# Enhancing the Freshman and Sophomore ECE Student Experience Using a Platform for Learning™

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***Abstract*—Outcomes based assessment has shown that introducing a platform for learning™ based on a robot referred to as TekBots™ into the first two electrical and computer engineering (ECE) courses enhances students' sense of community, innovation capabilities, and troubleshooting skills. At Oregon State University, Corvallis, ECE students enhance their fundamental understanding of ECE concepts as they construct and build upon their individual robot (TekBots). They experience first-hand the fun associated with engineering while gaining a sense of accomplishment. This platform will eventually extend through the four-year curriculum so that, rather than a single point project, the robot serves as a platform that connects and integrates the content from course to course.**

***Index Terms*—Design, education, educational technology, electrical engineering, engineering education, robots, TekBots™.**

## I. INTRODUCTION

THE CREATIVE aspirations and "can do" attitude spawned by the space race, Heathkits, and homemade crystal radios have been replaced with the passive satisfaction of video games, cell phones, and throwaway electronic appliances [1]. This attitude presents challenges in attracting and retaining engineering students who often lose interest in engineering because of the slow build-up to the junior- and senior-level courses where they finally learn and apply discipline-specific knowledge. In addition, the lack of the "fun factor" and the "you can do it" attitude is often missing in current engineering curricula. Thus, to make engineering more appealing to incoming freshmen, a major redesign of the engineering curriculum is necessary.

Any curriculum redesign will necessarily include the Accreditation Board for Engineering & Technology (ABET) 2000 outcomes-based assessment [2]. For each department, these outcomes are summarized as the program education objectives that describe the unique characteristics of that program. The curriculum changes introduced here are specifically designed to enhance the program education objectives defined by the constituents of the Department of Electrical and Computer Engineering (ECE), Oregon State University (OSU) [9], Corvallis. These are summarized in Table I. Depth and breadth of knowledge and professionalism are mainstays of any accredited engineering program. In addition to these core objectives, constituents identified the ability to troubleshoot hardware and software problems, the demonstration of innovative thinking, and the active participation in the professional community as key objectives of the program [1], [10]–[12].

A major challenge in curriculum redesign is bringing all of these aspects into the program and, at the same time, tying together the extensive number of discrete topics. At the National Science Foundation (NSF) Engineering Education Innovators' Conference, Bordogna's keynote address [12] identified a major challenge with the existing structure of engineering education. With most curricula consisting of separate (sometimes seemingly disconnected) courses, graduates may find it difficult to make the connection between the various topics within the curriculum. As he described:

> "...education appears to ignore the need for connections and for integration—which should be at the core of an engineering education..."

In this paper, the authors describe a novel concept for bringing excitement into the classroom, addressing the ABET 2000 outcomes and providing an integration platform for the curriculum. The goal is to use the development of the platform for learning™ based on a robot referred to as TekBots™ to enhance the students' depth and breadth of knowledge, professionalism, sense of community, ability to troubleshoot, and innovation aptitude. This paper demonstrates the implementation of these ideas and goals through the introduction of two courses into the freshman and sophomore ECE curriculum.

## II. KEY FEATURES OF THE PLATFORM FOR LEARNING

There are several key concepts that are referred to as "core values" that are integral to how to teach with TekBots.

*Ownership*—Each student constructs and owns his or her individual robot. This personal ownership motivates the student [16] and helps the student take ownership for his or her education. The student's robot can become an individual expression of the student's personality and what he or she has learned.

*Continuity*—The TekBots platform provides continuity throughout the entire program. It ties all the topics together [15].

*Context*—The TekBots platform provides an application for many of the concepts the students learn about in class [14], [15].

*Fun factor*—Through fun hands-on experiences students are inspired to learn more [16].

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TABLE I
PROGRAM EDUCATION OBJECTIVES FOR OREGON STATE UNIVERSITY'S ECE DEPARTMENT

| Program Learning Objective | Detail |
|---|---|
| Depth | Ability to troubleshoot, identify, formulate, analyze, and solve electrical and computer engineering problems by applying fundamental and advanced mathematical, scientific, and engineering knowledge and skills. |
| Breadth | Provision for a broad base of understanding at a systems level as well as at a component level through authentic engineering experiences, including current issues in ECE as needed to understand the impact of ECE solutions in a global and societal context. |
| Professionalism | Preparation for the complex modern work environment by building clear communication skills, responsible teamwork skills, development of project management capabilities, professional attitudes, and understanding of ethical issues. |
| Ability to Troubleshoot | Establishment of a process by which problems are identified, isolated, and repaired. |
| Innovation | Provision of a process by which technological ideas are generated, developed, and transformed into new business products, processes, and services that are used to make a profit and establish marketplace advantage.[10] |
| Sense of Community | Learning to lead, mentor, and/or contribute to the development of future engineers and on engineering teams. |

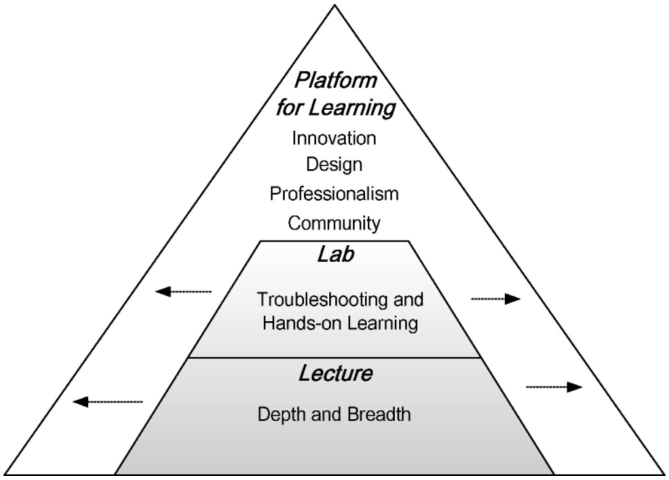


Fig. 1. TekBots platform for learning and the enhancement of the lecture and the laboratory material.

*Hands-on learning*—Students see theory put into practice with this hands-on approach [17].

Fig. 1 illustrates how the lecture, traditional laboratory, and TekBots interrelate. The subject matter is typically first introduced and expanded in the lecture portion of the course. Since students often see this material, for the first time in lecture, typically some, but not all, of the material "sinks in" and is completely understood. In laboratories, students experience first-hand how the theory can be applied. With the TekBots platform incorporated into the laboratory, key learning objectives such as troubleshooting, community, and innovation are interleaved into the laboratory experience. This integration gives students a more sophisticated appreciation for the fundamental theory presented in the lecture. The material is represented by the arrows that circulate from the laboratory to TekBots and back to the lecture in Fig. 1.

At this point, a distinction needs to be made between this curriculum approach and a *robot class*. Several universities have developed robot classes to improve undergraduate education. Most universities that employ robots do so only in a single class or a small number of courses where the emphasis is on robotics [3], [5]–[8]. Very often in these classes, students use shared robots that must remain in the laboratory, rather than personally building and owning their individual robots.

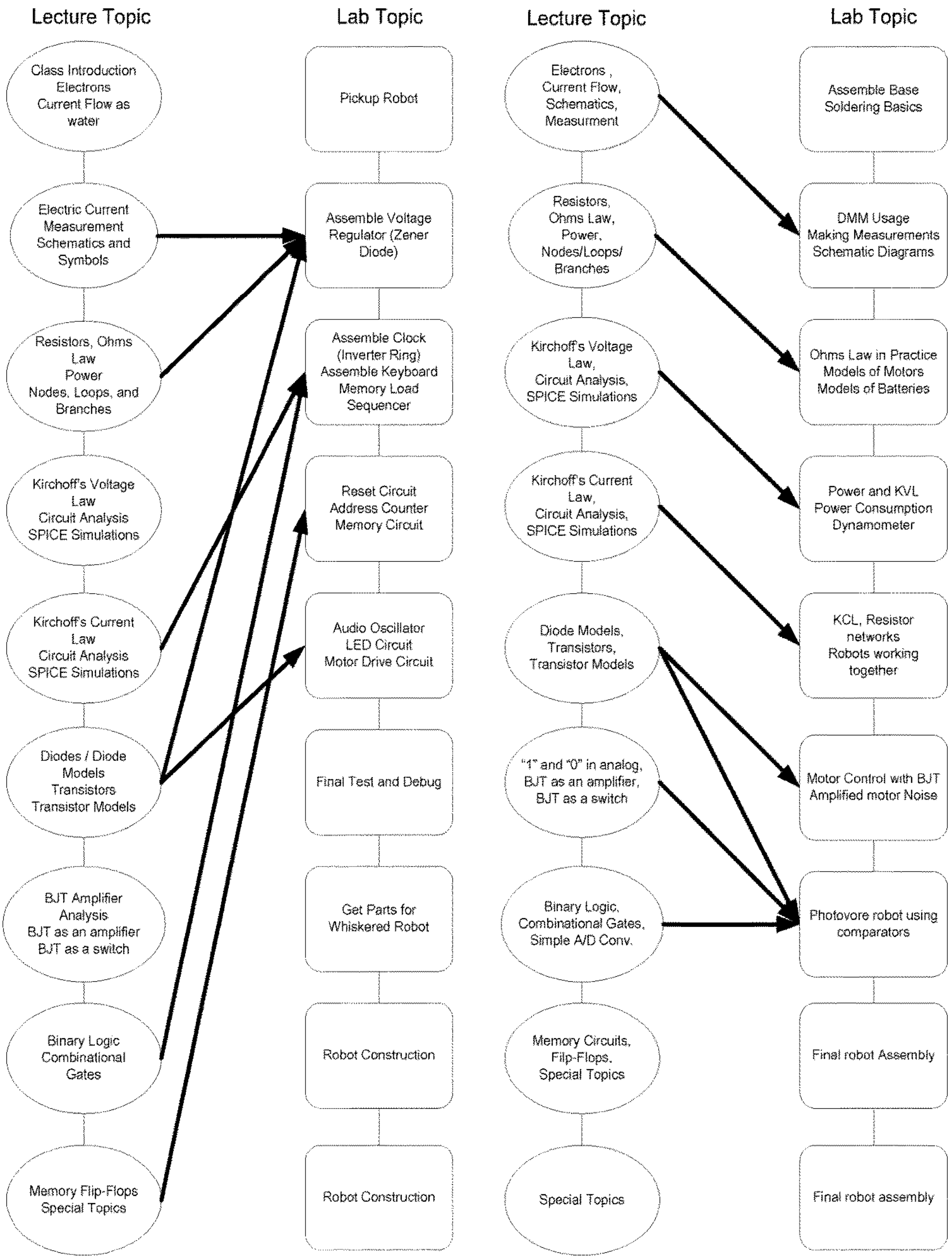
One primary difference of the approach presented here versus other programs is that the platform for learning is continuous and connects topics across many different courses, integrating knowledge from one course to the next.

The TekBots platform is intended to be a large-scale multidisciplinary platform that encompasses many areas of learning in engineering. Tekbots is not a single course or limited set of courses. It is intended to be used throughout the four-year curriculum. It is a tool that helps students keep information from various courses fresh in their minds by keeping the platform flexible and expandable. For example, the foundation of the robot that is built in the freshman orientation course is the same robot that a student will use in the sophomore, junior, and senior levels.

## III. TEKBOTS IN THE FRESHMAN ECE COURSE

### A. Background

Possibly the most important course in any engineering program is the freshman-level orientation course [3]. This course is the first exposure that a student has to engineering at a university. As such, it should be the most dynamic and exciting course in the program, but it cannot be atypical of courses that the students will take during their college careers. A mix of good technical exposure along with applications that intrigue the students provides a sample of things to come.



(a) (b)

Fig. 2. (a) Original freshman orientation lecture–laboratory connections. (b) Orientation lecture–laboratory connection after TekBots revisions.

### B. Course Description

Two things changed in the introductory class with the introduction of the concept of the platform for learning: 1) the lecture material was altered to align carefully with the topics covered in the laboratory, and 2) a robot base was designed to accommodate the "layering" that would occur in successive courses. Fig. 2(a) and (b) illustrates the lecture and laboratory topics before the change and after the change, respectively. In both of these figure sections, the correspondence between the lecture material and laboratory material are shown with arrows. For example, in Fig. 2(a), early lectures in the term cover Ohm's law, Kirchoff's Laws, and other basic concepts. At the same time, the students start building their robots by constructing a Zener diode voltage regulator. This topic is covered much later in the term, making it difficult for the students to fully grasp the fundamental concepts. With the changes in the lecture and the corresponding robot platform, the lecture and laboratory topics carefully align. The experiments are carefully designed to reinforce what is being presented in the classroom. This level of integration is necessary in order to allow students to connect theory to practice.

A rugged robot base, shown in Fig. 3, was created [18]. The base includes the servomotors, batteries, whisker circuitry, motor circuitry, and an analog controller. Very careful thought was given when choosing the hardware elements [3], [5]–[8], [19]–[22]. It was particularly important to make wise choices that provide a good learning experience since the students will use the platform for multiple years.

### C. Laboratory Work

The laboratory portion of the freshman orientation course is composed of seven laboratories, each designed to reinforce some part of the lecture material. The laboratories begin by requiring construction and analysis of simple circuits and progressing into more complex and intriguing circuits. This approach makes even the most basic and mundane topics come to life since each experiment contributes to the final moving, exciting, and functional robot.

For example, in the second laboratory, students assemble the circuit shown in Fig. 4. By adjusting each potentiometer, the students can directly observe Kirchoff's voltage law (KVL) in two loops in a real circuit. Since adjusting the potentiometers causes the motors to change speeds, students are excited because they can make their robot turn and move around. While doing this, the students also make measurements of voltage and resistance, making the connection between what they see and what they measure.

Once the students understand KVL analytically and have used it experimentally, they are asked to apply it to perform a *sobriety test*. The students adjust the potentiometers so that their robot travels in a straight line as far as possible (hence, the *sobriety test*). The students must adjust the potentiometers so that the voltage across the motors is the same on both sides of the robot. Students set their robots on the ground to see how close they are to having the robot go perfectly straight. They quickly observe that over longer distances, the robot will tend to turn to one side. This discovery introduces them to real-world problems with nonideal systems. They are encouraged to try to add a small correction factor to their calculations and measurements to make the robot continue in a straight line.

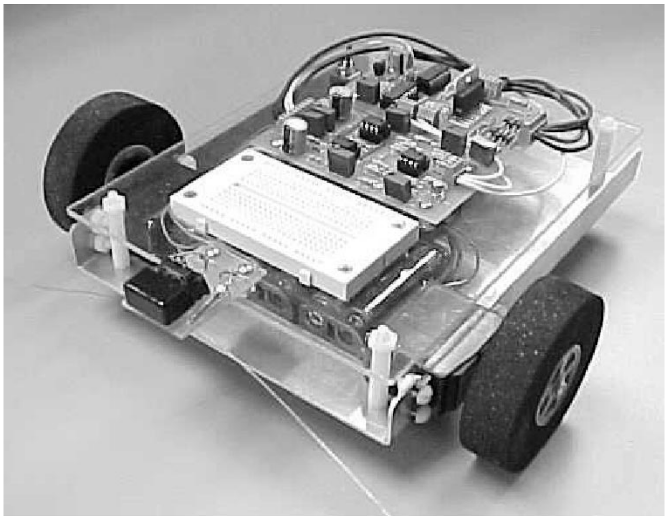


Fig. 3. Fully assembled freshman orientation TekBots robot.

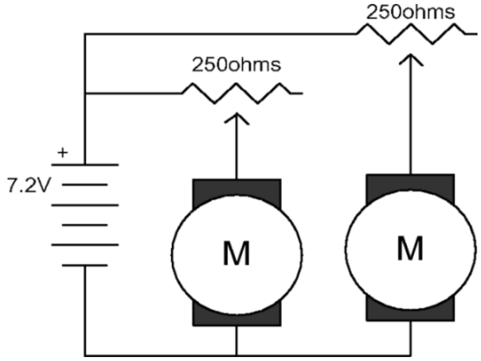


Fig. 4. Simple trimming circuit on the robot to introduce current and voltage relationships.

In later laboratories, students complete the assembly of their robot. Fig. 5 shows the top-level system description of the completed freshman analog robot. This simple robot functions by driving forward until it touches an object, then backing up, turning away, and resuming its forward motion. The system is divided into two separate printed circuit boards (PCBs). The analog controller board accepts the signal from the left and right switches and sends signals to the motor control board that operates the motors.

As the students assemble the parts of their TekBot, they develop basic assembly and verification skills. They are encouraged to construct the boards starting with the inputs and progressing toward the outputs so that they can verify that each part is working before continuing.

### D. System Details

The design of the circuitry on the TekBot is intended to illuminate many differing aspects of the freshman orientation course. For example, there is a ramp generator on the analog controller board shown in Fig. 6. When the robot bumps into an object, one of the two switches (right or left) closes, driving the gate of the field-effect transistor (FET) to $V+$. This action

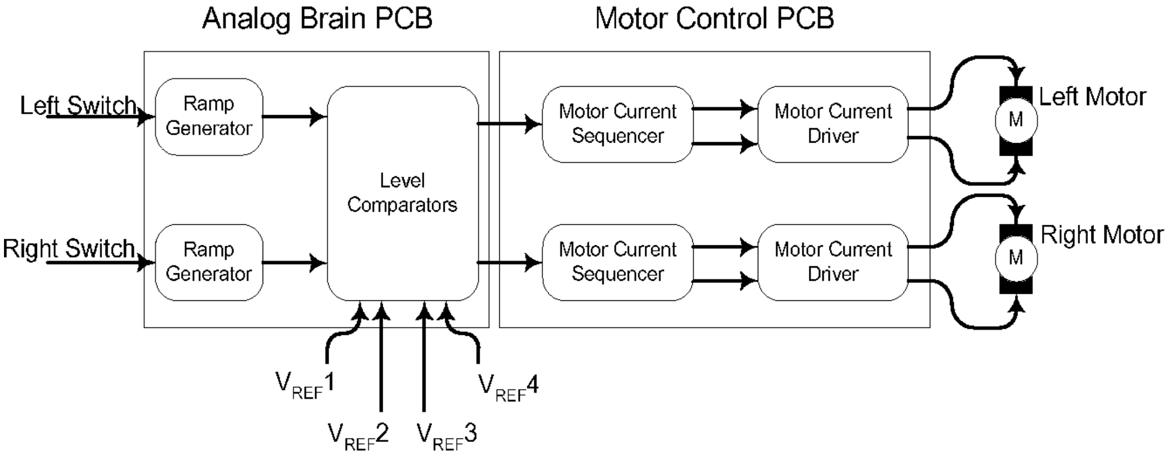


Fig. 5. Block diagram of the complete freshman orientation analog robot.

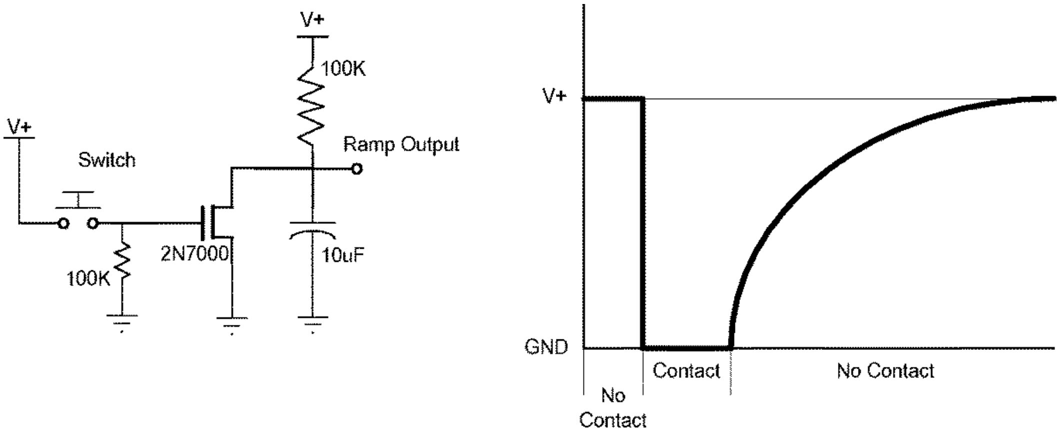


Fig. 6. Ramp generator circuit and timing diagram.

turns on the FET and discharges the capacitor, making the "Ramp Output" go to ground. Once the robot begins to reverse and the switch opens, the FET turns off, and the capacitor begins to charge through the resistor from V+. The charging curve of the capacitor is used to create the sequenced behavior of backing up, turning, and going forward.

This simple circuit with its 1-s time constant can be used to directly observe the magnitude and shape of a capacitor being charged through a resistance. Students can also observe metal–oxide–semiconductor field-effect transistor (MOSFET) behavior when it is used as a switch.

There is also a level comparator circuit, as shown in Fig. 7. It accepts the inputs from the ramp generators and controls the motors using the motor controller board. Each comparator has a reference voltage set by a potentiometer on one input with the other connected to a switch. These potentiometers set the references that control how long the TekBot backs up and turns. If one looks at the timing diagram when one of the switches in Fig. 7 is triggered, one can see that before the switch is triggered, both motors are driving in the forward direction. When the switch is triggered, the voltage drops below both $V_{REF1}$ and $V_{REF2}$, causing both motors to run in reverse. As the capacitor charges and the voltage exceeds $V_{REF1}$, one motor changes direction (to forward), while the other remains in reverse. This action causes the robot to turn. Then, once the voltage charges past $V_{REF2}$, the other motor changes direction (to forward), and the robot moves forward. This circuit lets the student see the basics of analog-to-digital conversion.

To illustrate simple digital logic to the students, a motor controller sequencer circuit is used to control the H-bridge attached to the motors. This circuit, shown in Fig. 8, is driven by the level comparator outputs on the analog controller board and prevents the H-bridge from short-circuiting when the motors change direction. This operation is accomplished by using delayed feedback between the two cross-coupled NOR gates shown in Fig. 8. For example, when the "Motor Direction" signal changes from ground to V+, "Path A" immediately switches OFF. Then, after the short delay (switching time) caused by the delay element, "Path B" switches to V+.

The motor current drivers control the direction of current flow through the motor controlling the direction of rotation. In Fig. 9, one sees that the motor current driver is composed of several transistors arranged in a classic "H-bridge" configuration. When Q1 and Q4 are turned ON, the current flows from left to right in the motor; however, if Q2 and Q3 are turned ON, it flows from right to left. This current flow can be seen also in Fig. 9.

While an integrated h-bridge can be used to control the various motors on the robot, the H-bridge is constructed from discreet transistors. This approach does not hide circuit elements from the student, but instead, allows them to probe

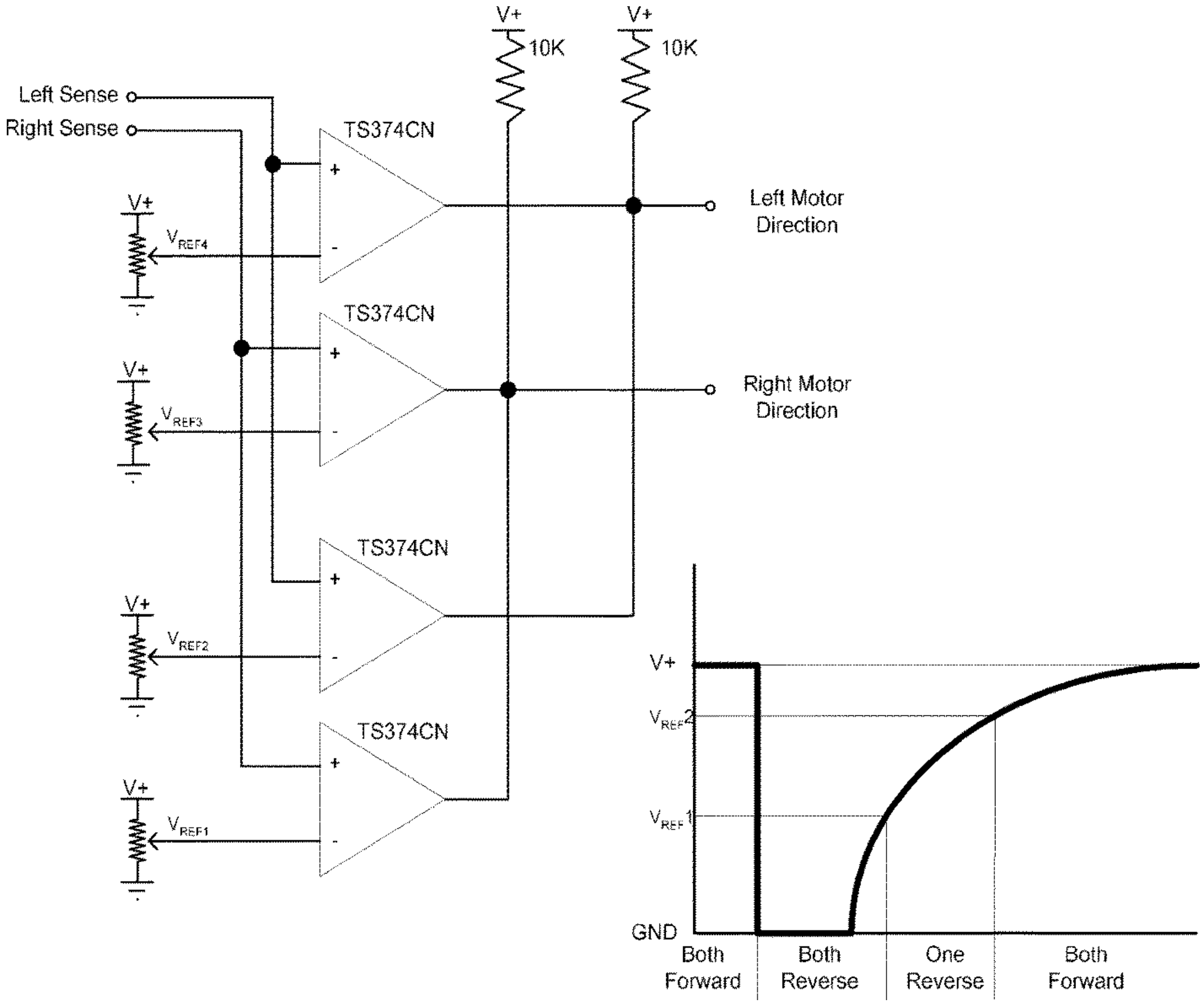


Fig. 7. Level comparator circuit and timing diagram.

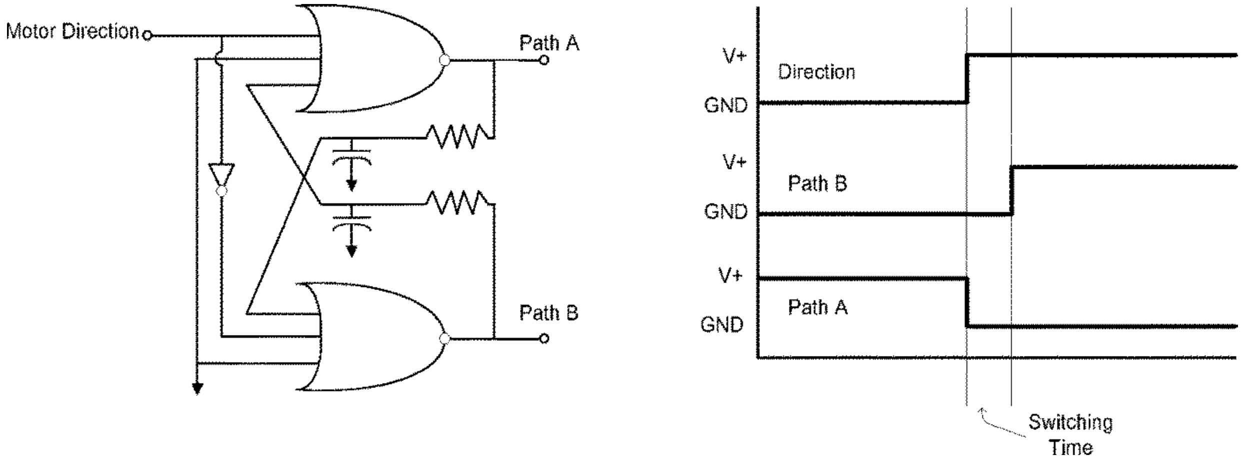


Fig. 8. Motor control sequencer circuit and timing diagram.

and examine the inner workings of the H-bridge. In addition, it gives the students access to these transistors and allows them to calculate beta and measure important attributes such as $V_{CE}$ and $V_{BE}$.

### *E. Challenges to Promote Innovation*

An important aspect of many of the laboratories is the challenge problems given at the end of the laboratory. These problems are designed to go well beyond what they have learned in

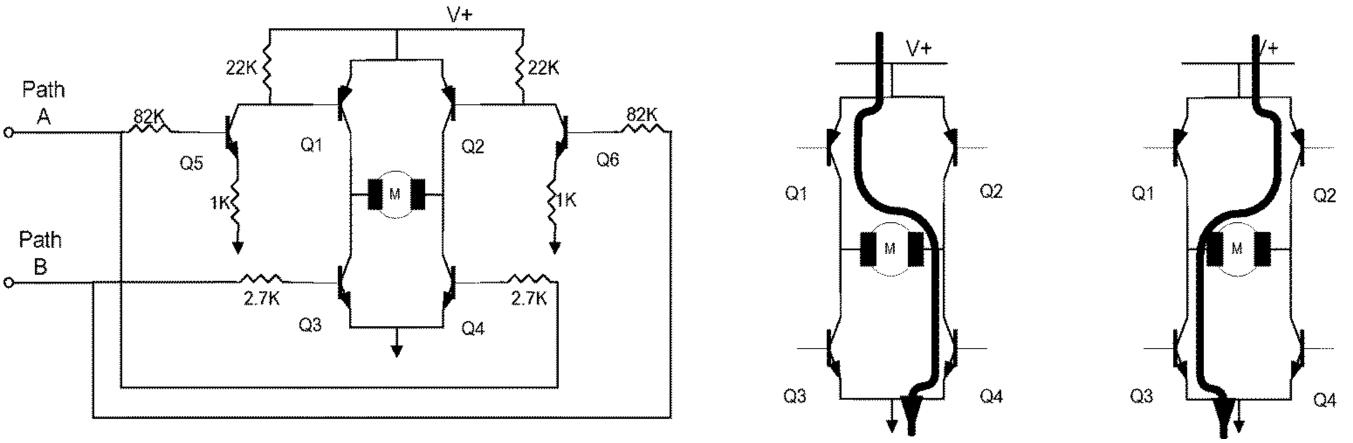


Fig. 9. Motor current driver subsystems and examples.

TABLE II
CHALLENGE PROBLEMS GIVEN TO THE STUDENTS TO ENHANCE INNOVATION IN FRESHMAN ORIENTATION COURSE

| Lab Title | Challenges |
|---|---|
| Robot Gymnastics | Speed and Accuracy Challenge: Set your TekBots robot to make as many laps as possible without straying from a defined circle in a minute. |
| Ohm's Law in Practice | Make a 'Resistor': Build a PWM from a 555 timer chip that models a resistor in series with your motors. Make a simple cruise control. |
| KVL: Friend or Foe? | Exploring Power: Explore why power consumption is important on cell phones, Martian rovers, and vacuums. |
| Working Together Works | All Powered Up: Explore the differences if any of various series/parallel circuits made from motors and batteries. |
| Transistors | Can you Feel the Noise: Build a simple amplifier and inspect the noise on your robot's motors. Find how to reduce this noise. |
| Go Towards the Light | Reverse Psychology: Can you make your light-loving robot scared of the light? |

the laboratory or lecture. They also provide a key strategy to encouraging innovation in the laboratory. A summary of the challenge problems by laboratory are given in Table II.

To understand how the challenge problems are integrated with the laboratory, one should consider the "KVL, Friend or Foe" laboratory. In this laboratory, students combine making measurements to verify KVL with a hill-climb test and power computation for their robots. This idea is extended when the students investigate the power consumption and component ratings for a device of their choice. Students must find an electrical device that they think is interesting, ranging from consumer devices to industrial and research devices. The students are then asked to explain its special power requirements and how to address them. This open-ended search encourages the students to continue, extending the knowledge they have gained.

To further encourage innovation, students are given a carefully chosen freshman-level design project as one of the laboratories. This project is a "photovore" design. Students design and build a simple robot that always moves toward the brightest light in its field of vision. The steps in the design process of identifying the problem, brainstorming solutions, examining resources, and implementing an electrical system are presented as part of this experience. The teaching assistants help to guide the student through this design project/process.

## IV. EXTENSION OF TEKBOTS

With the excitement generated with this first TekBots experience, the authors have extended the platform for learning to the freshman-/sophomore-level digital logic course. Prior to incorporating the TekBots platform, this class had good alignment between the laboratory and lecture. However, it lacked real application of the digital logic principles to real systems. As such, only minor revisions were required to incorporate the platform for learning.

### A. Digital Logic Hardware and Educational Experience

New hardware was developed to include digital concepts onto the TekBots. A complex logic device (cPLD) was chosen, in this case a Lattice Semiconductor mach4 series device. It was relatively inexpensive yet had a large number of product terms and

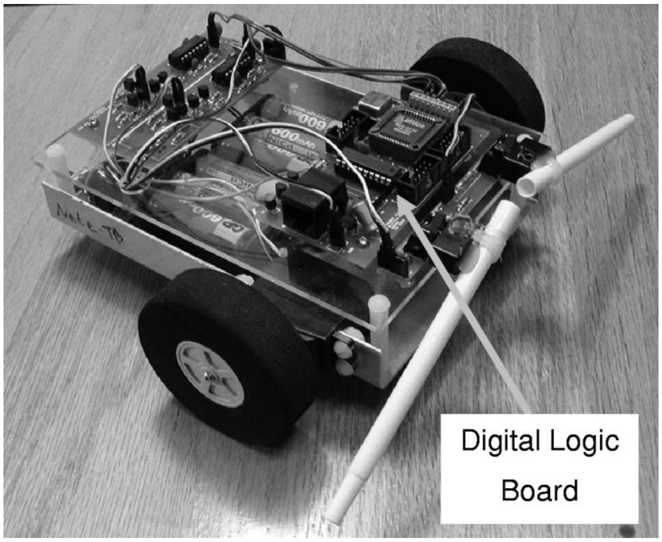


Fig. 10. TekBots platform used in the digital logic course.

a considerable number of input–output pins. To keep the hardware small for integration with the robot and yet keep it versatile with numerous inputs and outputs, two printed circuit boards were developed. The programming hardware and the cPLD are on one board with the input and output hardware on another connected by cables. The design had to use simple tools that were available and free to students, and the boards had to easily mount onto the TekBots platform.

The digital hardware has many different types of inputs and outputs to allow for a range of experimentation. Dual inline package (DIP)-style switches, momentary contact switches, discrete light-emitting diodes (LEDs), and a two-digit seven-segment display are incorporated onto the boards. The programming interface for the system is a simple Joint Test Access Group (JTAG) programming device connected via a parallel port to a host computer. Since one of the important features of TekBots is the reuse of previous course material, the digital logic board replaces the analog control board from the freshman orientation but keeps the remainder of the platform intact. Fig. 10 shows a picture of a robot from the digital logic course with the digital logic board attached on the front of the robot.

### *B. Laboratory Revisions*

The laboratory sequence was tightly tied to the learning in the lecture, as illustrated in Fig. 11. The digital logic course begins by introducing combinational logic for half of the course and then teaching sequential logic for the second half of the course. Each section starts with a *gate-level* introduction of the topic and builds from there. The laboratory follows this same flow and begins with a simple *Combinational Gates* laboratory followed by a *Sequential Gates* laboratory.

As the students learn more about the combinational logic aspect of digital systems, the laboratory difficulty is increased to include multiple levels of logic and dissection of real logic systems. For example, the students are shown a multiplexer gate-level logic schematic without telling them what it is and are asked to build the truth table for it. After the truth table is understood, the student is told that it is a multiplexer. This plan allows the student to see what's inside before they begin to use

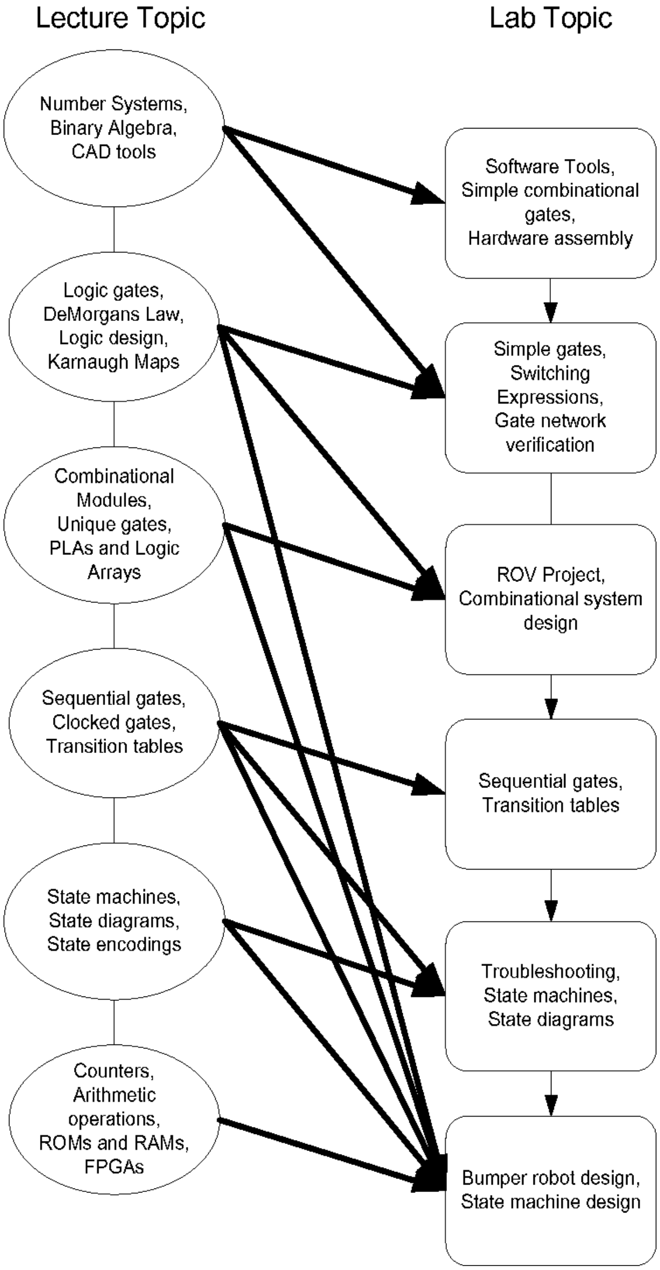


Fig. 11. Lecture–Laboratory connection in the beginning digital design course.

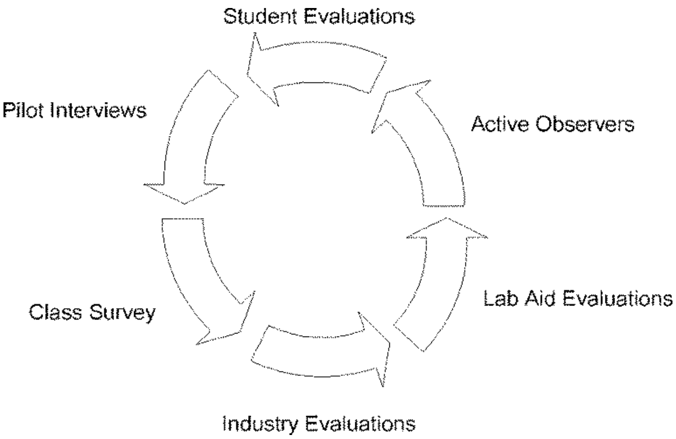


Fig. 12. Types of evaluations used to assess ECE272 revisions.

TABLE III
RESULTS FROM THE ECE272 SURVEY

| Subscales and scales | Pre survey score | Post survey score | Percent Change | Probability that measured quality changed from TekBots. |
|---|---|---|---|---|
| Mentoring | **10.5** /20 | **12.2** /20 | **15.9%** | **99.87%** |
| Leadership | **9.8** /20 | **11.4** /20 | **16.1%** | **98.72%** |
| Total Community | **20.3** /40 | **23.6** /40 | **16.0%** | **99.8%** |
| | | | | |
| Novel Ideas | **11.3** /20 | **10.5** /20 | **2.7%** | **94.57%** |
| Many Solutions | **10.5** /20 | **10.8** /20 | **1.5%** | **35.18%** |
| Technical Competence | **8.8** /20 | **10** /20 | **13.6%** | **84.66%** |
| Likes Problems | **9.8** /20 | **10.3** /20 | **5.1%** | **58.7%** |
| Valuable Answers | **8.7** /20 | **9.7** /20 | **11.4%** | **82.39%** |
| Total Innovation | **49.1** /100 | **51.3** /100 | **2.4%** | **50.49%** |

the multiplexer. Once the student understands the basics of logic design, a simple design project is introduced that allows the students to transform their TekBots into remotely operated vehicles (ROVs). This ROV is constructed from the TekBots robot, connected with a long tether to a remote control. The students are asked to design a system that takes inputs from the remote and translates them into movements for the robots. The students have significant latitude in what their final gate diagram is, but they must try to minimize the size of the logic.

As the students learn more about sequential systems, they learn to repair a broken-state machine. A simple vending machine design that dispenses a soda and gives change back at the same time is the chosen example. The students were given the program. They had to step through the machine's operation and draw the transition diagram. They then had to repair the logic. In the final project, students design a bumper robot. This robot functions identically to the analog robot that students constructed in the freshman orientation, but it uses the digital controller that replaced the analog controller.

## V. ASSESSMENT OF TEKBOTS

Fig. 12 shows the organized set of evaluations that were performed to gauge the impact of the TekBots integration into the curriculum. Since a single method could not completely measure all of the effects of the changes, this multifaceted approach was used. The evaluations included student surveys, student evaluations, laboratory assistant evaluations, industry surveys, active observers, and individual interviews.

Another method that was used to observe the student perspective was the evaluation of the teaching assistants (TAs). This evaluation was used to gauge the students' sense of how the teaching assistants contributed to building a community. Students were asked to measure the amount of mentoring that they received from their TAs and how it was given.

One of the most insightful evaluation methods used was a series of pilot interviews with students. An impartial observer was asked to randomly pick a representative sample of students and conducted short interviews with them. The transcripts of these interviews have been invaluable in revising the course work to its current form. Students gave frank and complete opinions about their experiences in the course work.

A large-scale survey was given to the digital logic class both at the beginning and end of the term. The survey was designed to measure whether innovation and community were enhanced with the platform for learning. A unique aspect of the digital design course is that there are both ECE students and computer science students enrolled in the class. The computer science students do not take the laboratory section of the course, allowing for this assessment to have a control group.

In Table III, the survey results are summarized. In relation to innovation, the authors wanted to explore whether TekBots helped in several different ways. Could the students come up with more novel ideas? Could they see many different solutions and feel that they were technically competent to complete them? Did the students enjoy problems, and did they feel they could make valuable answers? The survey contained several questions about each of these areas. The survey could not show that the change in most of these areas was a result of TekBots, except in the area of novel ideas. Here, there was a 94.5% probability that the improvement seen (from 11.3 to 10.5) was a result of TekBots.

Community was also surveyed by looking at two categories: whether students felt they were mentored and whether they felt they could mentor others. Under both of these categories, TekBots enhanced their experience. Mentoring had a 10% (2-point) improvement, while leadership had an 11% (2.2-point) improvement. To assess community, a larger score is "better" than a smaller score; with innovation, a smaller score is "better." Setting up the scoring this way helped to see whether students were just filling in the survey in a pattern or they were actually answering the questions truthfully.

## VI. CONCLUSION

The TekBots platform for learning helps to integrate concepts from one class to the next in the ECE curriculum at OSU. The integration of TekBots into two freshman/sophomore courses at OSU improved several important key attributes of the course, including innovation, community, troubleshooting, depth, breadth, and professionalism.

The five key concepts that contribute to the success of a platform for learning are personal ownership, contextual learning, curriculum continuity, fun, and active learning. Future work will focus on integrating the platform for learning into junior- and senior-level courses and exploring how this approach might be used in other engineering disciplines.

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