Experiential-Based Curriculum to Increase Retention and Graduation

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Abstract
Two things have combined to encourage a significant change in the engineering curricula at Purdue Calumet: (1) a desire to improve student retention and graduation rates, and (2) a faculty based decision to require that all PUC graduates have at least two experiential-based courses, and the availability of small grants to support this development.

This resulted in a funded proposal to introduce experiential education into the first-semester ENGR 190- Elementary Engineering Design course. The intention is to increase the hands-on component and the excitement level of the course to help retention and learning. In addition, this will provide a basis to build on for upper-level courses using the same hardware and software.

An Experiential Education Design and Development Award was received, and LEGO Mindstorms NXT robotic education kits have been purchased for use in ENGR 190 starting fall 2007. The students were introduced to the robots in the electrical part of ENGR 190, where they are exposed to team-based, hands-on experiential learning and project-oriented activities. These will provide a basis for more-advanced projects and will allow the Engineering departments to modify the curriculum to extend experiential learning using the robotic kits to upper-level courses. This paper presents some of the lab experiments that were introduced to start using the LEGO robotic kits in the freshmen class.

A set of lab experiments were added in ENGR 190 to allow students to learn and understand the fundamental concepts used in the Electrical and Computer Engineering programs. First the students are introduced to the basic concepts of dc resistive circuits. Then the resistor color code is explained and the breadboard used to construct simple resistive circuits. The students learn to do resistance and voltage measurements using the lab equipment and instrumentation. Then, the students are required to make a comparison between the experimental results and the theoretical solutions obtained by hand calculation. The next step is a brief introduction to simulation tools for electric circuits with software such as PSpice. The students finish with the comparison between measured, calculated and simulated resistances, voltages, and currents by using simple lab reports.

When the students have received enough circuit construction and instruction, simple lab experiments are added to help understand the construction and the use of sensor input circuits associated with the LEGO robotic kit light, sound, touch, rotation, and ultrasonic sensors. Another set of applications are related finally to the output ports of the NXT robots using their dc motors and simple loads such as lamps, LED’s and relays. All the applications are intended to develop in parallel the students programming skills using the NXT-G graphical environment provided with the Lego robotic kit.

Key Words
Interdisciplinary Approaches, ABET Accreditation, Diversity Retention Programs, Education Methods, Engineering Curricula, Freshman Engineering Programs, Innovative Teaching Methods
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Introduction

Two things have combined to encourage a significant change in the engineering curricula at Purdue University Calumet (PUC): (1) a desire to improve student retention and graduation rates, and (2) a faculty-based decision to require that all PUC graduates have at least two experiential-based courses, and the availability of small grants to support appropriate course development.

This resulted in a funded proposal to introduce experiential education into the first-semester ENGR 190-Elementary Engineering Design course-taken by all incoming engineering freshman. The award was used to purchase LEGO Mindstorms NXT robotic education kits in the summer of 2007, and to initially introduce their use in fall 2007. The students were introduced to the robots in the electrical part of ENGR 190, and they were exposed to team-based (groups of two-three students), hands-on experiential learning and project-oriented activities. The intention is to increase the hands-on component and the excitement level of the course to help retention and learning. In addition, this will provide a basis to extend experiential learning using the robots to upper-level courses.

This paper presents the proposed lab experiments and project activities that were introduced to redesign the Electrical Engineering (EE) component of ENGR 190 in fall 2007, and the feedback obtained.

Elementary Engineering Design Course Objectives

This course has a one-hour lecture and a three-hour lab each week. In the first half of the semester students learn the basic ME concepts, and design, build, and test a bridge. In the second half of the semester the students are introduced to the EE fundamentals, and complete a design using the LEGO Mindstorms NXT robotic kit. This paper presents the EE component of the course.

The first objective is learning to solve simple EE problems. In the first two lectures, and first two labs, the students are introduced to the basic concepts of dc circuit analysis, the resistor color code, and the use of the breadboard to construct simple resistive circuits. The students perform
resistance and voltage measurements using the lab equipment and instrumentation (dc power supply and multimeter). Then, they are asked to compare the experimental results and the theoretical solutions obtained by hand calculation, and to report their comments. The next step consists of a brief introduction to simulation tools for electric circuits using PSpice. Finally, the students compare the measured, calculated and simulated resistances, voltages, and currents.

The second objective is to introduce students to the resistive-capacitive (RC) and timing circuit analysis and design. A lab experiment is dedicated to using the function generator, the oscilloscope, and analyzing and visualizing the charging and discharging process of a capacitor through a series-connected resistor. An assignment is given to the design of the external timing circuit of a configuration using the 555 timer which operates as a square wave form generator with an imposed frequency and duty cycle of the output clock signal.

A third objective is the introduction of the binary number system, the construction of the truth tables for small scale design problems, and the implementation of simple logic functions using the basic AND, OR, and NOT gates. The students study in the lab the BCD decimal decoder, the seven segment display, and complete a small design of the combinational logic circuit of a beverage vending machine.

When the students have received enough circuit construction and instruction, the newly created set of lab experiments is introduced using LEGO Mindstorms NXT robots. The intention is to allow students to apply the newly-learned fundamental concepts in a practical and attractive way, knowing that the analytical techniques used in classical lectures are not very convincing or exciting to freshman.

A first set of lab experiments help students to understand the functionality and the use of the NXT sensors provided with the LEGO robotic kit. A second set of experiments are applications related to the output ports of the NXT robots allowing students to command the dc motors and other small power loads such as relays, or light-emitting diodes (LED's). All the applications were intended to develop in parallel the students programming skills using easily the NXT-G graphical environment of the LEGO robotic kit. The students finally build their own original project, where they are asked to program and to use as much as possible the set of available sensors and output ports of the NXT robots.

**Lab Experiments using the NXT Input Sensors and Output Ports**

There are four input ports on the bottom of the NXT brick, so that the external Touch, Sound, Light, and Ultrasonic Sensors can be connected and used to explore the robot's surrounding environment. In addition, the students learn to enhance their projects by making use of the four internal sensors (NXT Buttons Sensor, Rotation Sensor, Timer Sensor, and Received Message Sensor) contained in the Mindstorms NXT kit.

In the following, the experiments are briefly presented and then, the first one is described in more details to demonstrate the coverage of the learning objectives.
Lab Experiment 1: The Ohmmeter

The experiment consists of two parts: (a) breadboard and modified NXT connector cables used for the hardware construction, and (b) NXT-G program design to create a simple ohmmeter using the NXT-G programming. The ohmmeter, based on the NXT-G software, determines the values of unknown input resistances for resistive sensors such as thermistors, photocells, and potentiometers.

Lab Experiment 2: Angular Displacement Sensor

The experiment consists of two parts: (a) hardware construction on the breadboard, where a rotational slide potentiometer is inserted and connected to an NXT analog input. Changing the center tap position of the potentiometer, different variable angles will determine different Raw values, and (b) NXT-G program design, to create a protractor that reads the potentiometer angle and displays it on the screen.

Lab Experiment 3: Design of a -5 V to +5 V Voltmeter

The experiment consists of two parts: (a) hardware construction on the breadboard, where an external voltage source to be measured is connected to an NXT analog input by means of an external resistor, and converted to a Raw value, and (b) NXT-G program design, to create a voltmeter that reads the Raw values, converts them into voltages and displays them on the screen.

Lab Experiment 4: Flip-Flop Control

The experiment consists of two parts: (a) hardware construction on the breadboard, where two LEDs and one resistor are connected to one of the NXT output ports, and (b) an NXT-G program design, that will change repeatedly the sign of the output port voltage and will generate a periodic square wave with a programmable duty cycle.

Lab Experiment 5: DC Motors Control

The experiment consists of an NXT-G program design that is useful to be implemented in many projects where a direct adjustment of the level of the dc motors speed and the rotational direction is required. This is done by controlling the voltage level and polarity on any of the three NXT available output ports.

Lab Experiment 6: Relays Control by Doubling NXT Outputs

The goal is to control the voltage polarity, and thus the rotational direction of a dc motor requiring more power than the NXT output can provide. This is accomplished with two relays controlled by a single NXT output.
Lab Experiment 7: Sensor Data Logging Program

The experimental measured data, during the NXT labs, are collected using the sensor inputs. The NXT-G programming environment provides a block that can be used to save the data in a file. The block is called FILE ACCESS, and the created file is stored in the NXT Brick's memory. Some examples of using files to store data can be the number of motor rotations read by the rotation sensor, light levels read by light sensor, sound levels input by the sound sensor, or temperatures read by the temperature sensors. The proposed lab experiment is using the NXT ultrasonic sensor which detects the distance to a target obstacle during the robot's motion in forward direction. The sensor's measured data are sampled and stored in a file in order for later use to reconstruct the distance covered to the target.

Lab Experiment 8: NXT to NXT Bluetooth Remote Control

One of the most exciting experiments is using the Bluetooth (new added feature to NXT version of Mindstorms kit). The goal is to have one of the NXT robots (the master) running a program that sends commands (messages) to a second NXT robot (the slave), in this way determining a wireless communication. The second NXT robot is a remotely guided vehicle that runs a program to receive the messages sent by the first NXT robot and to execute some actions.

Sample Lab Experiment 1: The Ohmmeter

The touch sensor is the simplest sensor provided with the LEGO robotic kit, and we have used it to apply the basic concept of a switch in electrical circuits. The students are told that many automated electrical controls are done with switches that change state (on-off) with temperature, position, liquid level, pressure, humidity, etc. They learn now how a switch can be used as a simple model of the logic OR, AND operations. For example, a NXT robot is used as a vehicle with bumper switches (touch sensors) mounted on two sides (Figure 1), and touching anyone of the bumpers determines the same avoidance reaction. For the lab experiments with NXT bricks, because multiple switches cannot be plugged in the same input, this connection was done with modified NXT connector cables.

![Figure 1. "OR" logic operation with parallel touch sensors connected on one NXT input](image1)

![Figure 2. Touch sensor connected as a switch on one NXT input](image2)
The students learned that when using a switch the analog NXT input has two extremes, 0V or 5V. They do this simple analysis based on the schematic shown in Figure 2, where the pin 1 is permanently connected to +5V through a 10kΩ resistor. When the switch opens (off) the 10kΩ resistor provides the value of +5V (or logic "1" reading) to the sensor input circuitry. When the switch closes (on) it connects the analog input to ground, that is the zero volt level, and the sensor input circuitry detects a logic "0" reading.

In the next step, the students found that the input signal can range from 0V to 5V when using an analog sensor connected to the NXT's pins 1 and 2. Remember that this is a freshman class and there is no way entering in details about the operation of an analog-to-digital converter (ADC shown in Figure 2). Instead, it is a good opportunity to use a little binary numbers background, and to explain that the signal is now translated by the ADC into so called raw value, which is a digital value between 0, corresponding to 0V, and 1023 (that is $2^{10} - 1$) corresponding to 5V.

Figure 3 shows a resistive sensor (i.e. a photocell element, or a thermistor) represented by the resistor $R_2$ which is connected between the same pins 1 and 2.

In this case, the external sensor provides a variable resistance, $R_2$ that is now in series with the existent 10kΩ resistor, $R_1$. The students are introduced to a practical application of another basic concept which is the voltage divider formed by the two resistors $R_1$ and $R_2$.

Referring to the NXT example shown in Figure 3, the output voltage provided by the sensor, at the analog input pin 1, can be determined as:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_s = \frac{R_2}{10,000 + R_2} (5V),$$

where $R_1 = 10k\Omega$, and $V_s = 5V$.

The students check the output voltage equation (1) by using the basic Ohm's law for the resistor $R_2$, and applying Kirchhoff's voltage law on the closed circuit loop formed by the dc voltage source (5V), and the series resistors $R_1$ and $R_2$. The NXT's analog-to-digital converter (ADC) scales this voltage to what are called Raw units.
Thus,

\[
\text{Raw} = \frac{1023}{5} V_{\text{out}} = \frac{1023R_2}{10,000 + R_2}.
\]  \quad (2)

The lab experiment consists in designing and implementing an ohmmeter, and there are two parts:
(a) The hardware part construction, using the breadboard, and
(b) The NXT-G program to design and create a simple ohmmeter using the graphical NXT-G programming environment provided by the LEGO Mindstorms NXT kit.\(^1\,^2\)

The designed ohmmeter determines and displays the value of an unknown input resistance provided by different resistive sensors such as thermistors, photocells, and potentiometers. The voltage divider series circuit (Figure 3) is build by simply connecting the external resistor, \(R_2\), to the NXT analog input. The resistor \(R_2\) is chosen to be a standard (carbon film) resistor, a thermistor, and a photocell, all provided with the existent lab resistor box. For each of the above three resistors the voltage drop \(V_{\text{out}}\) is measured on the breadboard using the multimeter, and the values are recorded in the second column of the Table 1 below.

| Table 1. |
|-----------|---------------------------------|-----------------|-----------------|-----------------|
| Resistive sensor | Measured \(V_{\text{out}}\) (volts) | Calculated resistance \(R_2\) (ohms) | Calculated \text{Raw} value | Displayed \text{Raw} value |
| Carbon film resistor | | | | |
| Photocell | | | | |
| Thermistor | | | | |

The voltage division equation (1) is used to calculate the resistance value \(R_2\), and then, the values are recorded in the third column of the Table 1. The corresponding \text{Raw values} are calculated using the equation (2), and then recorded in the fourth column of the table. The fifth column of the Table 1 is completed in the part (b) of this experiment which is presented next.

An NXT-G program is finally created to calculate and display the value of the resistance \(R_2\) on the NXT brick’s LCD screen. Based on equation (2) the unknown resistance value can be determined as:

\[
R_2 = \frac{10,000 \cdot \text{Raw}}{1023 - \text{Raw}} \text{ [\(\Omega\)]}. \quad (3)
\]

The \text{Raw} value is available in NXT-G programming by using the data hubs of the Touch, Sound, or Light sensors. As a first step of the design learning process, a simple NXT-G program is drawn in order to learn how to read the available Raw value of a sensor. For example, a
Touch sensor block, a Number to text block, and a Display block will be placed inside of a Loop block as shown in Figure 4. The functions of all required blocks are easily found in the Help and the tutorials available in the LEGO Mindstorms NXT education kit, or in other sources.

Figure 4. A program to read and display the Raw value.

By downloading and running the program in Figure 4 on the NXT brick, the displayed Raw values are read directly on the NXT's LCD screen for each of the three resistors. Now, the last column of the Table 1 will be completed, and the students are required to write their comments about how well these displayed Raw values match the calculated Raw values in the first part of the experiment.

All the ohmmeter program needs to do is to be able to read the available Raw value and to run it through the equation (3) by performing three simple mathematical operations, as shown in Figure 5.

Figure 5. The NXT-G program to design the ohmmeter.

**Student Performance Assessment**

The students' performance assessment was based on four components with different weights:

a. Lab Experiments Participation (40%): an instructor and two teaching assistants were helping the students during the three-hour lab sessions. This was an ideal configuration considering the three existing sections with an average of 26 students per section, and this also ensured the
quality of the instruction and learning process. The average grade on student participation was 96%.

b. NXT Robot Final Project (40%): each team member, (most of teams formed by two students, and very few by three students) was required to make an oral presentation of his/her contribution on the project, followed by a practical demonstration. It was no specific imposed subject, only the constraint to use as many as possible the available set of sensors, and the care of a decent minimum set of actions to be executed by the robots. In this way the instructor learned about the student's capabilities and their willingness to present a good project. The final project average grade was 87%.

c. Assignments (10%): the labs were completed with two additional assignments related to binary number basic operations, and a combinational logic design for a vending machine. The students average performance was 89% on the homework assignments.

d. Final Test (10%): the students were required to take a final test consisting of five problems covering the lecture topics: dc circuit analysis, timer circuit analysis, binary number operations, given a small design to construct the truth table, and finally to implement the combinational circuit with basic logic gates. The student’s average grade was the lowest on this component, namely 67%.

The overall average grade using all the above components was a very encouraging 89%.

Conclusions

The introduction for the first time at PUC, in our Engineering freshman class, of a new set of experiments based on LEGO Mindstorms robotic kit can be considered a promising attempt to implement an experiential-based course.

Due to the time schedule constraints (only the second half of the semester is allocated for the introduction to Electrical Engineering), the basic concepts of the EE were taught in parallel and in conjunction with the use of the LEGO Mindstorms NXT robotic education kits.

The student CD, *NXT Robotics Engineering Vol.1*, which came with the kits, was made available in the lab for students use. Despite the fact that this documentation about the NXT-G programming software is easy to use, there were few students requiring more time during the lab sessions to enhance their programming skills.

The newly created lab experiments at PUC were developed based on the available published literature1,2,3, and these experiments were not included in the pre-packaged purchased kits. The lab experiments were created to successfully develop both the students hands-on and their programming skills. This was demonstrated by the results the students obtained on the corresponding components of the student performance evaluation.

On the students overall grade, larger weights have been used on the lab experiments participation and the final project using NXT robots (points (a) and (b) in the previous section). The student’s feedback was very encouraging, and they really enjoyed participating on hand calculations needed to apply in the experiments. One of them wrote, referring to the Ohmmeter lab experiment 1:
“Great class today! Although my mathematics is lagging, once I do the expression or equation a few times, I begin to understand. But applying these formulas was wonderful. Thanks for the class!”

The results the students obtained on the final test (having a weight of 10% on the overall grade, see point (d) in the previous section) express the general abilities of a freshman student to solve theoretical problems and this poor score should not be a big surprise. Let’s not forget, this is the first engineering class, and the problem solving skills surely will be, and must be, enhanced by any one willing to pursue an engineering school and career.

Bibliography


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