LEGO Robotics in Engineering

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Abstract

Students learn the most about robotics when they have hands-on opportunities to build and program. At the college level there are a myriad of options, in terms of materials, that can be used in a robotics course. Two highly successful courses, offered at the freshmen and senior level, have been taught at Tufts University using LEGO elements, the RCX (the programmable LEGO brick), and ROBOLAB, a graphical programming language based on LabVIEW. The limitations of the RCX (3 inputs and 3 outputs) do provide some restrictions in terms of robot capabilities. However, the benefit of rapid prototyping and ease of programming using ROBOLAB permits students to address a wider range of issues and topics. The freshmen robotics course allows students to get excited about engineering and learn about robotics with no previous building or programming experience. Freshmen were able to use the icon based software with little or no instruction and build and program robots in their dorm rooms. Freshmen projects ranged from robotic animals to a search and rescue for the lost “Mars Polar Lander”. At the senior level, students were able to address distributive intelligence issues with multiple robots ranging from determining relative positioning to sharing acquired data. This paper will present theses two courses and the difficulties and successes associated with using the LEGO materials and the ROBOLAB software.

Introduction

Hands-on learning opportunities are powerful and necessary at the college level. Students need experiences that give them the chance to apply what they have been taught in order to construct their own knowledge. Providing meaningful, relevant hands-on experiences is always a challenge for course instructors. These types of opportunities often take significant amounts of time, materials, and funding to set-up. Robotics is a subject that naturally lends itself to hands-on learning and students of all ages are excited by the prospect of creating their own robot to perform various tasks. Building their own robot provides them an opportunity to apply math and physics and even exercise their own creative flair.

Two courses offered at Tufts University at the freshman and senior level through the Mechanical Engineering department try and capitalize on that excitement and interest the field of robotics

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generates. The goal of the course for first year students is to give them hands-on engineering opportunities in order to help excite and engage them in the math and physics courses that will dominate their first two years of school. The course at the senior level, however, grew out of student demand to explore distributive intelligence. In both cases, students coming into the courses had different backgrounds with regards to electronics/building experience and programming languages. Hence, a tool set was needed that all students could quickly and easily use regardless of their previous experience. Moreover, the course instructors wanted tools that would be easy to support and maintain and allow students to complete projects outside of the classroom or laboratory if necessary.

While many tools exist for teaching robotics, the need for text based programming experience, eliminated many of them as possible choices. The Lego RCX and the ROBOLAB programming environment were selected for ease of use, availability, and ease of support. While the RCX, has limitations in terms of inputs, outputs, and memory storage, the device is relatively inexpensive and easy for students to use. ROBOLAB, based on National Instrument's LabVIEW, is a graphical icon based language that students can learn quickly and easily. LabVIEW is also used in other undergraduate Mechanical Engineering courses which makes ROBOLAB is a good introduction for many students. This paper explores how effective these materials were in the two different courses.

Course Materials

Lego Components
Lego components have long been used at the college level for prototyping designs. The abundance of compatible pieces ranging from gears and cams, to motors and sensors, to pneumatics makes them a convenient and easily expandable solution for building and designing. They are also a cost effective and convenient material to provide to students that can be used in a laboratory setting or in a dorm room. The freshman course utilized the Team Challenge Kit (Figure 1), which includes an RCX, 2 motors, and 3 sensors, and retails for around $220.[3]

Figure 1: Team Challenge Set

The RCX
The RCX, is a microprocessor embedded in a LEGO brick (Figure 2). This programmable LEGO brick can acquire data (up to 2000 points at 180Hz maximum) or control a robotic

creation. It can be controlled locally, over the web, or be completely autonomous. The RCX has three sensor inputs and three power outputs. The inputs can acquire information from LEGO sensors (basic temperature, rotation, light and touch sensors). Other companies have developed more sensors (pH, humidity, voltage, position, etc..) that can be used with the RCX as well [1,2] The RCX can also use a sensor adapter module, developed at Tufts University, that accommodates any off-the-shelf sensor that requires a 5 volt excitation and returns a 0-5 volt signal to the RCX. The RCX uses an infrared port to communicate with the host computer or other RCXs, has four onboard timers and supports true multitasking.

Figure 2 – The RCX

ROBOLAB

ROBOLAB, developed by a three way partnership between Tufts University, Lego DACTA, and National Instruments, provides a graphical way to program the RCX on both PC and Mac platforms. Powered by National Instrument's LabVIEW, ROBOLAB is fairly intuitive to program by wiring together icons that represent commands. The software has a significant amount of built in help functions, examples and multiple levels to allow different entry points for students of different ages and abilities. The lower levels entitled Pilot, allows children as young as 4 to program while the higher level entitled Inventor has been used in 4th grade through college. At the highest level, ROBOLAB allows users to control all the capabilities of the RCX. In addition, by integrating certain LabVIEW functionalities, users can also program or control other RCXs via the Internet. ROBOLAB a relatively inexpensive piece of software to use at a cost of \$50 for an individual copy and \$176 for a site license.[3]

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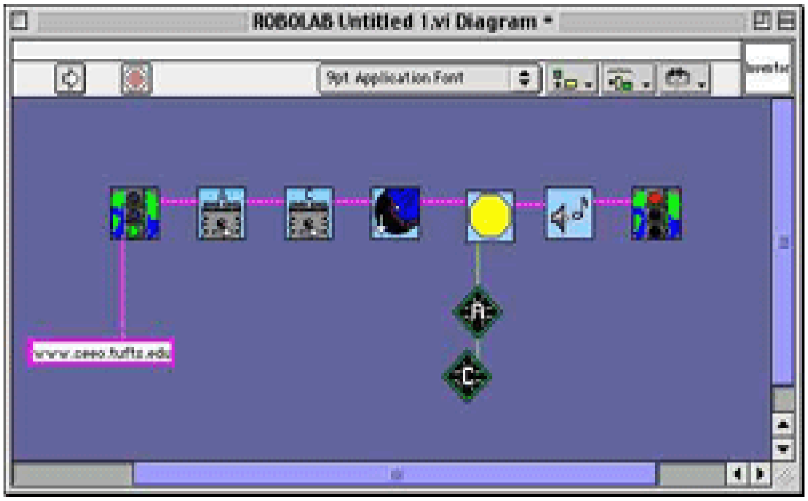

Figure 3: A simple ROBOLAB Inventor level program

Freshmen Engineering: Prototyping Home Robots

Prospective freshman engineering students at Tufts are required to take two half courses from any of the engineering disciplines (mechanical, electrical, civil/environmental and chemical). These half courses give students a taste of engineering and help to keep them engaged and motivated in the less hands-on coursework they will initially take. Since these courses are aimed at incoming freshmen, there are no pre-requisites for the course. Hence it is necessary to choose materials and software that any student can use. A robotics course based on the RCX and ROBOLAB is offered through the Mechanical Engineering department

This course, entitled Prototyping Home Robots, is made up of weekly lectures and robotics competitions and is typically filled to capacity. Each group of 2 to 3 students is given one Team Challenge Kit (which must be returned sorted at the end of the semester in order to receive a grade). The ROBOLAB software is available in university computer labs and each student can also obtain a copy to install on their own computer (via a site license agreement). The LEGOs provide an enormous amount of inspiration and motivation for the students.
The students are able to successfully program the challenges with very little programming instruction. Only a few minutes of class time in the first few weeks is used to instruct students on where structures or functions are located and how to implement them. Functionality and performance in the competitions are very important to the students who typically come to class at least an hour early and stay late to add features to their robotic creations. The level of difficulty in both building and programming increase as the competitions progress (Figure 4). Students sometimes need to be reminded that the course is only worth half a credit and to budget their time accordingly. Class participation is also excellent, as students are very interested in learning the course material because it helps them build a better robot.

Week	Class Topic	Robotic Competiton	Competition Summary
1	Brick and sensor overview	Stay in the box	Program your robot to stay inside a square taped to the floor. The tape will be whitish masking tape against dark floor tiles.
2	History and Terminology (HD)	Simon Says	You know the rules of the game, now we want you to make a robot that plays it as well as you do. Your Professor and TA will build a robot that acts as "Simon," and your robot has to do is exactly what we say, or suffer the consequences.
3	Microprocessors	Fetch the light	A flashlight will be placed somewhere on the floor pointing in the direction of your robot. Find this light and get as close as possible to it and stop.
4	Motors, gears and sound devices	Maze	Build a rover that can navigate its way through an arbitrary environment. In this case, your robot will have to successfully negotiate a maze to find the exit, while finding its way past turns and dead ends
5	Sensors	Zombie attack	Attempt to form your own robot army by defeating your opponents in a simplified version of laser tag. Send your IR to "kill" the other robots and make them part of your zombie fleet.
6	Machine vision/real robots	Robotic Zoo	Build a resident of our Lego zoo. What you build and how you build it is entirely up to you. Creativity will pay off and well-built structures will bode well during our all-out brawl.
7	Mars Lander Development	Work on Mars Lander	Your robot has just landed on the Mars surface. The terrain is unknown (except for a small helper grid that just happened to be at the landing site). You must find a rare type of Martian rock (we know it's white and cylindrical) and bring it safely back to your landing spot.
8	Work on Mars lander	Mars Lander Competition	

Figure 4: Freshmen Course Outline

Occasionally frustrations are voiced about the materials regarding the accuracy of the sensors or the sturdiness of the pieces. However, students generally like the freedom to work anywhere on their projects. They are able to solve a majority of their hardware problems on their own or with a few brief hints. Some students with more extensive programming experience are frustrated with using a graphical programming language. However, the graphical programming language has proven extremely easy to support. Students are able to program on their own and even debug one and other's code. ROBOLAB eliminates many of the opportunities of syntax errors making programming quicker and easier for the majority of students. This class represents an integrated

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Figure 5: An Alligator
from the Robotic Zoo

learning experience where all engineering disciplines are touched upon without reducing the fun element that drives the learning process

Clearly the number of challenges and the complexity of the latter challenges would not be possible if the students had to learn to use more advanced hardware and software. Moreover, the focus of this and other freshmen half courses is breadth of opportunity. While there are definite benefits to more advanced options, like the Handy Board and Interactive C, we feel these elements are not well suited to an introductory half course that needs to communicate a number of possible avenues for the knowledge they will acquire. This course currently stands alone as an experience for freshmen. Additional robotics courses at Tufts have different focuses. However, many students are interested in continuing to explore autonomous robots and it is foreseeable that if a related course at the next level was created it would include more advanced hardware and software.

Senior Engineering: Distributive Intelligence with Robots

The senior level course was a special topic opportunity offered at the request of a small group of seniors who were interested in exploring distributed intelligence with robots. The course focused more on the design of the algorithms related to distributed intelligence and less on the construction of the robots. While the seniors had a majority of the coursework behind them in math and physics, they all had limited programming experience and each in a different language. They also had limited experience with electronics. Hence, it was decided to use the RCX and ROBOLAB so that a number of group projects could be undertaken and everyone could participate equally in terms of building and programming.

The class was structured such that all students worked cooperatively on 5 group projects (Figure 6).

Challenge	**Description**
1. Younger Brother	The goal of this challenge is to manually control one RCX while another automatically follows. Place two RCX's on the table - when you move one by hand, the other will move in the same fashion (i.e. slow, fast, forward, back, left, right). You should be able to do this with the RCX's in IR range or by having the two communicate over the internet so that the younger brother will actually be in a different

	room.
2. Whistling Brothers	The goal of this challenge is to place five RCX's down on the table and they all have to whistle a specific tone. Hit run and the leftmost one should sing 220 Hz, the next 440 Hz, and so on. Now, take the RCX's and rearrange them - when you hit run again, still the leftmost should sing 220 Hz, etc. This means that each RCX must determine where it is in the order and play the correct note.
3. Gophers	The goal of this challenge is to have a moving RCX find the path of greatest light. Four RCX's are planted to four different locations continually collecting light data. The mother gopher drives by and collects data from the stationary gophers to determine the path of greatest light.
4. Travel by Beacon	Set four RCX's down on the table. Each RCX has a single message (such as "wait 30 seconds", "turn around", "turn right", ...). The Mothership (RCX #5) comes by and will respond to each beacon by obeying the command and then moving on. With this scenario, you can "program" the Mothership by where you place the various beacons.
5. Wandering Cyclops	Place five RCX's on the table along with a number of obstacles. All RCX's must get the light intensity information back from Com Central (the computer). You must do this while maintaining line-of-sight. That is, when one RCX moves behind an obstacle, it must relay its message to Com Central through the other RCX's. If it is not in sight of any other RCX it must retrace its steps so that it is.

Figure 6: 5 group projects in sequential order

For the first few weeks of the semester the class met once a week with the instructor to discuss algorithm design and development and very brief ROBOLAB programming instructions. For the most part students independently learned to use the software and had few questions. During this the first few weeks the initial two challenges (Younger Brother – Figure 7 and Whistling Brothers – Figure 8) were completed and presented. Over the rest of the semester the students worked independently on the challenges and scheduled meetings for help and to present their solutions to the challenges as needed.

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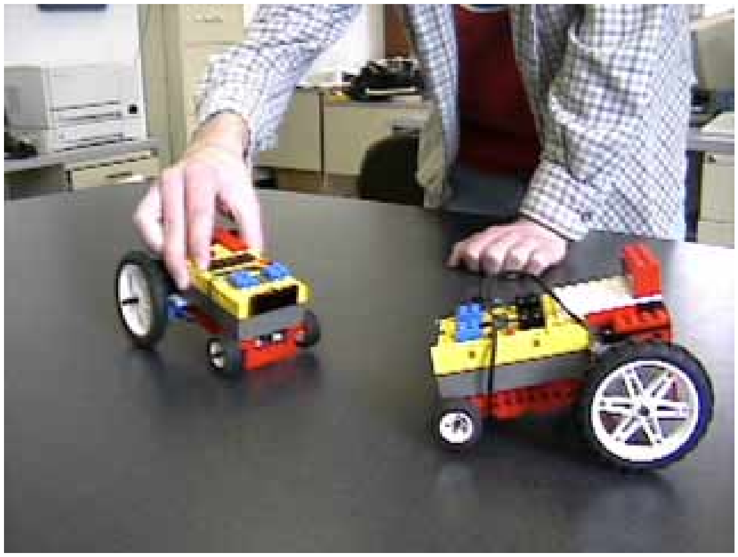

Figure 7: Younger Brother – One RCX must mirror the behavior of another. The task was accomplished using IR communication and rotation sensors.

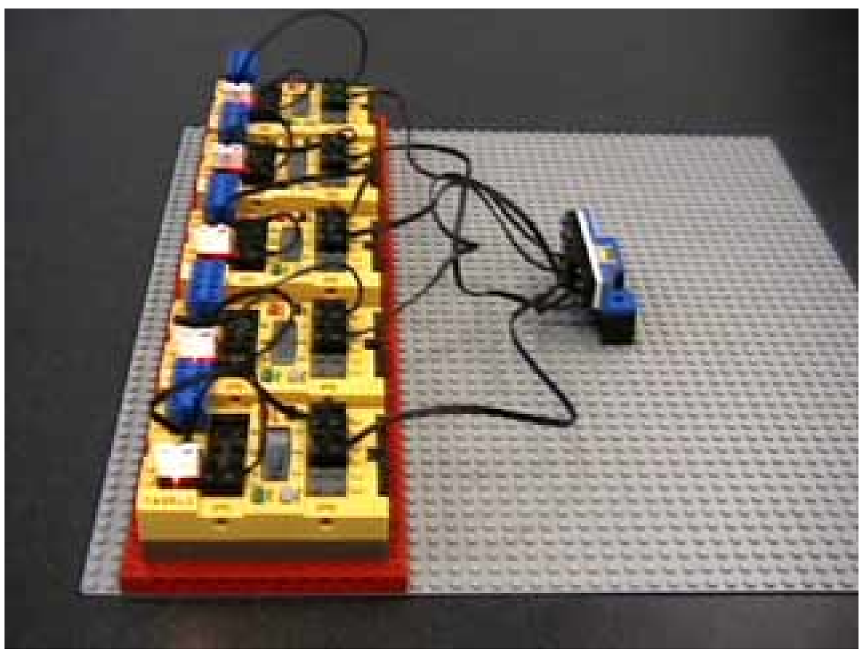

Figure 8: Whistling Brothers – RCXs determine their position using lights and light sensors and play the proper frequency.

The challenges were structured to deal with increasingly more complicated programming and algorithm topics. An effort was made to keep building requirements as simple as possible. However, there were still many mechanical issues to be dealt with but the senior students were easily able to address the majority of them with their engineering background. While the students voiced some desire for additional inputs and outputs, they devised innovative solutions to the constraints and acknowledge the real world likeliness of similar constraints from cost or space requirements. LabVIEW is used in other undergraduate mechanical engineering courses so the students were very adept at using ROBOLAB. The students' programming did reveal some limitations to ROBOLAB, in terms of making the best use of the RCX functionality but these commands have since been added to the latest version of the software.

The student feedback from the course was very positive and they felt the programming and algorithm strategies were a significant addition to their knowledge that had not been found elsewhere in their education. They also expressed that although ROBOLAB would not be used in their future careers they had been able to address more concepts and topics than with a programming language they were unfamiliar with.

Conclusions and Future Directions

The combination of the RCX , ROBOLAB and Lego elements provide a tool set that is easy for the students to use and learn and is also easy for the instructor to teach. It requires a small amount of time for instruction which frees up class time to focus on the topics of the course. Little support from the instructor or teaching assistants for hardware or software problems is needed. As the students can program at home or in existing computer facilities, it does not require lab space or time. All the components are relatively inexpensive, easy to replace, and offer great possibilities for expansion. While there are many other hardware and software options for teaching robotics topics at the college level, this tool set has a place in courses that wish to focus on the broader concepts of programming and building and haven't the resources or time to devote to software instruction and hardware support.

Tufts University also uses the RCX in combination with LabVIEW in other courses in the undergraduate Mechanical Engineering curriculum. It is also used at the sophomore and junior level as way to introduce experimental methods. Because of the RCXs ability to capture data, it makes an easy way to introduce students to data acquisition and analysis concepts. Students can first learn programming techniques and acquisition concepts using this inexpensive piece of hardware before moving on to more expensive data acquisition boards and equipment.

Tufts University's School of Engineering's Center for Engineering Educational Outreach (CEEO) also uses the RCX, ROBOLAB, and Lego elements with K-12 students and teachers. The tools are used to add a hands-on component to existing school subjects as well as introduce engineering. Kindergartners have created towns with a bus that stops and picks up every child. First grade students have designed lunar rovers that can traverse hilly sand boxes. Second grade students have built and programmed spiders that look and behave like the ones they have been studying. Fourth grade students have built satellites that travel through the solar system and position their solar panels towards the sun. The excitement in creating an autonomous creation motivates students to learn math and science, to read stories more carefully, and to integrate all their subjects to help enhance their creation. More information on the CEEO's K-12 programs can be found at http://www.ceeo.tufts.edu.

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