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A Hands-on, First-year Mechanical Engineering Course

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A Hands-on, First Year Mechanical Engineering Course

1 Background

Cal Poly Pomona is one of the only seven polytechnic universities in the nation and its College of Engineering graduates 1 of every 14 engineers in the state of California. Our engineering graduates are well-respected and employed by both large corporations and small businesses in California and around the country.

There is a greater need today to educate our students with multi-disciplinary skills than ever before while we are still facing the challenge of recruiting and retaining engineering students. Researchers [1-2] have studied these issues and one of the many challenges is the lack of preparation. The real preparation for engineering begins in high school. However, first year engineering courses can play a significant role in motivating and providing important skills to freshmen students. Numerous engineering educators [3-8] have introduced innovative first year engineering courses focused on engaging students early on.

ME 100L is an introductory engineering course required by all incoming mechanical engineering students at Cal Poly Pomona. It is a 1-unit course with a 3-hour lab each week. Approximately 400 incoming mechanical engineering students take this class every year. Since its inception almost two decades ago, ME 100L introduced students to the field of mechanical engineering and various career options, emphasized team work, and culminated in a rubber band car competition. The course was outdated and was long overdue for a change. With the introduction of a new first year experience course (EGR 100) common for all engineering students at Cal Poly Pomona, most of the topics of ME 100L have become redundant creating the opportunity to overhaul the course.

Our students are called Net Generation [9]. They are technology savvy, impatient and look for instant gratification. Additionally, they want to know the relevance of the material they are learning, making it difficult to frontload these students with information and telling them they will need this material later in their career. Our goal is to provide a meaningful hands-on experience to the student early in their education. We have completely redesigned ME 100L to excite our incoming first year students, provide them with a 100% hands-on experience and acquire useful and transferable skills. This paper presents our redesign efforts.

2 Course Redesign

Arduino is the most widely used low cost, open source prototyping platform based on easy-to-use hardware and software [10]. It is predominantly used by engineers, hobbyists and students around the world. In the last several years, most engineering students use Arduino in some form during their undergraduate studies. At Cal Poly Pomona, mechanical engineering students use Arduino in their control systems class, usually taken in their senior year. Many students also use Arduino in their senior design projects. Witnessing that Arduino is being introduced at high school level [11], and after experimenting with one section of first year students, we decided to introduce all mechanical engineering students to Arduino early in their first year. This gives an opportunity for our students to learn about microcontrollers, circuits, electronics, sensor-actuator integration and programming at the beginning of their education in a project-based environment. It is hoped that the students will become more confidant in integrating mechanical parts and electronics, and likely to apply this knowledge in subsequent courses.

Today there are no purely mechanical engineering devices. An automobile, which used to be mechanical engineering marvel, now has numerous embedded microprocessors in various subsystems, from anti-lock brakes to smart suspension controlled by software. Modern mechanical engineers must be conversant with all aspects of product design and must understand the multi-disciplinary nature of engineering. In this context, we want to provide our students with a multidisciplinary engineering design experience early on.

In our experimental section, we found that while introducing students to Arduino robotics, they invariably ended up learning how to use a solid modeling application, 3D printing and soldering. Our redesigned course now includes solid modeling and soldering.

3 Course Structure

The assumptions we made in redesigning this class are that students like to build things, gain hands-on experience, learn new things, and want to be independent learners. These assumptions lead to the development of course materials focus on hands-on activities with minimal lecture. Specific activities designed to provide this experience include learning about gearboxes, electrical circuits, multi-meters, electronic components, soldering, Arduino microcontroller, sensors, C programming, 3D modeling, and prototyping. A lot of concepts are packed into this 1-unit course, but students love the new experience.

Ten sections of ME 100L are offered throughout the year with approximately 40 students per section. Since the course is taught by various instructors, including several part-time lecturers, it is important that the course is well-structured to ensure easy and consistent adoption by all instructors. We developed a repository of course materials which includes a syllabus, weekly activities, homework assignments, advanced topics, external resources, and practical tips that is made available to all instructors within Blackboard. We are currently in the process of making video tutorials for each activity about the robot assembly, sensor integration, and programming that can be used by the instructors in their classes. All instructors can access this material and modify it to fit their personal teaching style. 10-week course has the following schedule:

Week	Topics
1	3D Solid modeling of components and assembly
2	Introduction breadboard, circuits, and Arduino ; Multi-meters
3	Gearbox assembly and analysis
4	Basic robot assembly and motor control ; Fasteners
5	Obstacle avoidance with ultrasonic sensor
6	Line following (one sensor/two sensors and three sensors)
7	Soldering
8	Attachment design ; 3D printing ; Challenge announcement
9	Using servos ; Review additional programming techniques
10	Final challenge

The following activities take place during a typical three-hour lab session:

- Students attend class and listen to 15-20 minutes of lecture
- Remaining in-class time dedicated to a specific task (e.g., building a gearbox)
- Students are given an assignment that is due at the start of the next class meeting

While students work on a task, they can ask for help from the instructor or a couple senior-level mechanical engineering student assistants.

4.1 Week 1 Activities – Solid modeling

Students are expected to buy all the parts needed to build a robot or buy a recommended kit. Typically, it takes about a week for the students to get all the supplies, so we do not start building the robot until Week 2. In addition, the add/drop period occurs during the first week of the quarter and this avoids students missing an important class in the first week. Instead we use the first week to introduce solid modeling.

The Solidworks® software is installed in our local computer labs. However, most students want to use their own computers, so we are open to the use of any CAD software. Most students download Autodesk Inventor® as it is free and also easy to use. A short introduction on using the CAD software package is given in class, then student learn more about solid modeling on their own using online tutorials. Students work on designing an attachment for their robot during the next several weeks and the assignment is due on 8th week,

4.2 Week 2 Activities - Introduction to circuits, breadboard, and Arduino

In typical mechanical engineering curriculum, students learn basics of electrical engineering in a circuits course. However this occurs later in engineering curriculum, depriving students of their ability to use microcontrollers. One of the primary objectives of ME 100L is to introduce the multidisciplinary nature of engineering design. In Week 2, students learn about breadboards and how they work, as shown in Figure 1. They learn how metal plates make up a row, learn that voltage at any point along each row is the same, and learn to measure the voltage using a multi-meter. Learning how to use a multi-meter is a valuable skill which most students are usually not exposed to until their senior year.

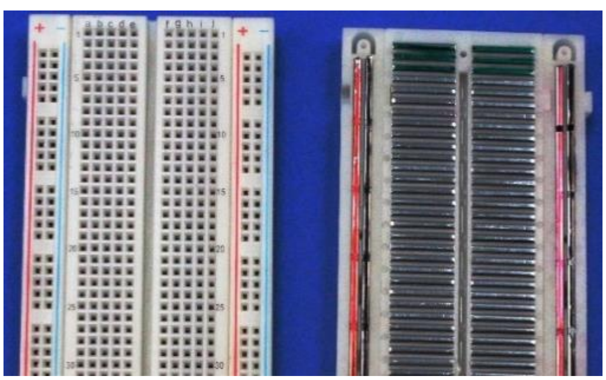


Figure 1: Understanding breadboard

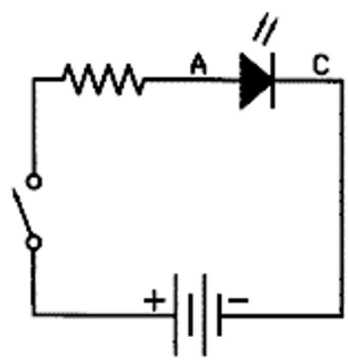
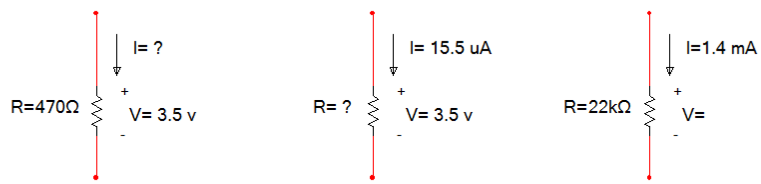


Figure 2: LED Circuit

As part of this activity, students learn how to light up an LED and program the LED to blink. They look at a circuit (Figure 2) and recreate the circuit using actual parts. In addition to learning about resistors and current, they learn how to use Arduino board and basic Arduino C programming to turn the LED on and off. The homework for this session involves designing and programming a traffic light. During this activity student learn how to measure voltage, current, and resistance using a multi-meter. Below is a list of sample activities students perform during this week.

Task	Questions and Activities
	Measuring Voltage
1	Measure the voltage of your batteries.
2	Measure the voltage by connecting your batteries in series and parallel.
	Understanding resistors
3	A resistor's first three color bands are; brown, black and red. - What is its value?
4	A resistor's first three color bands are; red, yellow and black. - What is its value?
5	Specify the color code for 4-band 220 Ω resistor with 5% tolerance
6	Measure the resistance of some of your resistors using multi-meter and verify with the value with the resistor code.
	Ohm's Law
7	For the resistors shown below, use Ohm's Law to calculate the unknown quantity. 
	LED Circuit
8	Wire a simple LED circuit shown above using battery power (use 6V power supply, 4 x 1.5 V Batteries). In our kit, color of the LED is indicated by the wire color (positive). Ground is black. Calculate the resistor value if the LED current is limited to 20 mA. Learn how to use a jumper wire from the controller board to breadboard. Is your LED lighting up?
9	Measure the voltage across the LED. And note down (V_{led})
10	Measure the voltage across the resistor (V_r)
11	What is the total voltage, $V_t = V_{led} + V_r$?
12	Measure the voltage across the circuit and compare with V_t
13	What is your conclusion? Can you measure the current in the circuit?
14	Build a circuit with two LEDs. Draw a schematic diagram with two LEDS.
15	Can you create a circuit with 3 LEDs?
	Experiment with Tri-Color LED
16	Identify the tri-color LED from your kit. Tri-color LED is essentially an LED made of three individual LEDs. Our tri-color LED is made of Red, Green and Blue LEDs. Remove individual LEDs from your breadboard and replace with the tri-color LED. The black wire from the tri-color LED will go to the ground. Connect one wire at a time and record your observation
17	**Use a buzzer along with tri-Color LED**

18	Make a traffic light using the tri-color LED on pins 9, 10, 11. Put the buzzer on pin 6. The buzzer should make one beep when the green light flashes, two beeps when the yellow light flashes, and three beeps when the red light flashes.

4.3 Week 3 – Gearbox assembly

Students assemble a Tamiya double gear box which can be assembled in 4 various configurations. Students have to assemble the gearbox for a particular gear ratio. Before they begin gearbox assembly, a short introduction to gears is provided by the instructor. They learn about spur, helical, worm and bevel gears. Students also get to view an automotive transmission in the laboratory and perform gear ratio calculations. Figure 3 shows one possible configuration of the gearbox they assemble. Figure 4 shows a fully assembled gearbox. Figure 5 shows a group of students working on their gearboxes.

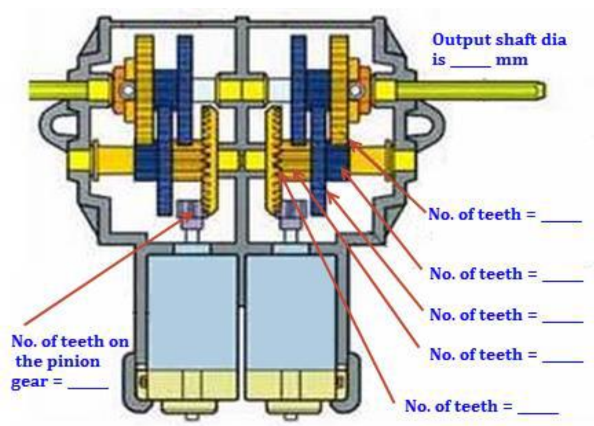


Figure 3: Gearbox assembly configuration

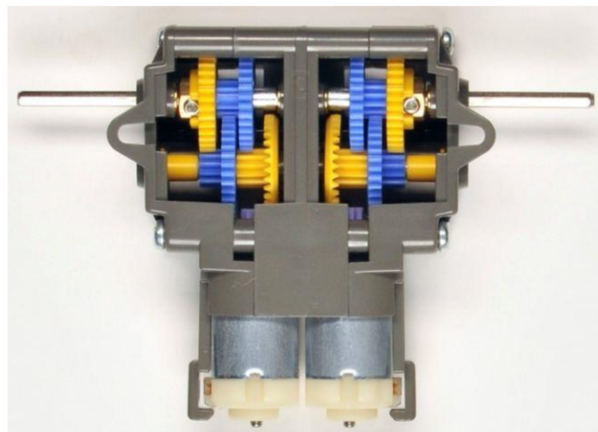


Figure 4: Assembled gearbox

Figure 5: Students assembling gearboxes

Homework assignments on this topic include counting the number of teeth on each gear used in the gearbox, calculating the overall gear ratio.

4.4 Week 4 – Robot assembly, wiring DC motors, and H-bridge

Students start building their robot during Week 4, which is powered by two DC motors. For DC motors, the direction of current determines the rotational direction of the output shaft. The H-bridge allows them to change the current direction without manually rewiring the robot. The concept of H-bridge is discussed using the simple diagram shown in Figure 6. Figure 7 shows the actual chip used in this project. At this point, students are eager to make their robot move, and show lot of interest in this part of the course. Many students wire their robot incorrectly at first, but eventually fix their mistakes.

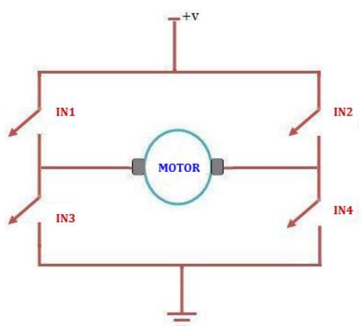


Figure 6: H-Bridge schematic

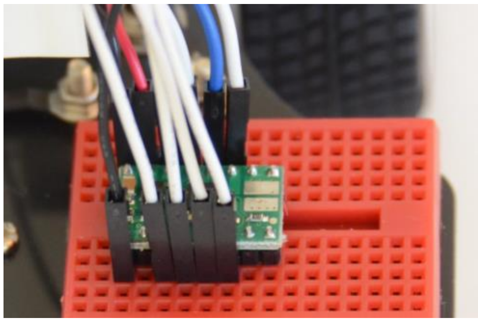


Figure 7: H-Bridge with wiring

Below is a list of sample activities for Week 4 in class. A vinyl mat (see Figure 8) is used for these activities.

- Make your robot to go forward 30 cm.
- Watch your robot and see if it goes straight. If it is biased to one side, one motor is faster than the other (weight distribution plays a role too). Adjust the power so it can go as straight as possible.
- Motor speed can be changed from -255 to 255. Zero value stops the motor, +255 is the highest speed, and negative values move the robot in the opposite direction.

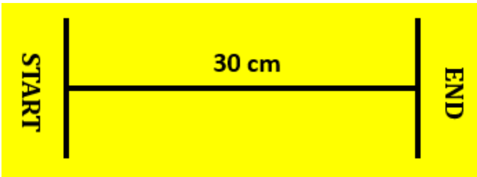


Figure 8: Move Task

For homework, students much accomplish the following tasks:

- Make the robot move between two concentric squares, as shown in Figure 9. The robot must not completely cross over either the inner or outer squares. This activity is also very helpful to learn the loop function in C.
- Additional activities include making the robot to go around an equilateral triangle or a special path.

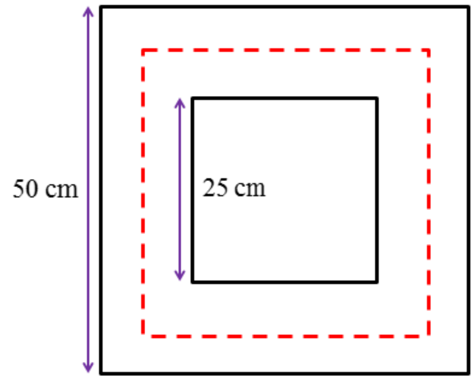


Figure 9: Square task

4.5 Obstacle avoidance with ultrasonic sensor

In week 5, students learn how ultrasonic sensor work and are reminded about the speed of the sound. Further discussion includes how animals such as bats, whales and dolphins use ultrasonic waves for communication, and the frequency hearing range of humans.

The specific sensor used in this class is the HC-SR04 sensor (shown in Figure 10), which offers non-contact range detection from 2cm to 400 cm (1 inch to 13 feet). Students learn about the function of echo & trigger pins and wire them as shown in figure 11.

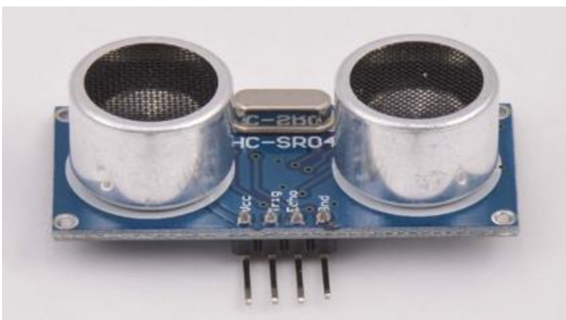


Figure 10: HC-SR04 Ultrasonic sensor

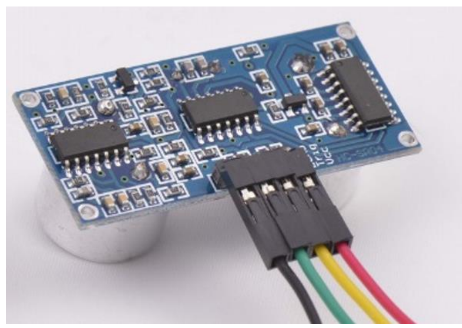


Figure 11: Sensor wiring

Below is a list of sample activities students perform during this week.

- An ultrasonic sensor takes 160 µs to hit an object and return. How far away is the object?
- How long for an ultrasonic sensor chirp to hit and return from an object 40 cm away?
- How many milliseconds for an ultrasonic sensor chirp to hit and return from an object 10 inches away?
- Write a new program combing both so your robot goes forward till it sees an object in front of it within certain distance (example 125 mm) of the object. Stop, then turn (right or left).
- Test the robot in a 70 cm x 70 cm area as shown in figure 12. Include a few obstacles and see if the robot navigates through obstacles without touching. A modified version of this course is shown in figure 13 in which the robot has to exit without hitting any obstacles as soon as possible.

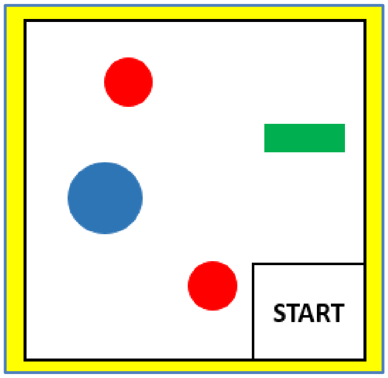


Figure 12: Obstacle course

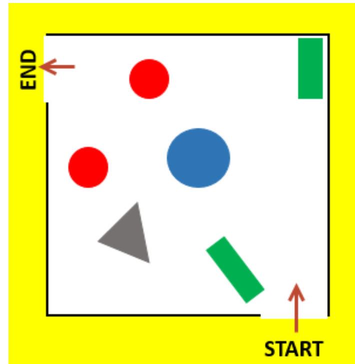


Figure 13: Escape Course

4.6 Week 6 – Line following

Many real-world systems, including robots performing warehouse operations, use line following algorithms. Line following can be a very important and rewarding activity in robotics. In ME 100L, we use an array of three light sensors (HY Studio light sensor). Students learn how a light sensor illuminates the surface with light and then picks up the reflected light based on the reflectivity of the surface; white surfaces reflect more light while black surfaces reflect less light (absorbs more light). This allows the sensor to detect a dark line on a white surface, or a white line on a dark surface. The HY Studio light sensor outputs "1" when black is detected and "0" when white is detected.

Since there are 3 light sensors on the array, students can start with simple programming using one sensor, then move onto writing the code for two light sensors, and finally utilize three sensors. The tasks for students include:

- Program the robot to stop when it sees a black line
- Follow a black line using wiggler approach
- Follow line using two sensors
- Follow line using three sensors
- Compare the performance

Figure 14 shows the comparison table that students use for this activity.

Approach	Attempt	Time (sec)	Accuracy	Comments
Line Following with one sensor	1			
	2			
	Best time			
Line Following with two sensors	1			
	2			
	Best time			
Line following using three sensors	1			
	2			
	Best time			
Advanced line following	1			
	2			
	Best time			

Figure 14: Compare the performance of various line following approaches

4.7 Week 7 – Soldering

Soldering is a very useful and important skill for all engineering students. In general, mechanical engineering students do not learn soldering as part of the program, but instead as needed. As a result, most of our students are not confident about soldering. We have now incorporated a soldering project using a using a commercially available kit. At the beginning of the soldering lab, students get a short lecture on the following topics:

- Safety procedure
- What is soldering?
- How to populate a printed circuit board with components
- What is solder?
- What is flux?
- Proper soldering techniques
- Video demonstration

4.8 Week 8 – Creating robot attachment

During Week 8 week, students complete the design of their attachment for the robot – students often can be quite creative. Their design may be part of the casing, a decorative piece, or a functional part to attach to a servomotor. The Mechanical Engineering Department provides resources for all students to build their models using 3D printers. During Week 8, students also are shown the layout of the final challenge obstacle course (see next section)

4.9 Weeks 9 and 10 – Miscellaneous topics and the Final Challenge

Week 9 is dedicated to introducing miscellaneous topics such as servomotors and advanced topics in sensors and programming. The course culminates in a fun and exciting challenge during Week 10. The specifics of the challenge is changed every quarter but the challenge requires various fundamental skills including line following, obstacle avoidance, and using LEDs and a buzzer depending based on the environment. Figure 15 shows the Final Challenge course used during Fall 2014; an 8 ft by 4 ft table with two courses is used for this event. Two students can demonstrate their robot simultaneously, and students are given multiple chances to revise their algorithms if their robots do not pass the challenge. Figure 16 shows one group of students with their completed robots.

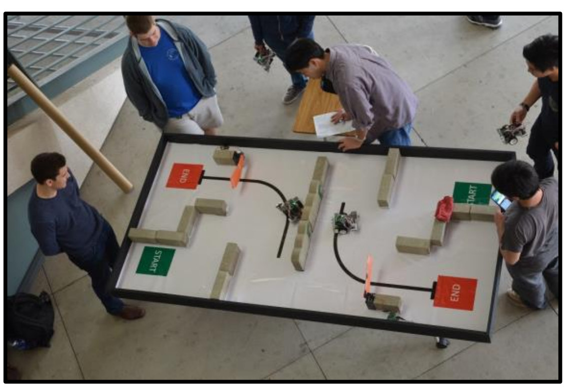


Figure 15: Final Challenge course

Figure 16: ME 100L students with their robots

5 Assessment

183 students from six sections took the survey for F2014. 80 students from four sections took the survey for F2015. For all questions, first column is selected answer, second column is number of respondents, third column is percentage of respondents

Are you a freshman?

	F2014		F2015	
yes	116	63.4%	43	53.8%
no	66	36.1%	37	46.3%
not answer	1	0.5%	0	0%

Select the phrase that best represents your opinion about ME 100L:

	F2014		F2015	
really liked	95	51.9%	60	75.0%
somewhat liked	70	38.3%	16	20.0%
neither like nor dislike	11	6.0%	1	1.3%
somewhat disliked	6	3.3%	2	2.5%
really disliked	1	0.5%	1	1.3%

What is your opinion about the following statement?
I enjoy being a mechanical engineering major more due to ME 100L.

	F2014		F2015	
strongly agree	66	36.1%	43	53.8%
slightly agree	75	41.0%	24	30.0%
neither like nor dislike	32	17.5%	10	12.5%
slightly disagree	7	3.8%	2	2.5%
strongly disagree	2	1.1%	1	1.3%
not answer	1	0.5%	0	0%

Which topics did you learn about for the first time in ME 100L? (Select all that apply)

	F2014		F2015	
gearboxes	116	63.4%	50	62.5%
electrical circuits	80	43.7%	37	46.3%
microcontrollers	157	85.8%	64	80.0%
computer programming	113	61.7%	51	63.8%
sensors	142	77.6%	61	76.3%
3D modeling	79	43.2%	30	37.5%
resistors and LEDs	77	42.1%	39	48.8%
DC motors	110	60.1%	41	51.3%
soldering	111	60.7%	49	61.3%
not answer	8	4.4%	4	5.0%

Which topics do you feel more confident about after taking ME 100L? (Select all that apply)

	F2014		F2015	
gearboxes	124	67.8%	52	65.0%
electrical circuits	113	61.7%	46	57.5%
microcontrollers	129	70.5%	51	63.8%
computer programming	112	61.2%	48	60.0%
sensors	123	67.2%	46	57.5%
3D modeling	77	42.1%	40	50.0%
resistors and LEDs	119	65.0%	47	58.8%
DC motors	89	48.6%	37	46.3%
soldering	137	74.9%	54	67.5%
not answer	1	0.5%	2	2.5%

Select your three favorite topics in ME 100L. (Select up to three)

	F2014		F2015	
gearboxes	72	39.3%	30	37.5%
electrical circuits	49	26.8%	22	27.5%
microcontrollers	52	28.4%	36	45.0%
computer programming	62	33.9%	40	50.0%
sensors	56	30.6%	29	36.3%
3D modeling	97	53.0%	37	46.3%
resistors and LEDs	28	15.3%	18	22.5%
DC motors	31	16.9%	6	7.5%
soldering	95	51.9%	31	38.8%

Select your three least favorite topics in ME 100L. (Select up to three)

	F2014		F2015	
gearboxes	21	11.5%	15	18.8%
electrical circuits	56	30.6%	31	38.8%
microcontrollers	54	29.5%	19	23.8%
computer programming	105	57.4%	33	41.3%
sensors	54	29.5%	12	15.0%
3D modeling	27	14.8%	17	21.3%
resistors and LEDs	40	21.9%	29	36.3%
DC motors	44	24.0%	20	25.0%
soldering	21	11.5%	20	25.0%
not answer	11	6.0%	2	2.5%

6 Discussion

The redesign of ME100L is a success. 90% of the students liked ME100L in Fall 2014 and this increased to 95% in Fall 2015. Even though different faculty members taught this course, the level of interest has increased mostly due to the past experience and some corrective measures we took in making changes in the sequence of the new curriculum.

One of our objectives of this course is to ensure that it inspires our students to be mechanical engineers and continue to be with the major. 83% of the students agree with the statement “I enjoy being a mechanical engineering major more due to ME 100L". For most topics in the course, ~60-80% of the students stated that they learned about the topic for the first time in ME 100L. For example, ~80% of the students learned about microcontrollers for the first time. The surveys also give us insight into which topics students are being exposed to in high school. For example, a much smaller percentage of students (~40%) learned about 3D modeling for the first time in ME 100L compared to microcontrollers. For most of the topics in the course, more than half of the students felt an increase in confidence after taking ME 100L.

Overall results indicate that we are able to inspire a very large number of students about being a mechanical engineer, helped them learn about topics, and feel more confident about their knowledge.

References

1. Rojas-Oviedo, R. & Qian, X.C., (2002). Improving Student Retention of Undergraduate Students in Engineering through Freshman Courses, ASEE Annual Conference and Exposition, Montreal, Quebec.
2. Johnson, J., & Niemi, A. D. (2015). A First-year Attrition Survey: Why Do They Say They Are Still Leaving? ASEE Annual Conference and Exposition, Seattle, Washington.
3. Meyer, M. & Marx, S., (2014). "Engineering dropouts: A qualitative examination of why undergraduates leave engineering", Journal of engineering education, Vol. 103, Issue 4, Pages 525-548, October 2014
4. Skurla, C., Thomas, B., & Bradley, W., (2004). Teaching Freshman Using Design Projects and Laboratory Exercises to Increase Retention, ASEE Annual Conference and Exposition, Salt Lake City, UT.
5. Hall, D., et al., (2008). "Living with the Lab: A Curriculum to Prepare Freshman Students to Meet the Attributes of The Engineer of 2020", ASEE Annual Conference and Exposition, Pittsburgh, PA.
6. Caverly, R. H., et al., (2015). A Core Course Component in a Project-based First-year Engineering Experience, ASEE Annual Conference and Exposition, Seattle, Washington.
7. Anastasio, D. D., et al., (2015). A First-year Project-based Design Course with Management Simulation and Game-based Learning Elements, ASEE Annual Conference and Exposition, Seattle, Washington.
8. Vernier, M., et al, (2015). "Design of a Full-Featured Robot Controller for Use in a First-Year Robotics Design Project", ASEE Annual Conference and Exposition, Seattle, Washington.
9. Oblinger, D., & Oblinger, J., Ed., (2005). Educating the Net Generation, EDUCAUSE
10. Fish, Elizabeth, (2011). Geek 101: What is Arduino?, PC World, URL: http://www.pcworld.com/article/239454/geek_101_what_is_arduino.html
11. Shultz, R., Ueda, D., Ward, J., & Fontecchio, A., (2015). A Hands-On, Arduino-Based Approach to Develop Student Engineering Skills and Introduce Cybersecurity Concepts to K-12 Students, ASEE Annual Conference and Exposition, Seattle, Washington.
12. Shepard, T. and Carlin, B., (2014). "A First-Year Soldering and Analog Music to Light Modulator Electronics Lab Project", ASEE Annual Conference and Exposition, Indianapolis, IN