Using the Lego Robotics Kit as a Teaching Tool in a Project-based Freshman Course

A.C.Shih and M.C. Hudspeth
California Polytechnic University
MEP Program

Abstract

For an incoming freshman, beginning of his/her college life can be an exciting but challenging experience. Some of these challenges may include: displacement from home, lack of friends, tough course work, and unfamiliar environment in general. The Maximizing Engineering Potential (MEP) program at Cal Poly Pomona recognized the difficulties that the freshmen face, and has designed a sequence of freshmen classes to help the students deal with the problems mentioned above. One of these classes is the Freshmen Orientation (EGR111) to be taken during the winter quarter of the freshmen year.

EGR111 is a project-based class. Through different projects, the goals of this laboratory are to:

- Familiarize students with computers and software, including word processor, spreadsheet, and programming.
- Expose students to engineering concepts.
- Help students understand and value teamwork during the project.
- Develop the students' proficiency in writing technical papers and making technical presentations.
- Establish a mentoring relationship between students and faculty.
- Retain students in engineering.

One of the projects incorporates LEGO Robotics Kit in the class. The students are to utilize the available parts in the kit to design, build and program a "smart car," so that the car will maneuver itself through an obstacle course. Throughout the quarter, the students are required to turn in a weekly memo documenting the progress of the car, drawings of their design, calibration reports for the motor and sensors, and a video report documenting the progress of the car. A final oral team presentation and a race through the obstacle course are required at the end of the quarter. Results of a survey recently conducted indicate that students, in general, have expressed satisfaction about this class and indicate that this class had help them to learn to work as a team and become better engineering students.

Introduction

Cal Poly Pomona is a four-year comprehensive university with a mission to “advance learning and knowledge by linking theory and practice, and to prepare students for lifelong learning, leadership and careers.” Established in 1938 and located 30 miles east of Los Angeles, the campus serves over 17,500 students with 2500 faculty and staff. The College of Engineering at Cal Poly Pomona is the largest engineering school in Southern California with enrollment over 3,500 in eight engineering disciplines.

The MEP (Maximizing Engineering Potential) program at Cal Poly Pomona, initiated in 1983, is an academic enhancement program for more than 650 African American, Latino, and Native American students in Engineering and Computer Science each year. The program’s purpose is to increase the number of minority students who graduate in these technical disciplines. The MEP offers a variety of services to support students including workshops, summer program and advising and counseling, and it also offers a sequence of three freshmen orientation courses lasting a year long to enable new students to quickly become a part of the Cal Poly Pomona and MEP community. In the first of the three courses, offered during the fall quarter, the students develop problem-solving skills, learn study techniques for technical courses such as mathematics and chemistry, and receive guidance counseling to deal with the campus bureaucracy. In the second course, offered in winter quarter, students experience the engineering design process first hand through team project-design competitions. And in the last course, offered in the spring quarter, the students focus on career exploration and company tours.

As the middle course in a sequence of three, the EGR111 course consists of a one-hour lecture and a two-hour activity session every week. In the lecture portion of the course, a different guest speaker from industry is invited each week to talk to the students on what real engineering is all about. In the activity session, students are grouped in teams to participate in different design projects. Some of the past and current projects include construction of a bell tower with the minimum cost using bond paper and paper boards, building of a bridge using popsicle sticks and glue, and designing and building a catapult using available material. Two years ago the Robotics Invention Kit was introduced to the market by the LEGO group, and this is when the kit was incorporated into the class.

The Lego Robotics Invention kit consists of a programmable RCX unit, a CD-ROM disk containing Lego's own programming language, and over 700 different Lego parts. In addition to traditional Lego building blocks, the kit includes mechanical components such as motors, gears, pulleys, tires and sensors. The robotics kit allows us to introduce other components of engineering design, such as programming and simulation, which were previously not possible in this project-oriented course.

Pilot Offering

The course with the Lego project was first offered during the winter quarter of 1999 to 31 students. The students were assigned to teams consisting of students from different majors. There were a total of six teams for this class (five teams of 5 members and one with six), and each team was provided with a Lego Robotics Kit. All the teams had a common objective: to build and program a "smart" racecar using Lego pieces that it would self-navigate through an obstacle course. The obstacle course was constructed on a whiteboard with obstacles placed on the whiteboard and with black electrical tape to indicate the border of the course; the students did not know the route of the course ahead of competition time. The only instructions given to the students at the beginning of the course are:

- The racecar must be constructed using only Lego pieces from the Robotics Kit.
- The racecar must use the light sensor to detect the black border on a white background and to steer away from it.
- The racecar must incorporate touch sensors in its bumper to detect obstacles by touch and it is programmed to steer away from obstacles when the bumper is hit.

Lectures were deliberately kept to a minimum so that the students were free to explore and discover on their own. Construction of the racecar, programming of the RCX unit, and grading and homework policies will be discussed below.

Constructing a "Smart" Lego Racecar

Lego pieces

In addition to the regular Lego pieces, the Robotics Kit comes with other pieces that make the construction of a "smart" racecar possible. It includes:

- Two motors.
- Various sizes of gears.
- Various sizes of tires.
- An infrared unit which allows downloading of programs from a computer to the RCX unit.
- Two touch sensors which can be programmed to control the motors when "touched".
- One light sensor which can be programmed to control the motors upon sensing and to distinguish "black" and "white" areas.
- A programmable RCX unit, which has three input ports allowing data input from sensors to control the motor; it also has three output ports which allow for connection of up to three motors.
- A CD-ROM, which contains Lego's own graphical programming language.

Design and Construction

It seemed easy to play with Legos, but students discovered that it is actually quite a challenge to construct a sturdy and reliable racecar using Lego pieces. The tasks that the students needed to perform to successfully construct a "smart" racecar are described here.

First, a sturdy chassis for the car, using the RCX unit as its main body, needs to be designed and constructed. Then, a bumper system is designed and constructed as well. Through trial and errors, the students discovered that the bumper system needs to cover the entire front part of the car, and it needs to incorporate both touch sensors in its design. When the bumper is touched, the touch sensor will be activated and the RCX unit is programmed such that the motors are controlled to steer the car away from the obstacle. Steering of the car can be accomplished through the utilization of either one motor or both motors. The students are responsible for the design of the transmission system and the attachment of motors to the chassis.

To recognize the border of the obstacle course, a light sensor is placed at the front of the racecar. The light sensor is able to detect a "black" and "white" contrast in light intensity. Thus, when the border is detected, the RCX unit is programmed to use the motors to steer the racecar away. All the teams go through a number of iterations in the design and construction process before a satisfactory racecar is built.

Programming

The most challenging aspect of the course is the programming. None of the students had any prior programming experience. The programming language used for this course is the graphical language included in the kit. The language includes commands similar to those in a high-level language such as if-then-else and do-while. In addition, it also offers additional commands to detect the conditions of the sensors and to control the motors. The students needed to write their own program to control the racecar using a personal computer, and then download the program to the RCX unit via an infrared port.

Grading and Homework Assignments

There were no tests or exams for this class. Students' grades were thus determined by in-class participation, written reports and oral presentations. A total of three reports were required. The first report was an investigative report where students studied building a racecar using Lego pieces. The second report was a technical report where students presented a preliminary vehicle design and discussed their design philosophy. In the final report, students were required to document the entire project by presenting their final design, a detailed discussion of challenges that they faced and a conclusion describing possible future improvement of their racecar. Drawings and figures were required in the reports, and a style guide is provided to the students. The grades of the reports were dependent on three factors: content, grammar, and graphics. Each report is assigned a letter grade, with all team members sharing the same letter grade.

Two presentations were required as part of the students' grade. The first presentation was made during mid-quarter when the preliminary version of each group's racecar was presented to the entire class. A final presentation was made on the day of competition. Each team had 15 minutes to talk about how the design of its racecar evolved, the challenges it faced and possible improvements to the racecar. Each team member is expected to speak during each presentation. Then each car was put to the test through the obstacle course. Grading of the presentation was based on technical content, posture, eye contact, and graphics. Each team was given a grade for overall presentation, and each member received a separate grade for his/her part in the presentation.

Pilot Course Evaluation

During the first competition in winter, 1999, none of the racecars navigated out of the obstacle course successfully. Most teams had a problem with a faulty program while several teams had experienced fallen-apart racecars during competition after impacting with the obstacles. After the competition, a survey asked the students to describe the most challenging aspects of the course and to identify areas for future improvement. The students' comments indicated the most challenging parts of the course were:

- Programming the RCX unit.
- Constructing a racecar that does not breakup upon impact.
- Constructing a bumper that does not fall apart upon impact.
- Working with other team members when everyone has a different schedule; difficult to delegate responsibilities.
- Report writing, unsure about what to put into the report.
- Lots and lots of trial and error regarding testing of the car.

The areas the students have suggested for improvement include:

- More instruction in programming.
- Make the report requirement guidelines more specific.
- Fewer members to a team, preferably 4 or less.

The Second Time Around

The course was offered again during the winter quarter of 2000. This time, two sessions were offered, where one session had 29 students and the other one had 11. Based on students' comments and the prior experience, a number of adjustments were made to the course.

First of all, in response to the students' suggestion, each team had no more than four members. This resulted in the first session of the course having 8 teams, and the second session with 3 teams. To simplify the issue of delegating responsibilities, each student was assigned a title to make each student responsible for an aspect of the project. The titles available for each team include project manager, programmer, technical writer, and systems engineer. It was made clear to all the students that everyone needed to share all the work including designing, constructing, programming, presenting and report writing, although the person with the title was responsible for ensuring everyone is adhering to the deadlines that fell under his/her category. This eliminated the problem of responsibility sharing.

In respond to unclear guidelines in report writing, more instructions and guidelines were provided to the students. Instead of only three reports, the students were required to write reports every week. For the first several reports, a general outline of the expected contents for the report are provided to the students. This helps the students to learn what the focus of the report should be. No grade is assigned to the first report. It is marked and corrected extensively for style, grammar, language usage and content so that the students can use it as a guideline for later reports. The quality of reports did improve as the students had more guidelines to work with.

Because of the nature of the Lego pieces, it is very easy to allow rapid iterations and design changes to the racecars. Oftentimes, the students are too busy taking the pieces apart and putting them back together to realize and learn the basic engineering concepts. Now the students are required to document the different racecar designs through the use of camcorders. Each time the design of the racecar is modified, the students are required to record the new design and to comment on why they made the modifications. These video reports are collected three times a quarter. Moreover, calibration of the light sensor and motors are required as well. For the motors, the students need to develop correlation curves between motor power and turning angles, and between motor power and average vehicle velocity. For the light sensor, students are required to use the calibration panel provided by Lego software to correlate light intensity and colors. And finally, several lectures on simple programming techniques are given in the beginning of the quarter to help the students with programming the RCX unit.

This time, three out of eleven racecars successfully navigated the obstacle course.

Observation and Discussion

Throughout this course, the students exhibit a high level of enthusiasm and great energy. Many students have indicated that they thought playing with Legos was fun, and yet they had not anticipated that it could also be challenging and educational as well. Through hands-on experiences and much trial-and-errors, some students were able to come up with designs of sophisticated transmission systems using gears.

In this course, the students must learn to work with other students in a team environment. While most of the students did not know each other prior to this course, most of the teams worked very well together throughout the quarter. No meddling or mediation was required from the instructor either time the course was offered. Furthermore, this information-sharing environment exists not only among members of the teams, but among all the teams as well. It was anticipated at the beginning that each team would guard its designs closely for fearing of other teams stealing the design, since there was going to be a competition at the end. That was not the case, however. Actually, the teams were sharing each other’s designs and learning from others’ mistakes. Oftentimes, the design of one team is the improvement of a design from another team. The team-project approach of the class also helped students form strong bonds that last a long time. Many quarters after taking classes together, the students from the same team/class still study in groups and support one another.

In terms of faculty-student relations, there appears to be a better bond with students in this course; this can be attributed to several reasons. First, the course is set in a non-lecturing environment where the instructor is seen as less authoritative and intimidating. Second, the setting of the course requires the instructor and the students to work very closely together on a knowledge-sharing basis. The instructor is no longer the person who know all the answers; rather, towards the end of the class, the students become the experts and instructor merely facilitates. In a certain respect, the line between instructor and students is blurred. I believe that this had allowed the students to form a closer, more personal bond with the instructor.

The format of the course also encourages students to perform tasks that they, very often, did not like to do, such as report writing. In the friendly, competitive setting, students appeared enthusiastic even in writing reports. In fact, each team was eager to turn in the reports on the due date, wanting to know if it had "the best report". Moreover, due to the numbers of papers that students have to write, a steady progress of report writing skills is observed. At the end of the quarter, most students attending the class were able to master the simple tasks of writing a simple document on a word processor, graphing using a spreadsheet and programming using Lego's language.

A survey was performed at the end of the class to ask the students the following questions:

- Do you think this is a valuable experience?
- Do you think all freshmen should take this?
- Do you wish more upper division classes can utilize this kit?
- What improvements can be made from this class?
- Would you recommend this class to other students?
- Please recommend other future Lego projects.

The survey results indicate that students were happy with the class. On the survey, a majority of the students indicated that the Lego project had been a valuable experience and it had taught them the importance of teamwork. In addition, it had helped them in improving communication skills and writing reports. The students also indicated that this course would be appropriate for freshmen, but the project would not be challenging enough for upper-division students. The major complaint the students had was that the Lego kit does not have enough pieces so that they can build more sophisticated robots.

Data is currently being obtained and studied to determine whether this course has helped to retain students in the major and in the university. Surveys were sent out to students who took the course, who are currently second and third year students, to find out how this course had impacted them. The preliminary data indicate that out of 31 students enrolled in the pilot course, one student had changed out of a technical major; one student dropped out of the university for unknown reasons, and 4 students dropped out of the university for academic reasons. More data are being collected and evaluated. As it becomes available, it will be published in a later paper.

Conclusion

The Lego course is currently in its third year. This year, there are 40 students enrolled in the course. It had been a success among students. Many junior and senior students have expressed an interest in taking this course as a technical elective course. This course is also being considered as a required freshmen orientation course for all mechanical engineering majors. The students in the Lego classes have participated in Cal Poly Pomona's Engineering Open House during the last two years, when the College of Engineering invited families of potential students to spend a Saturday on Cal Poly campus. The students demonstrated to the parents how they built the racecars and how they programmed the RCX unit. Many proud students invited their own family members to attend the Open House to show them what he/she is doing in school. Efforts are made currently to incorporate internet into the class, so the students can document the entire design and construction process on the web. This would make it easier to share the results of this course among students, parents and educators.

ANGELA SHIH
Angela Shih is an Associate Professor in the Mechanical Engineering Dept., at California State Polytechnic University, Pomona, and has been involved with the MEP program since 1996. She received her BSAE from UCLA and her M.S. and Ph.D. degrees in Mechanical Engineering from California Institute of Technology.

M. CATHARINE HUDSPETH
M. Catharine (Kay) Hudspeth is the Director of Maximizing Engineering Potential (MEP) at California State Polytechnic University, Pomona, and also serves as the NSF AMP campus coordinator and co-directs the Academic Excellence Workshops. She received her B.A. from the University of Texas and her M.S. in mathematics from Syracuse University. She has extensive experience in teaching mathematics.