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A Proposal To Incorporate LEGO® Mindstorms™ into an Introduction to Engineering Course

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Abstract

Hands-on experiences excite interest in engineering students. Freshmen tend to be more interested in applications than theory, but they have many math and science courses confronting them before they can effectively apply what they learn. A freshman year course that shows engineering students the applications of the theory would help maintain a high level of interest. This paper introduces a robotics unit to give students that hands-on experience. Designed to be included in an introductory engineering class at the University of Wyoming, this unit utilizes the versatile components included in the LEGO® Mindstorms™ system. The unit addresses various concepts related to engineering principles and real life applications, such as remote sensing, artificial intelligence, and the integration of different components. Students working through this unit would design and build a series of robots beginning with one that uses a touch sensor to maneuver around obstacles and ending with a robot that mimics an animal's behavior, such as eating and sleeping. The construction requires a basic grasp of mechanical engineering concepts, and some programming ability, but use of the kits requires no previous skills. The LEGO®s kit encourages problem solving and teamwork. The unit was piloted with a pair of volunteer interns, both rising high school seniors. The volunteers worked with the unit in seven one-hour sessions. The interns chose to put in extra time to work on their projects, demonstrating the enthusiasm inspired by both the materials and the projects.

Introduction

Hands-on experiences are vital to stimulating the interest of college students. Nowhere is this more true than in engineering and robotics. Students want to know what awaits them when they have completed their math, computer, and science courses. Showing students interesting future possibilities will help motivate them and encourage them to continue, where many students might otherwise drop out or change fields. A robotics unit utilizing LEGO® Mindstorms™ has been designed and is currently under consideration for inclusion by the University of Wyoming College of Engineering in one or more of its introductory courses. This unit accomplishes two goals. It creates interest in robotics and engineering, and it encourages creativity and teamwork among students.

LEGO® Mindstorms™ are ideal for this course. The Mindstorms™ system consists of a basic set of LEGO® blocks, several motors and sensors, and a microprocessor housed in a large LEGO® brick. The wide variety of languages available for programming Mindstorms™ make it easy to use for students who have programming experience as well as those who do not. The flexibility of the LEGO® pieces allows for students to be creative with their designs. The restrictions of the Mindstorms™ kit--3 input ports and 3 output ports--can simulate real-world restrictions, such as weight and size requirements. Finally, the Mindstorms™ kit is relatively inexpensive, costing about $200 per basic kit with each serving a team of 2-4 students.

The proposed unit was piloted by a pair of volunteer Department of Energy research interns over the course of seven one-hour segments. The purpose of piloting the course was to determine the effectiveness and feasibility of this proposal. The projects that the interns completed were similar to the projects that are proposed for the actual course. It should be noted that the instructor teaching the course should treat the course outlined in this paper as a set of guidelines, and should apply his or her own creativity to enhance the unit.

Research Procedures

This project reflects the results of a review of literature about engineering classes taught at other universities that use LEGO® Mindstorms™. Many universities, such as Tufts University[1], Southern Illinois University--Edwardsville[2], and Virginia Polytechnic Institute[3], have incorporated Mindstorms™ into introductory engineering classes because of their ease of use, relative cost efficiency, and ability to give a hands-on experience with engineering while encouraging creative processes.

Following this literature review, it was necessary to determine the capabilities of the Mindstorms™ hardware and software. This created a level of familiarity sufficient to design feasible projects. This was accomplished by constructing various robots and programming these robots.

Several different programming environments were experimented with, in order to decide on a preferred way to program the Mindstorms™ microcomputer, the RCX brick. The preferred environment should balance power with ease of use. The basic graphical programming environment provided with the Mindstorms™ kit, called RCX Code, is intuitive and easy to use, but not very powerful. The second programming environment experimented with was Mindscript, the language provided by LEGO® for use with the Mindstorms™ SDK (Software Developers Kit), available for download from LEGO's website at no charge. Although more powerful than the RCX Code, several problems were identified with Mindscript. One problem was the inability to make control structures, such as *while loops*, function correctly. The final programming environment used was RCX Command Center, an environment for the NQC (Not Quite C) code developed for Mindstorms™ by David Baum.[4] In addition to being very powerful, the NQC code is closely related to the common languages of C and C++. This makes it easy for students with background in C or C++ background to adapt to the language, and it provides a steppingstone toward those languages for students who are not fluent in them. The environment provided by the RCX Command Center (RCXCC) also makes programming easier by color-coding different aspects of the program and by providing an extensive help manual. It was concluded that the RCX Code is a good way to familiarize students with the basics of the system. However, the students should then advance quickly to RCXCC and NQC.

After experimenting with the hardware, it was obvious that the use of LEGOs makes the construction aspect of robot design relatively easy. Some effort, however, is required to construct a robot that is structurally sound. Building one or two of the robots included in the manuals, before starting the projects discussed below, can help students learn about sturdy construction.

Course Unit Description

The Mindstorms™ unit should be divided into approximately 7 one-hour blocks. The projects recommended are based in part on projects used in classes at other universities. While designing this unit and the associated projects, it was decided that students would first need to acquire an understanding of the Mindstorms™ system and associated programming languages. The first two blocks and the accompanying projects are intended to provide that understanding, as students learn the programming languages and explore the capabilities of the Mindstorms™ kits. Next, the students should be introduced to the light sensor and how it is used for controlling motion and collecting data. This is accomplished in the two projects that make up the third, fourth, and fifth. These projects involve building robots capable of remote sensing and mapping. The final project was designed to give students an opportunity to be creative while teaching them to integrate different components and was designed to take the last two blocks of time.

The first one-hour block should be spent introducing the RCX and RCX Code, as well as the motors and sensors. The students should build and program a robot that uses a single touch sensor to maneuver around obstacles. The second block should be used to introduce the students to NQC and RCXCC, a graphical interface that makes programming in NQC easier. During this block, students will first reprogram their single touch sensor robots in NQC. Students will then expand their robot and program it to incorporate two touch sensors. We suggest the beginning of the third hour block be used to create a robot that can follow a black line on a white surface. Students can then be given the opportunity to use either one or two light sensors for their robot. At this point the students will be using RCXCC to program their robots.

After the students have completed their line-following robots, the first major project should be introduced in the fourth block. This project consists of teams of students building robots to remotely sense an unknown environment, similar to robots examining the surface of another planet. This can be done by attaching various flat materials to the bottom of a large box. The students would have to build a robot to map the reflectivity of the bottom of the box. This project would teach the students about the applications of engineering and robotics to remote sensing and even planetary exploration. Each group of students would create a map based on the data read by their robot. To do this, the concept of the datalog (a data storing array built into the RCX microcomputer) on the RCX should be introduced immediately after the project is introduced, in the fourth block while students will create their map in the fifth block.

The final project is developed during blocks 6 and 7. For this project, student teams create robots that behave like simple animals. The students construct an environment for the robot to live in, make the robot eat 'food,' and have the robot find a dark area periodically to go to sleep in. In addition to this, the groups of students must create a non-LEGO attachment to perform some task specified by each group of students[5].

Table 1, below, summarizes each of the study blocks. The full descriptions of each block are available at http://wwweng.uwyo.edu/electrical/doeepscor/.

Table 1: Outline of Proposed Blocks for the Robotics Unit

First Block	Introduction to the basics of Mindstorms™, such as the RCX, RCX code, motors, and sensors Construction of a robot that uses a single touch sensor to avoid objects
Second Block	Introduction to NQC (Not Quite C) and the RCX Command Center (RCXCC) Reprogram first robot using the RCXCC, and modification to use two touch sensors to go around obstacles
Third Block	Construction of a robot that is capable of following a black line on white paper using RCXCC
Fourth Block	Introduction to the datalog on the RCX Introduction to the first major project: students must map the reflectivity of the bottom of a prepared box
Fifth Block	Completion of remote sensing project
Sixth Block	Introduction to the final project: the creation of a robot 'animal,' an environment, and a non-LEGO component of the robot (the specifics of the project should be determined by each group of students) Students should be encouraged to work outside of class on this project
Seventh Block	Completion of the animal projects Brief presentation of 'animals' to the class and teacher

Piloting the Unit

In order to determine the feasibility of this unit, it was piloted on two volunteer EPSCoR interns. One of the students had previously had some familiarity with RCX Code, while the other had no experience with Mindstorms™, but had previously learned Visual Basic. For one hour a day, for seven days, the unit was taught to the interns and they worked on the projects. The reflectivity-mapping project was simplified in that the interns did not need to create a different sensor or generate a map. Instead they merely recorded the data and uploaded it to the computer. The final robotic animal project was simplified so that the students built a robot that would find a ball and return with the ball to a marked location. Throughout the pilot, the volunteers-- despite the fact that they did not receive a grade or other direct compensation-- exhibited enthusiasm and determination. The next few sections of this paper describe the experiences of each day spent piloting this unit.

Pilot, 1st Day

After a few initial setbacks in construction (mainly that the robot collapsed when it hit a wall), and a little help from the manual, a relatively sturdy obstacle-avoiding robot was constructed. By the end of the hour allotted, the interns had successfully built and programmed their robot. The students were enthusiastic and put effort into their work. The interns became very animated, following an initial ten-minute period of reticence. They did not want to stop at the end of the hour.

Pilot, 2nd Day

The primary discovery during this session was that students pick up NQC fairly quickly. After spending about 10 minutes explaining NQC and the various tools of RCXCC to the interns, it took them about 40 minutes to reprogram the single touch sensor robot. This seems to be a reasonable amount of time to spend figuring out the language. Much of this time was spent making sure they understood how to write the code in NQC that would be a block in RCX code. The piloting session ran into difficulties when the computer would not recognize the RCX brick, believed to have been caused by IR interference from the sun. Due to this difficulty, the obstacle avoiding robot project that would use two touch sensors was abandoned for the pilot course.

Pilot, 3rd Day

The students worked again with NQC in order to program a line-following robot. The students were shown how to determine the reflectivity of the line and the surrounding paper in order to guide the robot, and learned the details of programming the light sensor. The interns displayed enthusiasm about the project as they worked to make their robot deal with various turning environments. It can be considered a measure of the students' enthusiasm that they stayed after the hour block in order to finish their robot.

Pilot, 4th Day

The interns were introduced to the mapping project. They picked up the idea of the datalog quickly, with no difficulties. The biggest problem encountered during this session was getting the robot to turn exactly 90 degrees on the varying surface types on the bottom of the box. The lesson learned from this is that the surface of the box should be uniform in everything but color. The lack of uniformity of the surface gave the interns a distorted data grid.

Pilot, 5th Day

The interns were introduced to the modified final project. They had to create a robot that locates a ball ('food'), takes it to a specified area, and then goes to another specified area and pauses ('goes to sleep'). A few difficulties were encountered. Locating the two-color ball was rather difficult, so the interns used the LEGO® Vision Command camera to locate the ball. (The purchase of this camera adds an additional $50 to the cost for each team of students). The other major difficulty was picking up the ball to move it. To accomplish this, the interns made use of a third motor.

Pilot, 6th Day

This day was spent in the same manner as the previous day. The construction of the robot was completed during this session, with the final session reserved for programming and testing it. To increase the power, two worm gears were used to reduce the speed of the motor and create more torque. The creativity LEGO® Mindstorms™ excites is obvious in the solution devised to the problem of picking up the ball. The interns made extensive use of gears, including two worm gears, to increase the power of the motor and to prevent gravity from lowering the ball after power was no longer being applied to the motor.

Pilot, 7th Day

The robot constructed during the previous two days was programmed and the Vision Command package was introduced to the students. It was intended that the students use the camera from the Vision Command package to facilitate locating the ball. However, there was difficulty locating the ball with the camera due to the range of shades on the ball caused by inadequate lighting. It was decided that the interns should directly control the robot while it went in search of the ball. It is recommended that, in attempting this task, a solid color ball be used and that uniform lighting be available. This project was successfully completed within the time allotted.

Conclusions

The pilot illustrates that this unit is a feasible addition to an introductory engineering course. All projects except the double bumper, obstacle-avoiding robot were completed within the allotted blocks.

The pilot reinforced the value of hands on experience. Despite some reservations about doing so much programming in such a short time, the interns enjoyed the process of designing and constructing LEGO® robots. This unit does in fact excite and maintain interest in engineering. Teamwork and creativity appeared in abundance. This was evidenced by the solutions that the interns devised for solving the various problems before them and the way they collaborated on both construction and programming. Piloting this unit has confirmed both its feasibility and its effectiveness.

Several universities have successfully incorporated robotics courses using LEGO® Mindstorms™ into their curriculum. This study demonstrates that the robotics elements can be introduced as a part of an introductory engineering course. Experimentation to determine the capabilities of the Mindstorms™ components showed that they are extremely versatile, allowing them to be used for many different projects with different goals. The Mindstorms™ kits are relatively inexpensive for what they allow an instructor and students to do. Finally, the ease with which students become familiar with LEGO® Mindstorms™ makes it feasible to use them as a part of a broader course.

In conclusion, the feasibility and effectiveness of LEGO® Mindstorms™ at providing hands on experiences, exciting interest, and encouraging creativity at such a low cost, makes them ideal to include in one of the University of Wyoming's introduction to engineering courses. Similarly, the unit described above could be modified for inclusion in introductory engineering courses at other universities.

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