper and Plexiglas. The experimental setup consists of an object resting on one of the surfaces to be tested, connected to a bag of marbles by a string that passes over a pulley. The students add marbles to the bag just until the object starts to move, and then use the known weight of the marbles and the mass of the object to calculate the coefficient of static friction. To determine the coefficient of rolling resistance, students roll carts down a Plexiglas ramp and measure (1) the distance the cart travels along a horizontal section of track made of one of three materials: carpet, sandpaper and Plexiglas, and (2) the time it takes the cart to travel that distance.

In both parts of the lab, students are expected to apply the Standard Problem Solving Procedure discussed in lectures to derive the equations needed to calculate the coefficients from their experimental data. They are also asked to consider what factors might cause their results to be inaccurate, and which of these factors they expect to be most significant in introducing error.

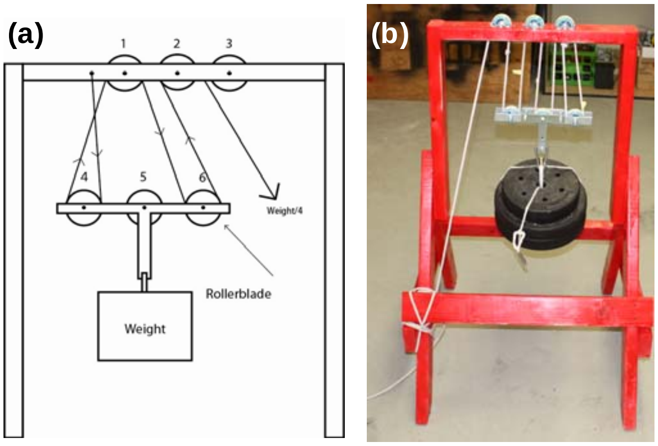

Figure 5: (a) Schematic diagram from the pulley lab handout. (b) Experimental pulley setup using rollerblade wheels as pulleys.

3.3 Pulleys Lab

In the pulleys lab, students explore the mechanical advantage that can be obtained when using pulleys and learn how to quantify the performance of pulleys. The students set up three different pulley systems (two, four and six pulleys) and use these to lift a mass. With each setup, they first use a force scale to measure the force required to lift the mass. They then measure the length of rope that must be pulled to lift the weight a specified distance. The students are expected to theoretically calculate the force and length of rope required in each case and compare these theoretical values with their experimental values. A schematic from the lab handout is shown in Figure 5a, while Figure 5b shows the experimental setup, which was designed and built by senior mechanical engineering students.

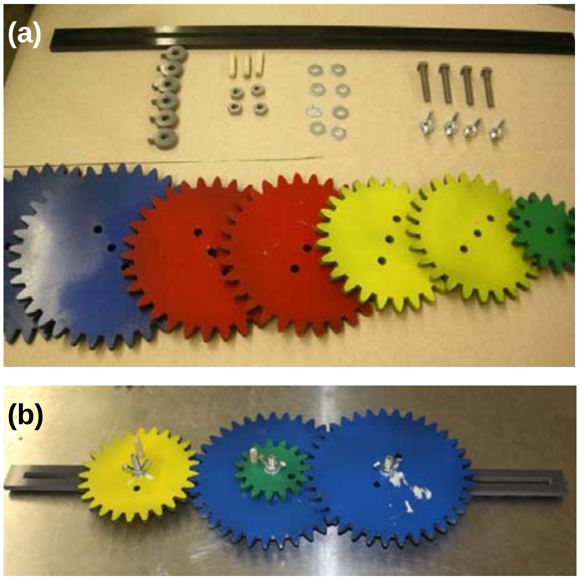

Figure 6: (a) Gear lab kits; the gears and guide rail were cut on the waterjet cutter. (b) Compound gear train example.

3.4 Gears Lab

In the gears lab, students get hands-on experience with both simple and compound gear trains, and also learn to design gear trains that have specific gear ratios and directions. The gear kits, shown in Figure 6a, consist of two each of four gear sizes (35 teeth, 30 teeth, 25 teeth and 15 teeth) and the necessary hardware to attach the gears to a guide rail. The gears and rail were fabricated from ¼” thick ABS plastic using the waterjet cutter. The gears were spray painted to match the color scheme used in the gears lecture for the various gear sizes.

The initial experiments have pairs of students build simple gear trains with zero, one or two idler gears, and then measure the number of revolutions of the output gear when the input gear makes a single revolution (this value is equivalent to the ratio of the output angular velocity to the input angular velocity) and note the direction of rotation of the output gear. They then calculate the gear ratio from the number of teeth and compare this to their angular velocity ratio. Next, the students perform the same set of tasks for two different compound gear trains (e.g., Figure 6b). Finally, the students are asked to design several different gear trains, e.g., a gear train in which the output gear rotates -1.2x for each single revolution of the input gear. The gears lab takes place late in the fall semester in preparation for using gear boxes in conjunction with motors in the spring semester design project. In an early lab in the spring semester, students receive their DC motor and gearbox kit. Typically the students are given Tamiya kits, which have multiple options for the gear ratio depending on which gears are used in assembling the gearbox. Thus, students need to think about what gear ratio is appropriate and then build the gearbox as a team.

3.5 Fourbar Labs

Students are introduced to fourbar mechanisms in the SolidWorks® animation lab during the second lab of the spring semester. (SolidWorks® instruction is “spiraled” throughout the new ME curriculum, with basic SolidWorks® tools taught during fall semester of the freshman year, and more advanced topics such as mechanical mates, animation and motion analysis are taught during spring semester.) In the animation lab, students first create an assembly of a crank-rocker fourbar and generate an animation lasting a specified number of seconds and showing the crank making three full revolutions. They then modify the fourbar assembly to make a double rocker and use the Basic Motion feature to capture the toggle points in an animation video.

Following a lecture on fourbars, students are introduced to graphical methods of fourbar synthesis in lab. They first synthesize a Class 1 crank-rocker to achieve a specified angular displacement, and then learn two ways – coupler output or rocker output – to achieve complex motion between specified start and end positions of a link. After determining the link lengths, they are asked to verify the output motion of the three fourbars by modeling and animating them in SolidWorks®.

In this same lab, students use physical models to explore the functionality of Class 1, Class 2, and Class 3 fourbars using fourbar kits that were fabricated using the waterjet cutter (Figure 7a). The kits consist of four each of the following link lengths: 9 cm, 12 cm, 18 cm and 24 cm, and threaded rivets to fasten the links together. The students start by designing one Class 1, one Class 2 and one Class 3 fourbar that they can assemble simultaneously using the provided links. After building these fourbars, the students are instructed to hold each of the four links in turn as ground and investigate the behavior and toggle positions of the different inversions.

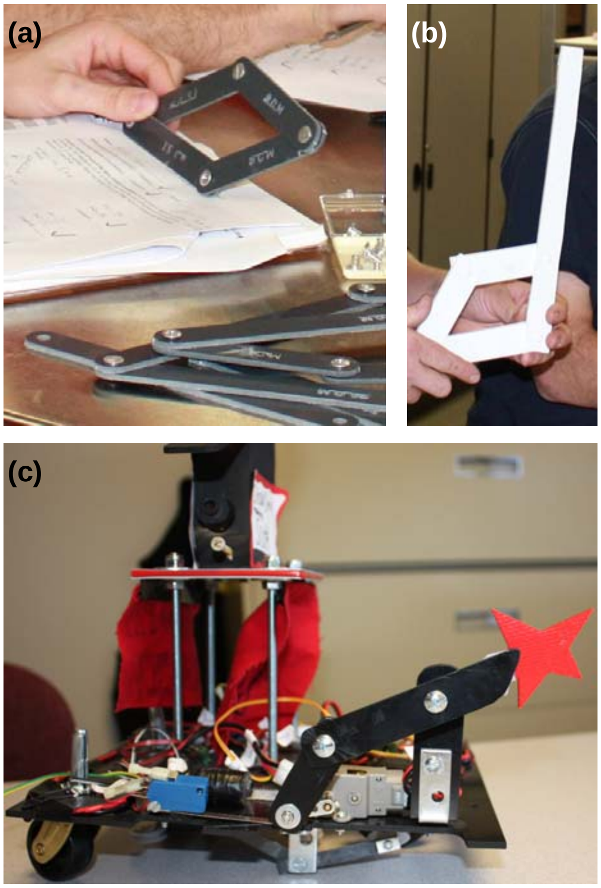

Figure 7: (a) Fourbar kits, fabricated using the waterjet cutter. (b) Fourbar prototype made foam core. (c) Fourbar cut on the waterjet cutter, used to wave the team's flag in the design competition.

Each design team is required to utilize one fourbar linkage on their design competition device. Following the fourbar labs described above, each student is expected to graphically synthesize a proposed fourbar, model it in SolidWorks®, and fabricate a prototype (e.g., out of foam core as shown in Figure 7b). After testing all of the prototypes, the team chooses one or more of the fourbars to fabricate out of ABS plastic and prepares the CAD files for the waterjet cutter. Figure 7c shows a fourbar linkage, manufactured on the waterjet cutter, used to wave a team flag in the spring semester design competition.

4. Introductory Electronics, Electromagnetic Hardware and Arduino Labs

The laboratories that focus on introductory electronics and Arduino® are taught in the spring, before our students have taken either second-semester physics (electricity and magnetism) or the required introductory electrical engineering class. Thus, for the introductory electronics, the focus is on basic techniques such as using prototyping breadboards, soldering wires and printed circuit boards, constructing connectors, and investigating simple circuits and components. All students receive an Arduino®, and in teams, the students build a custom-designed shield board for use in the lab and the design project.

4.1 Circuits Lab

To introduce the students to circuits and electronics, in this first electronics lab, students gain an understanding of simple circuit components, learn how to build circuits on a solderless breadboard, practice circuit bookkeeping techniques, and learn to test circuits and measure voltages using a multimeter. Students build circuits containing resistors, transistors, phototransistors, LEDs, and dual in-line package (DIP) switches. The first circuit is a basic LED circuit, where the LED must be connected with the correct polarity and a series resistor is used to limit the current through the LED. Next, students build series and parallel LED circuits. Finally, students build two phototransistor circuits. The first is a simple circuit that produces a voltage change as the light intensity incident on the phototransistor is varied. The second circuit causes an LED to change in brightness as the phototransistor sees more or less light.

4.2 Motor Introduction and Soldering Basics Lab

In this lab, students are introduced to the basics of DC motors, soldering, and component connectors. The students' first hands-on experience with motors is to simply disassemble a permanent magnet brushed DC motor, the type of motor used in the spring semester design competition, and familiarize themselves with the various parts and features of the motor. In the soldering part of the lab, students are introduced to soldering fundamentals (i.e., that a soldered connection is a joint between two metal components that is made by melting a metal filler such that it flows around the components and into the joint). The TAs and lab documents emphasize to the students that a properly soldered connection has both good mechanical strength and good electrical conductivity, while a poorly soldered connection has neither. Students practice tinning stranded wires and soldering solid core wires to prototyping breadboards. After practicing, students receive phototransistors and the DC motor provided for use in the design project, and solder wires to the leads and the appropriate connectors to the wires.

4.3 Shield Board Soldering

Every student in the class receives an Arduino Uno. Each team must use one in the design project, and the students keep their Arduino at the end of class for personal use and for use in sophomore classes. A custom "shield board" (Figure 8) has been designed for use with the Arduino to provide headers for connecting solenoids and motors, a motor driver, voltage regulator, resistors for voltage dividers for phototransistors (or other sensors), as well as LEDs, tactile switches, a potentiometer, etc. Each team solders at least two shield boards (so they can put one on their device and use the other one for

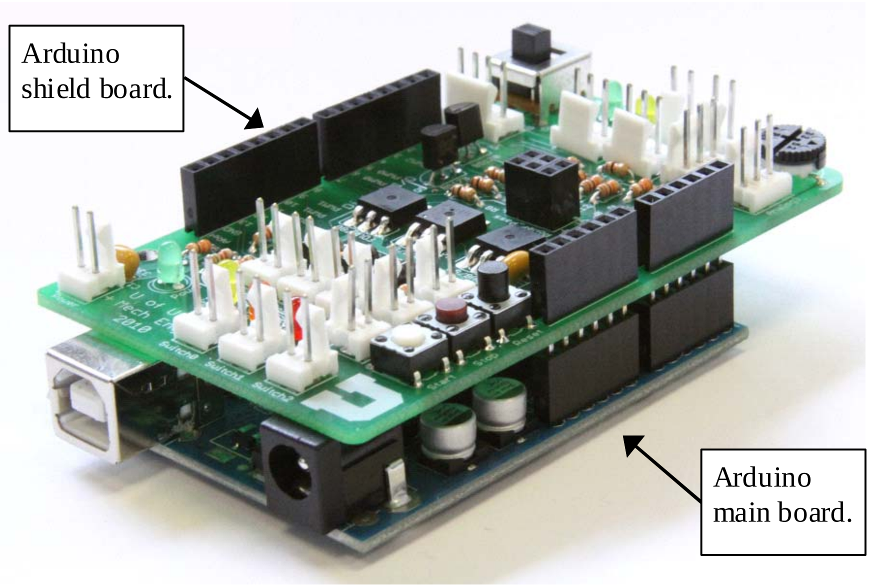

Figure 8: Arduino shield connected to Arduino.

practice programming without having to remove it). After building the shield boards, sample code is available to download onto the Arduino for testing and debugging.

4.4 Solenoid Lab

In the solenoid lab, students build and test a solenoid and also characterize a commercial solenoid. The homemade solenoids are used in the spring semester design project, e.g., to shoot a ping pong ball, "wave" a flag, or release a spring. Each team can use up to two of the solenoids, which are built by wrapping copper wire around a plastic tube as illustrated in Figure 9. The students characterize their homemade solenoids by (1) measuring the resistance of the coil to estimate the number of turns, (2) using a scale to measure the magnetic force exerted by the energized solenoid coil on the core as a function of the core position for different voltages and different cores (e.g., steel pin and permanent magnet) and (3) measuring peak force vs. voltage for the different cores with and without a ferrite sleeve. Students solder an appropriate header to the leads from their solenoids and the solenoids are activated using the Arduino (the necessary code is provided to the students). As the final part of the lab, students characterize a commercial solenoid by measuring the locking force vs. voltage.

Figure 9: Students use an electric screwdriver to wind copper wire around a plastic tube to make a homemade solenoid for use in the design competition.

4.5 Motor Characterization Lab

In this lab, students experimentally determine the torque-speed curve of their competition motor. To do this, they use the motor to lift a water bottle containing different volumes of water for a fixed distance and measure the time it takes to lift the water. The experimental setup for this lab is shown in Figure 10. The water bottle is attached to a string that is wrapped around a spool as the axle of the motor rotates. The motor is controlled using the Arduino (the necessary code is provided to the students). Larger masses are harder to lift and thus take longer to lift. After obtaining the torque-speed curve for a fixed gear ratio in this lab, the students use this data to calculate the torque-speed curve for the motor itself (no gearbox present) and for the other gear ratios provided with the motor/gearbox system. The quantification of the motor's performance is expected to help teams make design decisions such as what gear ratio and wheel diameter to use to get the fastest possible speed during the competition.

4.6 Arduino Programming Lab

The Arduino programming language is based on C and C++ and the Arduino development environment (free) provides an extensive set of functions and code libraries that facilitate using the features of the Arduino's microcontroller. There are also user-contributed code libraries that allow the Arduino to interface with hardware such as LCD screens, wireless modules, etc.

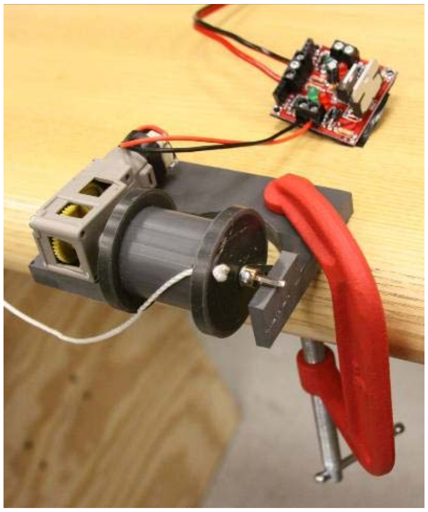

Figure 10: Motor characterization set-up; a water bottle is suspended from the string.

In this lab and for the design project, students use a code library developed specifically for the shield board. This library provides functions to read the sensors (phototransistors and microswitches) and control the actuators (solenoids and DC motors) that each team is required to use in the design contest (see Figure 11). Students are introduced to the differences between MATLAB® and C/C++, and they learn to use the Arduino development environment to modify and create "sketches" (programs), and upload them to their Arduino board. Students also learn how to use the provided code library functions to read information from their sensors and use those inputs to control the program execution and their actuators. (In this class, students essentially use pseudocode to program their Arduino rather than writing C code, since this class is their first introduction to programming and the majority of class lectures and assignments use MATLAB®. In the sophomore curriculum, students have several additional Arduino labs where they learn to write C code for a variety of tasks including battery compensation, writing to an LCD, servo motor control, DC motor control using pulse width modulation, and use of interrupts with an encoder for position and velocity information.)

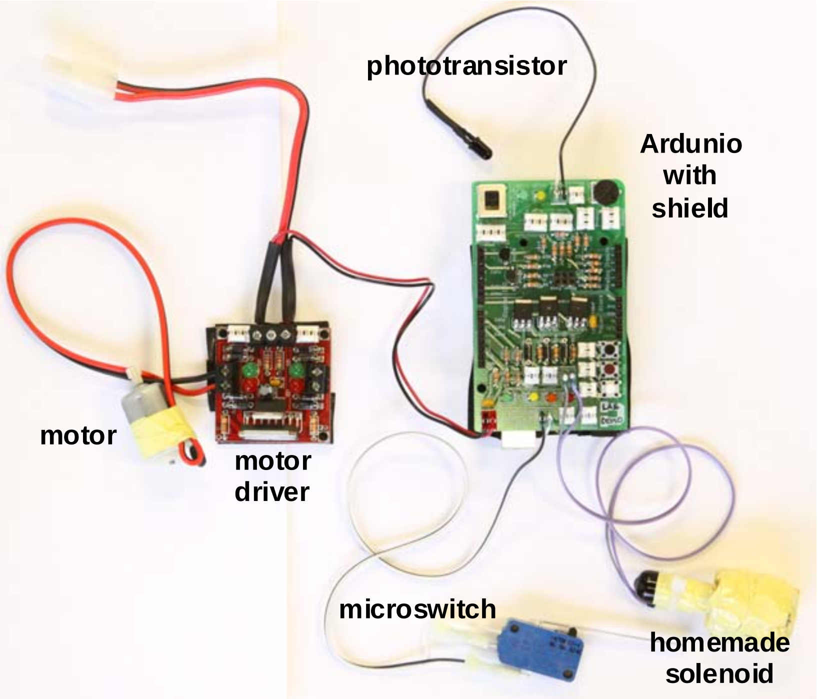

Figure 11: Arduino microcontroller with shield board and the sensors (phototransistor, microswitch) and actuators (DC motor, solenoid) used in the spring semester design project. (The most recent version of the shield board includes an integrated motor control circuit.)

5. Assessment

We are assessing our progress by following our students' performance on final exam questions, and tracking student retention by following whether students who take ME EN 1000 ever register for ME EN 3200, our required junior-level Mechatronics I course.

5.1 Student Performance on Final Exam

The final exams in both the fall and spring are "competency-based" exams given in the computer lab. For the first semester, we directly assess students' performance by comparing the results from Fall 2009 and Fall 2010 (the first and second offerings of our revamped class) to the results from Fall 2008 (taught in a traditional lecture style). The format of the exams has remained the same with one third of the points each for questions using two different engineering software packages (SolidWorks® and Excel®), and the remaining one third covering the design content of the class, as well as engineering physics, hardware, teamwork, and communications via a paper exam and online multiple choice questions. (The final exams are not returned to students so that we can continue to use these questions with minimal concern that students are aware of the test content.) The exams are designed to be challenging and it is not uncommon for students to not finish all of the portions of the test. The scores for all years are summarized in Table 1.

Table 2. Student performance on the final exam.

Topic	Year	Average	Std Dev	Delta
Design (1/3 of final exam)	2008	59.6%	17.1%	
	2009	72.9%	17.7%	+13.2%
	2010	70.8%	16.6%	+11.2%
SolidWorks® (1/3 of final exam)	2008	71.9%	21.3%	
	2009	69.0%	25.0%	-2.9%
	2010	76.4%	24.5%	+4.5%
Excel® (1/3 of final exam)	2008	48.0%	22.8%	
	2009	48.5%	25.5%	+0.5%
	2010	63.7%	25.1%	+15.7%
Fourbars (part of Design)	2008	53.1%	35.4%	
	2009	86.5%	26.5%	+33.3%
	2010	n/a	n/a	n/a

Prior to Fall 2010, Excel® was taught using homework assignments, with assigned readings but no lecture or lab time. Starting in Fall 2010, Excel® tutorials were given during the first hour of lab, and instructional videos were available on YouTube®. Although there is still some overlap in standard deviations, the 15.7% increase in scores on the final exam can likely be attributed to this increased effort in lab toward teaching students how to use Excel®.

In all versions of the fall class, SolidWorks® was taught in the labs and lab assignments. Although the increase of 4.5% (compared to 2008, 7.4% compared with 2009) is smaller and within the standard deviation, this is an encouraging result. Teaching Excel® during the first hour of lab reduced the amount of time spent on SolidWorks® from 3 hours to 2. It appears that, at the least, this did not impact the learning environment for SolidWorks®.

The significant changes in the classroom learning environment (see [1-3]) were maintained from 2009 to 2010, with the scores on the Design exam remaining above those seen in 2008. We previously compared a sub-group of questions on the Design portion of the final exam with three questions about fourbar linkages that were identical on the two exams (calculating Grashof condition and identifying a specific link). In 2009, we saw a +33% improvement. This was gratifying but not unexpected given the changes in teaching style and increased content, including a laboratory exercise. This year, we have shifted the fourbar content from the fall class to the spring class, and we will again use the same sub-group of questions to investigate whether students are continuing to demonstrate an increased mastery of this material.

5.2 Retention of Students in the Program

Student retention levels have been tracked for the last six years, by comparing the student IDs of students who passed (grade of C- or higher) our introductory (ME EN 1000) class to the IDs of students who have achieved upper division status during the same time period (including Fall 2010 semester). Upper division status indicates that these students have reached the junior level, and is measured using the enrollment lists from our ME EN 3200 class. The results are shown in Table 3.

Our current retention is around 50%. The majority of the students who eventually achieve upper division status do so within two years, but as the older data from 04/05 and 05/06 indicates, we have a large group of students who take more time (the numbers to the right of the gray boxes). The makeup of our "commuter campus" student population is such that students are very likely to be working full or part time, and/or to take a leave of absence after starting school (e.g., for a religious mission). We also have a handful of transfer students each year who need to take our ME EN 1000 class, but are ready for upper division status the following year (the numbers to the left of the gray boxes).

Table 3. Retention of students from first-year enrollment to third-year enrollment; shaded boxes indicate the semester in which the students in a particular academic year are expected to be third-year students.

ME 1000 Year:	**Total 1000**	**Fall 04**	**Fall 05**	**Fall 06**	**Fall 07**	**Fall 08**	**Fall 09**	**Fall 10**	**Total 3200**	**Percent Retained**
F04/S05	146	0	6	38	12	8	4	1	69	47.3%
F05/S06	146	0	0	9	33	19	15	4	80	54.8%
F06/S07	139	0	0	0	6	42	18	8	74	53.2%
F07/S08	150	0	0	0	1	3	42	24	70	46.7%
F08/S09	133	0	0	0	0	0	1	34	35	26.3%
F09/S10	128	0	0	0	0	0	0	5	5	3.9%
Total:	842						*Total:*		333	39.5%

We would like to see our retention numbers increase well beyond the 50% level. We will continue to track the students who pass our first-year courses and who enroll in our ME EN 3200 class to see whether we can identify a correlation in increased retention over the next several years. As our initial group of students approaches graduation, we will inquire about their experience in these new classes during their senior exit interviews. In Fall 2011, our first cohort of students will be (theoretically) prepared to take ME EN 3200, providing us with more information about retention.

6. Conclusion

As part of an extensive redesign of our first- and second-year Mechanical Engineering curriculum, we have implemented many new hands-on laboratory experiences in our first-year course sequence. These active learning experiences all have significance to the semester-long, team-based design project, and are expected to motivate student learning and increase student comprehension of fundamental engineering topics presented in lecture. Since the design projects require fabrication of a physical device to compete in an end-of-semester competition, manufacturing labs introduce students to simple CAD-driven machine tools. Mechanical hardware labs help students choose and "size" the various components of their design in conjunction with required mathematical modeling assignments. Electronics and electromagnetic hardware labs are introduced in the spring semester as the focus of lectures and the design project shifts from mechanical hardware to sensors and actuators. We are currently teaching the new first-year courses for the second time, and assessment data will continue to be evaluated as we move forward.

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