LEGO Brick Sculptures and Robotics in Education

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Abstract

In an effort to increase the hands-on creativity for students, we have started to incorporate LEGO bricks in engineering education from kindergarten to graduate school. The versatility and natural appeal of these toys have led to engineering courses for elementary school students, new college advising environments, new college courses, and even a few engineering masters theses. Students at all levels have become excited about engineering and have become interested in learning math and physics through creating with the bricks. In this paper, we outline some of the courses that use the bricks and how they have improved the interest and education of students of all ages.

I. Introduction

For the past ten years, faculty members from the college of engineering at Tufts University have been teaching engineering to students ages 3 to 30. About five years ago, NASA funded Tufts to develop engineering curricula centered on aeronautics for this age group, starting the LEGO Data Acquisition and Prototyping System (LDAPS)[1]. Our main goal is to present students with a full engineering design project (construction of an airport, for example) and teach math and science - as well as reading and writing - along the way. We choose LEGO™ bricks as the engineering tool set because of its versatility and its computer interface[2]. To date over 4000 students across the United States have learned engineering from kindergarten to college through this program.

The LEGO bricks are used in college curricula as well, acting as the base material for introductory courses for freshmen and senior design projects[3]. Last year, Tufts formed an alliance with National Instruments and LEGO to develop the software for the next generation of LEGO bricks: the RCX™. The RCX is a LEGO brick with a microprocessor inside. This allows the students to leave the computer and animate objects and data acquisition remotely. The RCX led to a number of new courses, both in the college and in the precollege arena, that have caught student attention and have effectively taught engineering concepts with unprecedented student participation. The best part of it all, though, is that the college students and the kindergartners are using the same hardware and software. The materials have essentially no limitations on what can be done with them, but rather are designed to grow with the student.

II. College Designs

LEGO bricks and the RCX form the hardware backbone of a number of classes in the Mechanical Engineering Department at Tufts University. We use the bricks for advising, introducing engineering, teaching experimentation methods, prototyping senior design projects, and even for some masters theses. They have been used in the dorm room to play laser tag and

have flown on the NASA KC-135 experimental aircraft acquiring data and controlling fans. Below, we outline how we have used them in two of the undergraduate courses.

Figure 1: Kinetic Sculptures

II.I Freshman Advising

Rather than meet with freshman advisees twice a semester (before school starts and before finals), Tufts has an advising option that allows students to work with a professor on a research project and therefore meet weekly with their advising group. Instead of performing research, our group decided to build with LEGO bricks. Last year students built small drop-tower experiments and used small video camera to see how the experiments behaved in a real drop tower. This year, students took advantage of the new RCX technology to build a complete kinetic sculpture (see Figure 1). The eight students divided into four groups of two and built four different legs to the sculpture. Two of the four legs are visible in Figure 1. In one leg, the golf ball rolls down a zigzag track and then pops out the bottom, causing the RCX to sing a song. In another, it drops down a chute, then is lifted back up by an elevator to go down a second chute. In the third, the ball triggers an animated scene of a LEGO St. George attacking the dragon. In the forth, the ball flies off a ski jump into a box and then rolls back to the main tower. The students had a lot of fun building the different legs and the weekly meetings increased their overall satisfaction from a 4/5 to a 5/5 on advising scores. From an advisor point-of-view, these weekly meetings resulted in far better advising than the old style. Every week, students asked for advice on their courses, but also during the building often discussed issues they were having with various courses in a very open environment. The advice ranged from what courses to take, to how to do better in introductory physics, to getting signatures and discussing the pros and cons of taking a course pass/fail. The overall cost to start such a program is relatively cheap, as all that is required is some LEGO bricks. We actually started the course with a field trip to Toys 'R Us.

II.II Freshman Courses

We have developed two courses for the engineering freshman or the curious liberal arts major: one on how things work[1] and the other on robotics. The robotics course (Introduction to Robotics) was run for the first time with LEGO bricks last year and was highly successful. The main goal of the course is to give the students a feeling for engineering design and show them why they need to take the many required physics, math, and chemistry courses in their first two years.

Figure 2: Laser Tag

Every three students in the robotics course got an RCX and a set of LEGO bricks and sensors and ROBOLAB software. The course met twice a week (it was worth only half a regular course - 1/2 a credit): once for lecture and once for a competition. Figure 3 shows the syllabus of the course. The competitions included building robots that could navigate a known maze, robots that could follow a spotlight shown on the ground in front of it, and robots that could play laser tag. In laser tag, (Figure 2) each robot was assigned a number.   Using their infrared (IR) ports, they
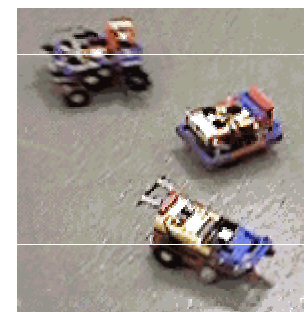
would "shoot out" their number once a second while continually checking for a "hit" from someone else's number. After they had been hit 4 times, they played a death march and then stopped. The last robot standing in the ring won. The final competition was modeled after a national fire fighting robotic competition. The students had to build robots that would navigate a known maze and blow out a candle that was arbitrarily placed in one of the rooms. They had three weeks to complete this task. Three groups actually succeeded in finding the candle and blowing it out. Students from all three of these groups submitted their robot to compete in the national competition in the spring.

		9/11	Class outline
9/14	How LEGO bricks work	9/18	Programming lesson
9/21	History and Terminology	9/25	Line follower (for fun only)
9/28	computers, A/D and DACs	10/2	Smart Fans
10/5	Motors, gears and sound devices	10/9	Maze
10/12	Sensors	10/16	Fetch
10/19	machine vision	10/23	Laser Tag
10/26	TEST	10/30	go over test
11/2	Real Robots	10/6	prelims
		10/13	Final Competition

Figure 1: Syllabus for Freshman Course

Student enthusiasm was extremely high in this class. Students would typically spend more time on their robot than on any of their other courses; coming early to class, and staying later to "add one more thing." The students rated this course a 4.9/5 on the final evaluation, often commenting how the workload in this course did not seem like work and was a lot of fun. They also learned a lot about engineering design and efficient programming. Since every group was free to create any design they choose, competitions often ended in design discussions between groups. On the programming side, one student found that after wrestling with a program that had over 400 processor commands, he scrapped everything to develop a new "...final code [that] was rather simple". The greatest complaint in the course was that they did not have enough LEGO bricks and sensors. As a teacher, listening to the groups was very rewarding. They would be arguing about design limitations, programming issues, and even timing and acquisition issues. Students were always fully engaged in the lecture portion of the course because understanding this material would lead to a better robot.

II.III Introduction to Experimentation

For the past three years, we have taught a required course on experimentation techniques to junior mechanical engineers using LEGO bricks and LabVIEW software.[3] The main goal of this course is to teach students how to create, instrument, interface, execute, and report an experiment. The LEGO bricks allow them the flexibility to create their own experiment, write their own interface and analysis software, and actively compare their results to those of the group next to them. In the past, students have measured temperature distribution on a fin, measured the expansion of balloons due to heating, built and calibrated a strain gage, and measured the force required to pull apart two LEGO bricks.[2,3]

This spring was the first time that they incorporated the RCX and the ROBOLAB™ software. Since ROBOLAB is written in LabVIEW™ (from National Instruments), the students can easily expand their analysis programs to take advantage of the full processing power of LabVIEW. Our goal for this upcoming year is to dedicate the semester to a single theme, integrating heat transfer, fluid mechanics, and dynamics into the problem. Students designed an automatic TANG™ dispenser. The user specified a mixing temperature and a volume ratio and the machine did the rest. In the first month, they perfected the heating system. This system continually monitored the temperature of a beaker of water and turned a heater on and off using a relay and the RCX. They performed this experiment, wrote a final report, and then returned to the lab and repeat the exercise. This allowed them the chance to improve both their experiment and their report based on what they found the first time. They also compared their measured results of how long it took to heat the water to theoretical calculations. At the end of the month, each group presented their results to the rest of the class. During this time, they learned in the lectures how the temperature sensors work and how to program the RCX to do the control loop. By this time they started learning about sampling theory in the class.

In the second month, students built, calibrated, and tested a flow meter and an RCX-controlled valve. This valve controls the final dispensing of the mixed TANG drink to the user. They did the experiment on two different occasions, compared to theoretical estimates, and turned in two different reports. This allowed them to learn from their mistakes - both in the lab and in the reports. The month ended with student presentations. In the third month of the semester, they built their own force sensor using an aluminum beam and two strain gages. They calibrated these sensors and built a system that dispensed a given weight of the TANG particles into a bucket mounted to their force sensor. In the final two weeks of class, they combined all three components to build their final project. In the end, a user will specify a TANG to water ratio, a water mixing temperature, and the amount they want in their cup and the dispenser system went to work. In their final reports, the students outlined the limitations and uncertainty of their manufacturing process and compared each component to the theoretical models.

By giving the coherent thread of the manufacturing process through each of the experiments, we maintained student enthusiasm and interest. By making the students repeat the experiment after having written the final report, we gave them the chance to make the changes they suggested in their conclusions. By forcing the student to rewrite the report, we could reinforce writing style and structure.

III Precollege Courses
We have worked with a number of precollege schools to teach engineering[4], but the first of these to actually use the ROBOLAB material and the RCX was by Shady Hill School in Cambridge, MA. There the RCX provided the tool set for a new eighth grade course entitled Physics by Design. In it, we teach the basic principles of mechanics and electricity/magnetism through engineering. Much of the lab work is done using LEGO bricks, the RCX, and ROBOLAB. Students began the year by building simple RCX vehicles, which they used to learn about velocity and acceleration. Later, they built more complicated vehicles: slow cars after studying friction and gears (last car across the finish line wins), line-following cars using light sensors, and relay racers that signal the next car on the team to start by sending it an IR signal. By letting

them design and create, they gained a pride of ownership, as one student said: "I like it when the car does what you want and you think, 'Hey, I figured out how to do that and I made it work. That's cool.'" Other LEGO projects include music boxes with dancing figures on top, "Rube Goldberg" machines, balances that can weigh objects to the nearest gram, and a miniature golf course. The class also designed robots for the Tufts fire-fighting robots contest and competed with the Tufts freshmen.

So many students signed up for the course this year that we had to hold a lottery to choose the participants. Next year we hope to offer two sections to help meet the demand. The students have responded to the course enthusiastically; as one wrote on an evaluation: "It's been the most fun I've had in class for years. The LEGOs are a great learning tool. If I could, I'd come for recess."

IV. RCX and ROBOLAB Capabilities

The RCX (figure 4) is a microprocessor embedded in a LEGO brick (8x12 pins). It grew out of the (and Fred) "handyboard" originally developed at MIT and can be the brain of a robot, can acquire data in remote locations, or it can simply control the automated house of the future. It has three sensor inputs and three outputs. The outputs can control motors (up to 8 speeds), lights and other devices. The inputs are multiplexed to a 10-bit A/D and can read almost any sensor available. LEGO builds temperature, rotation, light, and touch sensors. Finally, the RCX has 4 on-board timers, an infrared (IR) link allowing RCX-RCX communication, a sound generator and a clock. The IR port allows

Figure 2: The RCX (and Fred)

students to design robots with distributed intelligence using multiple RCXs. For instance, one child used two RCXs to play a piano piece: one played the bottom hand and the other played the top hand. The IR was used to synchronize the two hands. The RCX also has the capability of logging sensor data. It can take up to 2000 points as fast as 180 Hz or as slowly as 24 hours between data points. Further, the RCX is a multi-tasking environment, so that one can acquire data while simultaneously performing other tasks (like driving around the room).
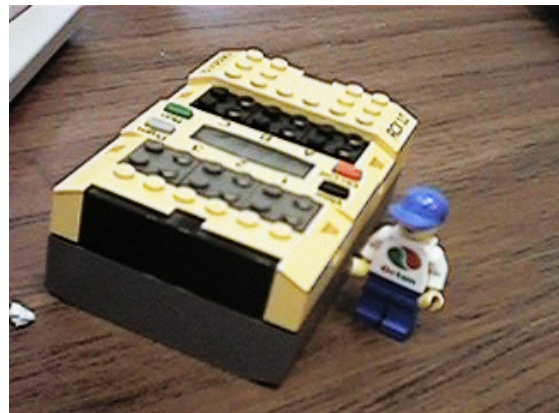
V. Conclusions

Incorporating LEGO bricks into any grade adds an element of fun that motivates the learning of the material. From kindergarten to college, students get very excited about building, controlling, and competing when it is something they can create - whether it is a robot or an experiment. In the future, we want to incorporate LabVIEW (ROBOLAB) and the RCX into all engineering junior-year courses. This would mean that in the sophomore year, students would learn how to program, how to write reports, and how to analyze the data. In the junior year, then they would use this information in each of their courses to explore examples of the material in the course.

For instance, this will allow them to actually measure the drag on an object rather than watch a demonstration. It will also allow them to change the shape of their object (or the flow speed) and see how that affects the drag force. Because the RCX is autonomous, they can actually build it into their object and the RCX can measure the acceleration of the object as they throw it through the air. No longer must the experiments be tied to a computer.

In the elementary schools, we hope to see engineering provide the link between the science in each grade as well as linking the science to the other subjects in any particular grade. The LEGO bricks provide an exciting way of allowing the students to be creative and gain ownership of what they do. They also motivate the students to learn the material so that they can improve their designs.

VI. Acknowledgements

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