AC 2008-2360: UTILIZING ROBOTICS TO FACILITATE PROJECT-BASED LEARNING: A STUDENT PERSPECTIVE

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Utilizing Robotics to Facilitate Project-Based Learning: A Student Perspective

Abstract

This paper describes a freshman engineering curriculum that utilizes a robotics kit to facilitate hands-on learning. Student participants are required to purchase the robotics kit in lieu of textbooks. In the first of three courses, students implement simple circuits and write BASIC programs to accomplish tasks such as robot navigation and detecting light levels with photoresistors. In the second course, students use their newly acquired skills to implement a system that controls the temperature and salinity of a small volume of water. Through this project, students learn to implement more advanced circuits, including 555 timer circuits, transistor-relay circuits, and resistance temperature detector (RTD) circuits. In third course, students complete an open-ended design project where they conceive, fabricate, and test a working prototype of a "smart product." The paper describes each of these three freshman courses and provides assessment results and student perspectives on the new project-centered curriculum.

Introduction

In 1998, the College of Engineering and Science at Louisiana Tech University moved to an integrated engineering curriculum based on the educational practices of the National Science Foundation Educational Coalitions. Our freshman integrated curriculum includes differential calculus, chemistry, physics and several non-technical courses. Students take these courses in "blocks" so that classes of 40 students share the same mathematics, chemistry and engineering courses. The topics presented in the mathematics and science courses are coordinated to some degree with the topics presented in the engineering courses to motivate student learning and to provide some content overlap. The engineering courses are set up in a lecture / laboratory format and meet twice a week for 1 hour and 50 minutes. These three engineering courses add up to six semester hours and span the entire freshman year.

The "original" freshman engineering course sequence between 1998 and the spring of 2007 included engineering fundamentals (circuits, material balance and statics), computer applications (Excel, Mathcad and Solid Edge), statistics, engineering economics, teamwork, communication skills, and a design project. The students did most of their work in teams, including homework problems, laboratory activities and presentations. The freshman year culminated in a design competition between student teams.

In 2002, the College began to pilot a robotics-centered set of freshman courses that were much like the original engineering courses only with a much stronger project focus that was facilitated by the use of mobile robots. The goal of this new curriculum is to engage students in project-based, hands-on learning and to foster innovation by building a wide and varied body of latent knowledge and specialist skills to feed the creative process (as recommended by Cropley and Cropley[1]). The course comprises seven threads that run throughout the year, including systems, electromechanical, fabrication and acquisition, software, fundamentals, communication and broadening activities; broadening activities include working in teams, giving presentations on global and societal issues, attending professional society meetings, and applying creative problem solving techniques. The course objectives that support these threads are directly tied to the ten attributes of successful engineers as defined by The Engineer of 2020[2]; these ten attributes serve as a guide to help us determine curriculum content. The courses in 2002 were offered to a group of 21 student volunteers. The courses were repeated the following year for a group of 40 students, and beginning in the fall of 2004, the robotics-centered course sequence was adopted as the honors curriculum for two groups of 20 students each year. Funding from a phase II NSF CCLI grant allowed the curriculum to be extended to approximately 400 freshman engineering students beginning in the fall of 2008.

This paper was largely written by three undergraduate students who participated in the engineering course sequence as honors engineering students and provides their experiences and perspectives. The paper focuses on how the robotics kit was utilized differently in each of the three freshman engineering courses, first using the robot as a "kit" and later as a platform for laboratory projects and an open-ended design project.

The Robot Kit

The robotics-centered curriculum required that each student purchase their own Boe-Bot from Parallax, Inc.[3] (Figure 1) as well as a tool kit to facilitate project work. The "boe" in Boe-Bot stands for Board of Education, which is a detachable circuit board equipped with a BASIC Stamp II microprocessor, a 5 VDC voltage regulator, 16 digital input/output pins, and a small breadboard.

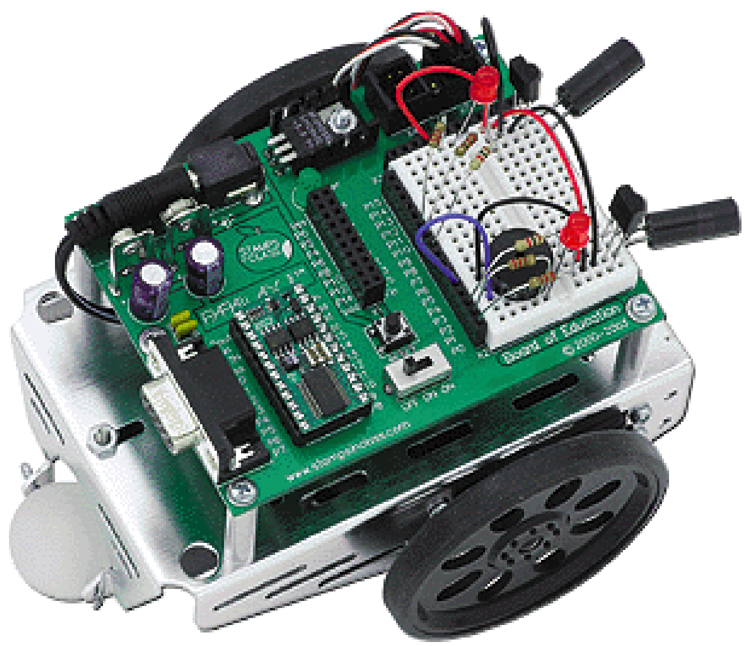


Figure 1 – A Boe-Bot outfitted with IR object detection, an LED and a piezobuzzer[3]

We chose the Boe-Bot because of its many features. First, it uses a modified version of the BASIC programming language called PBASIC, designed specifically for the Boe-Bot. Because PBASIC is simple, students with little or no previous programming experience can easily learn the language and quickly use it to instruct the Boe-Bot perform a variety of actions.

Second, the Boe-Bot kit comes with a variety of sensors and with two servo motors for locomotion. Metal whiskers, photoresistors, and infrared transmitter/receiver pairs are included with the kit along with resistors, capacitors, a piezobuzzer, LEDs, and jumper wires. A host of relatively inexpensive sensors and components that are compatible with the Boe-Bot can be purchased, including temperature, humidity, force, acceleration, color, and ultrasonic sensors. Other modules, such as RFID readers, RF communication modules, Bluetooth modules, and LCD displays are available and can be readily interfaced with the system.

Third, the kit is provided with a spiral-bound robotics "textbook" that contains directions for assembling, programming and attaching the circuit elements provided in the kit to the breadboard to create autonomous robot action. The course instructors use several of the activities in the robotics book as homework assignments to allow the students to independently implement and test various robot configurations.

Ultimately, the use of the kit allows instructors to supplement lecture-based course content with hands-on activities that can be performed inside and outside of class. Most importantly, the robot kit provides the hardware required for the projects that drive student learning of course skills and fundamentals and provide opportunities for written and oral communication and teamwork.

The Three Engineering Courses of the Freshman Curriculum

The new freshman curriculum is designed to introduce students to engineering concepts using robotics and hands-on learning. Students start with structured assignments and slowly transition to problems with multiple solutions and open-ended design projects. The curriculum is broken down into three different courses over the span of one year. In the first course, students are introduced to many of the fundamentals and tools they will be using for the rest of the year; assignments and projects are rigidly structured. In the second course, activities are more complex and require more effort. This course is defined by a major project that is made up of several smaller projects. In the final course students develop ideas for their own "smart product." Students design their products from top to bottom often with unfamiliar sensors, with supplies that they purchase themselves, and with nothing but advice from their professors.

Engineering Course #1 (Fall Quarter)

In the first course, students learn the fundamentals of robotics along with selected engineering topics. To introduce students to the concept of building a circuit, simple LED / resistor circuits are implemented on the breadboard of the Boe-Bot. Students quickly learn to write short PBASIC programs causing their LEDs to blink on and off, and they learn to measure current and voltage using a multimeter. To make their Boe-Bots move, students write programs to control the duration and direction of servo motor rotation (and wheel rotation).

Students then program their Boe-Bots to perform more complex tasks. One project three weeks into the first course involves programming a Boe-Bot to leave from a set starting position, circle an object, and return to the starting position. The students use subroutines to accomplish this task, thus applying a new programming technique.

Next, students are introduced to sensory input and learn to use these inputs to control the behavior of their robots. Students implement a whisker circuit that allows their Boe-Bot to detect obstacles by touch, and they use the information retrieved from the whiskers to direct their Boe-Bot around obstacles.

The final Boe-Bot project of the first course is the line following project. Here, students use a single photoresistor input to help their Boe-Bot to follow a curved black line on a white surface. Students are required to develop their own line-following algorithm, thus providing a challenging problem to strengthen their programming skills. Extension leads are soldered onto the photoresistor leads so the photoresistors can be placed just above the tape to better recognize "light" and "dark." The photoresistor project is implemented using a voltage divider circuit as well as an RC circuit, providing an opportunity to learn about capacitors and variable resistance. Students independently learn about the photosensitive semiconducting material, cadmium sulfide.

Engineering Course #2 (Winter Quarter)

The second course involves fabrication and testing of a system to control the salinity and temperature of small volume of water called the "fishtank," as shown in Figure 2. Students build and calibrate their own salinity and temperature sensors, implement several transistor/relay switching circuits, and interface this hardware with the Boe-Bot. Smaller projects build toward the larger "fishtank" project and effectively introduce students to the various engineering disciplines.

The salinity sensor is fabricated by pressing 316 stainless steel probes into an ultra high molecular weight polyethylene flow cylinder that has been center-drilled, faced and beveled on a lathe. On the first few days of class, students learn about salt-water chemistry which reinforces the content presented in their general chemistry courses. The two conductivity sensor probes are wired to the BASIC Stamp through a 555-timer circuit which is controlled by an RC circuit. The timer circuit produces alternating current across the probes of the conductivity sensor to reduce the undesirable effects of concentration gradients at the electrodes. Salinity is "measured" by counting the number of HIGH-LOW cycles experienced at an input pin on the BASIC Stamp due to the frequency of current oscillation which depends on the electrical resistance of the water (the "R" in the RC circuit).

The next assignment is the construction of the fishtank container which is actually a 3-inch long segment of 1.5 inch diameter schedule 40 PVC pipe closed off with an end cap. Students attach barbed fittings and tubing between the tank, the salinity sensor, and a small pump. They then calibrate their conductivity sensor by circulating water with known salt concentrations through their flow loops and performing regression analysis.

Figure 2 - A group proudly shows their fishtank project

The fishtank container is mounted to a wooden platform along with two elevated tanks, one with salty water and one with fresh water. The flow of salty water and fresh water into the fishtank container is regulated by two solenoid valves attached to the platform. Students open and close each of these solenoid valves using a cascaded switching arrangement consisting of a transistor and a SPST (single pole single throw) relay. An extra breadboard is mounted to the wooden platform to provide space for these switching circuits. Fabrication of the wooden platform and other system components provide students with significant hands-on fabrication experience.

The temperature of the tank is measured using a resistance temperature detector (RTD) that the students design and fabricate themselves, as shown in Figure 3. Students learn how the resistivity of a material is related to its resistance, cross-sectional area and length. They then design a nickel resistor pattern by computing the width and length of the nickel film that forms the RTD. Students draw the mask for the photolithography process using Solid Edge, apply a photoresist to a nickel coated substrate, expose the photoresist to UV light through their mask, develop the photoresist, and etch away the unwanted nickel film to produce their RTD. They then calibrate the RTD by immersing the sensor in water baths at different temperatures and apply regression analysis in Microsoft Excel to relate the discharge time of an RC circuit to the temperature (the BASIC Stamp can measure the time it takes an input pin to change state from HIGH to LOW using the RCTIME PBASIC command). The temperature is controlled by reading the temperature and switching an 18-ohm insulated resistor (heater) that is powered by a 12 VDC wall adapter.

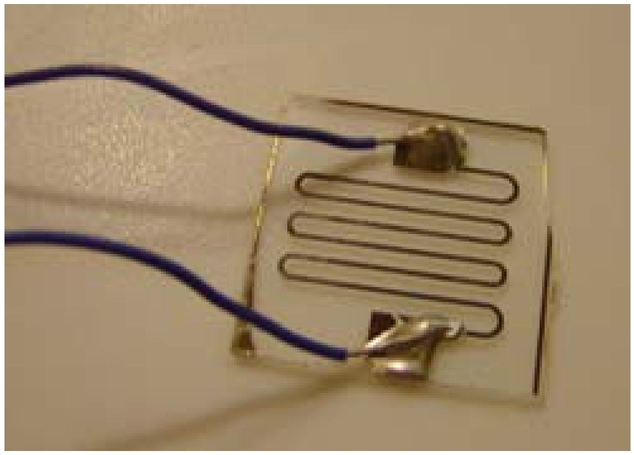


Figure 3 – Temperature sensor

The real difficulty lies in integrating all of the aforementioned systems. Students write one PBASIC program that monitors and controls all of the systems. Unlike most first-quarter assignments, students are not mimicking prewritten programs or circuits from the book. Instead, they face the difficult task of creating their own monitoring and control program and configuring their own hardware design. In the end, we feel that though this approach is more difficult, it is more rewarding when the project is complete, building student skills and confidence.

Engineering Course #3 (Spring Quarter)

The third course focuses on the development of a "smart product" and introduces students to creative problem solving techniques, force analysis and engineering economics. Throughout the first half of the course, individual students develop a "bug list" of potential design problems to address. Near the middle of the quarter, students form groups, compile their "bug lists," and focus on developing a smart product to address their "bug" of choice. The goal for the course is for student teams to design and fabricate a functioning prototype of their product.

To further open the possibilities of projects that can be attempted, an "unfamiliar" sensor is introduced almost every class period over the first three weeks of the course. Sensors covered in class include an RFID sensor, an ultrasonic sensor, an RF transmitter/receiver pair, an accelerometer, and a GPS sensor. Students are required to independently learn about other sensors as part of their homework assignments (using the Internet). Student exposure to a large number of sensors and devices provides them with the knowledge to consider a wider range of design problems.

The lecture topics in the first half of the course center on statics (force and moment analysis). To supplement these lectures, students take apart their servo gearboxes to count the number of teeth and measure the diameter the individual gears. Using this information along with the measured RPM of the output shaft, they estimate the input torque of the high RPM DC motor that drives the servos. They apply conservation of energy to compute the efficiency of the servos based on the speed of a weight as it is lifted and the current and voltage supplied to the DC motors on the servos.

Halfway through the class, the focus shifts almost completely to the product design project. Students learn about brainstorming techniques and creative thinking strategies. Small groups of students pool their bug lists to select a design objective. Students are introduced to the IDEO design process[4] which emphasizes prototyping early and often. They begin with a simple prototype (foam board – duct tape) to demonstrate the form and function of the device they wish to create. They then present their prototypes to the class, and afterwards, the professor and students critique the presentation, ask questions, and provide feedback. Once the professor has approved the project, work on the second prototype can begin.

The selection of the design product usually governs what sensors, actuators and/or output devices will be required for the project. Students can "check out" sensors from the course instructor to utilize in their projects. These sensors may or may not be the sensors discussed in class. Learning to use sensors not explicitly taught in class requires self-directed learning. Using the skills acquired throughout the year, students begin to configure their sensors, actuators and programs to accomplish their design objectives. Students locate and purchase their own supplies. Some class time is dedicated to shop work, providing the instructor time to interact with design teams.

After completing their final prototype, students prepare a PowerPoint presentation that includes a detailed cost analysis, specifications for their product, segments of the program code, and the fabrication steps. They must also demonstrate the functionality of their prototype. Examples of previous student projects are listed in Figure 4.While some project ideas are sometimes a little wacky, some are potentially patentable. Project presentation day can be very entertaining. In the spring of 2008 students will participate in a freshman design conference where they will present their work to a panel of judges.

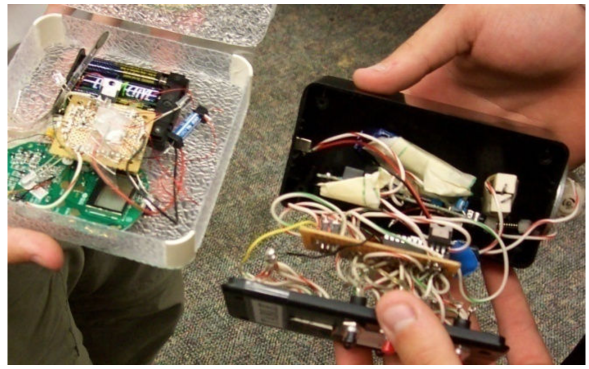
Assessment

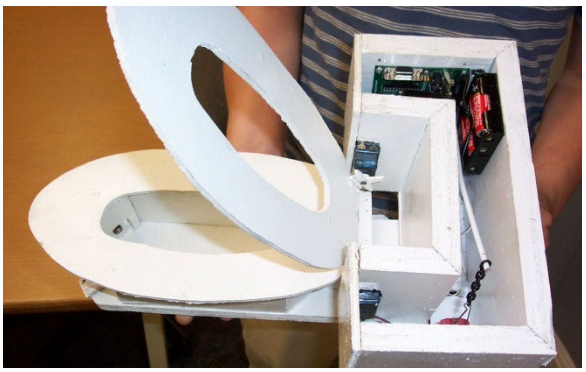
An assessment survey was administered to students at the end of each quarter to understand the influence of the curriculum on their learning. The course survey was developed with the help of an external assessment expert for our NSF CCLI grant.[5] Surveys were administered to 182 students in the spring of 2007. Students were asked to rate their confidence and frequency of use of selected course topics. Courses one, two, and three of the non-robotics curriculum were assessed and compared to course three of the honors curriculum that used the Boe-Bot.

Out of 16 common course outcomes, students in the Boe-Bot curriculum rated their confidence levels higher in all but three areas. Out of 24 electrical components and sensors, students in the new curriculum rated their confidence significantly higher in all but two elements. It is important to note, however, that honors curriculum students may rate their confidence higher than regular curriculum students.

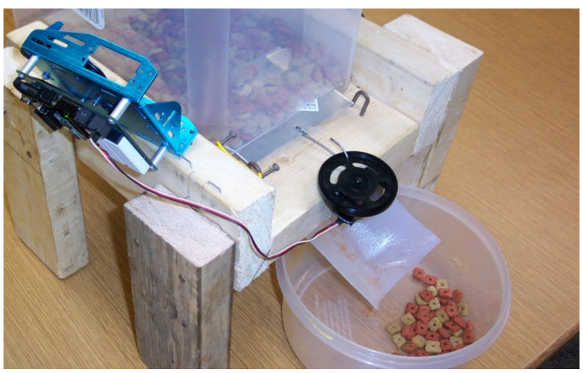
While confidence levels may not be the best indicator at this time, our assessment also includes frequency of use. The students in the new curriculum rated their frequency of performance in hands-on activities three to four points higher than regular curriculum students. Those in the new curriculum also rated frequency of use of over 24 different circuitry components. In general, they rated their usage phenomenally higher than those in the old curriculum. Lastly, students in the new curriculum stated that they performed hands-on activities many more times than those in the old curriculum as depicted in Table 1. Here, ENGR 120, 121 and 122 are the first, second and third courses in the non-robotics curriculum (the curriculum that has been phased out). The ENGR 122H course is composed of honors students taking the robotics-based curriculum.

RF coasters - transmits a message to waiter to fill drink

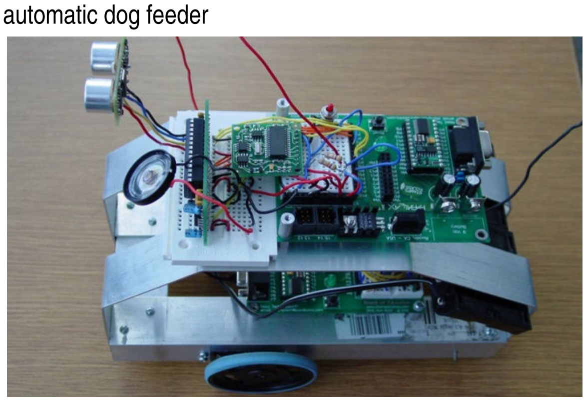

inside view of RF coasters


smart toilet – a way to stay clean in the restroom


remote controlled duck


automatic dog feeder


poker chip sorter – uses color sensor


seeing eye bot – uses ultrasonic distance sensor


musical relaxation fountain

Figure 4 – Example projects from the third freshman course

Table 1 - Average number of times activity was performed in the academic year per person

Item	ENGR 120	ENGR 121	ENGR 122	ENGR 122H
Assembly	2.15	.55	3.10	11.19
Drilling	1.81	.55	4.29	13.14
Implementing circuits on a breadboard	.04	.49	.62	21.73
Soldering	.14	.05	2.17	13.83
Using a multimeter	.26	.33	2.28	3.55
Writing PBASIC programs	.00	.05	.02	20.23

Student Perspectives

Students were randomly selected from the old curriculum and the new curriculum to discuss what they did and did not like. The opinions gathered give a good representation of how students felt about the curriculum.

One of the complaints that students had about the old curriculum was that the subject matter did not carry over across courses. The new curriculum addresses this using a threaded approach where each of the seven threads (systems, electromechanical, fabrication and acquisition, software, fundamentals, communication and broadening activities) span the entire year. For example, the Boe-Bot and basic circuits content is heavily used in all three courses. Students use many of the same hardware and software tools over and over during the year (multimeter, pliers, drilling/milling machines, soldering irons, dial calipers, Solid Edge, Mathcad, Excel, etc.). This threaded approach systematically improves skills and increases retention.

Another complaint from students in the old curriculum was that they felt as if they did not apply anything learned in class to the design projects. The new project-based approach was implemented to address this very issue. When one student was asked what he liked about the new curriculum, he said the he liked the hands on activities and how often he applied class concepts to the Boe-Bot projects. Another student felt he gained valuable troubleshooting skills. Another believed that the Boe-Bot helped him apply engineering principles to real problems. Students also enjoyed their freedom in design and liked being able to develop their own ideas.

Some students still have a few concerns about the curriculum. One student felt worried that the curriculum would not prepare him for future engineering courses. He felt that the focus on the Boe-Bot rather than book material may make it more challenging to move on to courses with no hands-on activities. Another student felt that he learned better from books rather than hands-on activities. The new curriculum requires an understanding of the material in order to apply the concepts to projects. Some students may find it difficult to adjust this new style of learning, but early results have indicated it may be more beneficial.

As the first three authors of this paper, we feel that we have a unique perspective to share on the curriculum. Two of us have already completed the curriculum, while the third is currently a participant.

Student 1

I am a sophomore student at the University. I loved using the Boe-Bot because it gave me a way to put theoretical engineering concepts into action in the physical world. I still use it today, even though it is not a part of any of my classes. While the activities involving the Boe-Bot were very time consuming and demanding, they were also very rewarding (much more rewarding than solving an equation in a textbook and doing nothing with it). I personally believe that I will never forget the concepts I learned in the freshman engineering courses.

Student 2

I too am a sophomore student. At first, I was apprehensive about the hands-on activities because I didn't think I had the practical problem solving skills necessary to succeed. However, the projects were easy enough at the beginning to help me gain the skills necessary to do more and more complex activities. I really enjoyed being able to apply my programming skills to make the Boe-Bot do what I wanted it to do. I think one of the best things about the freshman curriculum is how well the information and problem solving skills have stayed with me.

Student 3

Early in my high school career, I decided I would pursue biomedical engineering and enrolled in high school courses that would prepare me for a curriculum focused on math and science. I assumed that my university schedule would be filled with lectures focused only on theoretical approaches. The engineering curriculum at our university is quite the contrary. Though the curriculum has elements such as programming and three dimensional design that were unfamiliar to me, I feel that I have been successful so far because of the user-friendly hardware and software used in the courses. The new curriculum bridges theory and reality. As I continue on, I am learning and applying new skills and knowledge that I believe will be beneficial to me as I graduate and enter industry.

Conclusions

The freshman engineering curriculum at Louisiana Tech University is a robotics-centered curriculum that spans three two-semester hour courses. The courses utilize the Parallax Boe-Bot and begin by using the robot as a "kit" along with the included textbook. However, as the year progresses, students move away from the "kit" approach and begin to use the Board of Education with the Basic Stamp II microcontroller as a platform for more sophisticated measurement, control and design projects. The course content is sequenced in a way to progressively build the skills, knowledge and confidence required to complete meaningful freshman projects. The student authors of this paper feel that the use of robotics helped us develop good problem solving skills, improved our retention of the subject matter, and greatly piqued our confidence in the course material. Early assessment results indicate that the majority of other students in the curriculum feel the same way.

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