Engaging Students: A Framework Using LEGO® Robotics to Teach Problem Solving

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"Problem Solving Using LEGOs" is a three-credit hour course offered at Pace University of Pleasantville, New York and New York City. The class uses a project-based learning environment and teaches robotics, computer programming concepts, and problem solving skills to Pace students of all majors. Students work in teams toward the common goal of developing logical and creative solutions to problems using LEGO® robotics technology known as MINDSTORMS®. They perform service learning by going out to area middle schools, teaching students and their teachers and coaches about the LEGO robotics technology, and exciting the middle school students with a fun yet valuable experience in science and technology. This paper discusses the effect of service experiences on teaching and learning. Furthermore, this paper describes how students respond and develop when this strategy is implemented.

The first university to institutionalize service learning is thought to be the University of Cincinnati (Varlotta, 1996). Since then many institutions have embraced the notion of linking college students to the community via service learning. Dardig (2004) attempted to find a model of service learning for her course but was unable to locate anything similar, so she developed the course Urban Connections: Columbus Behind the Scenes. Professor Dardig seized the opportunity to help students explore the important links among academic disciplines in her course and to take a more holistic and integrated view of their studies and the world. Gujarathi and McQuade (2002) have established intellectual and pedagogical legitimacy for integrating service learning in their intermediate accounting course. These Bentley College professors revised their accounting course to include a service learning component in which students could offer professional assistance in bank reconciliation, general ledger, accounts receivable, accounts payable, etc., to local agencies. Likewise, Mark Stemen, coordinator of the Environmental Studies program at California State University Chico, created a service learning component for his course Nature and Society (Stemen, 2003). Regardless of the subject, more and more educators are seeing the value of service learning and redesigning their courses to include this vital component.

Although studies clearly indicate that alternative pedagogies, not lecture, are of great benefit to students, Siegfried, Saunders, Stinar, and Zhang (1996) and Becker and Watts (1996) report that an overwhelming majority of instructors still rely solely on the lecture mode of information transmission. A reexamination of the classroom paradigm is further supported through the work of Phillips (1984), which established that we remember 10% of what we hear, 15% of what we see, 20% of what we hear and see, 60% of what we do, 80% of what we do with active reflection, and 90% of what we teach. The goal of this paper is to detail a particular active learning technique, service learning. Well-planned service learning projects can take advantage of hearing, seeing, doing, and reflecting activities. This paper describes a course we have developed which reinforces

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problem solving principles through practice, i.e., teaching. Based on the results of Phillips's research, it is our hope that this practice will also have the added benefit of increasing the recollection of robotic principles over time.

The remainder of this paper focuses on one form of service learning, student-based instruction, and provides an example as well as an assessment of service learning at Pace University, the pedagogical methodologies employed, the students, and the course.

Service Learning at Pace University

Pace University is a participating member of Project Pericles, a national initiative funded by the Eugene M. Lang Foundation that encourages participants to develop institutional and individual conviction for the value of community service. Pace University interprets its mission of *opportunitas* as a mandate to collaborate across constituencies, both internal and external, to create an "engaged campus" (Pace University, n. d.). Thus, Pace University requires all students to complete a three-credit core curriculum service-learning course before graduation. The course described here is one of several that fulfill this requirement.

A typical service learning course at Pace University requires anywhere from ten to twenty hours of service with selected community-based organizations or schools. Faculty who teach service learning courses have found that there are numerous benefits to extending the boundaries of the classroom into the community. One of the key benefits to using service learning as a pedagogical tool is that this hands-on approach offers the student an opportunity to apply the material learned in the classroom immediately. The service experience elucidates the relevance of the course content. The service opportunities seek to further students' civic education while providing skill development that is valuable for career preparation. Hence, service learning is a complement to classroom learning. Service learning can be a teaching tool that focuses on critical thinking, problem solving, project management, and civic and community responsibility.

Problem Solving Using LEGOs

Problem Solving Using LEGOs is an introductory, robot-based design course that not only extends efforts in the field of computing and robotics but also serves the community by establishing robotics clubs in middle schools located in New York City and Westchester County, New York. As we developed this innovative new course, we established these specific objectives:

- The course exposes college students to the excitement, spirit, and intellectual substance of the physical sciences and engineering through hands-on robotic design projects.
- The course encourages explorations spanning a wide range of disciplines, including physics, computer science, mathematics, biology, engineering, and art, and is accessible to all college students with only the university-wide course Introduction to Computing as a prerequisite.
- The course has a civic engagement component that uses the pedagogy of community-based learning to connect students to their local community and sensitize them to the challenges of problem solving.
- Students are expected to demonstrate abstract robotic concepts acquired through concrete hands-on robotic manipulation by mentoring in middle school LEGO clubs.
- Students in the course will provide individual instructor training for those teachers who want to become coaches and create a LEGO club at their middle schools. In addition, they will prepare educational DVDs to complement their instruction.

The Seidenberg School of Computer Science and Information Systems (CSIS) offered the course as a pilot for the first time in fall 2005, with the coauthors serving as the instructors of one section on each of the Pleasantville and New York City campuses. Almost all of the assignments and activities in the course, both in Pace classrooms and in middle schools, were team-based, challenging groups to work together

to attain the common goal of each individual project while respecting individual contributions and differences of opinion. Participants in this course developed stronger skills in logical thinking, critical analysis, working effectively in teams, and oral presentation, as well as increasing their understanding of the value of community service and their general interest in science and technology.

The course content was based on the LEGO MINDSTORMS robotics technology product, which was designed for individuals aged 9 and up. This equipment allowed young students to learn the concepts of robotics technology and computer programming in a fun and engaging environment. For the college age student targeted by the course, the robotics set design allowed the Pace student of any major to learn the basics of using the material in a short time. Middle schools who participated in the course were given assistance in forming LEGO clubs and information on entering the FIRST LEGO League tournament, an international competition whose regional tournament has been hosted each year by Pace University.

PARTICIPANTS

The participants enrolled in this course ranged from freshmen to senior undergraduate students with varying majors. Table 1 shows a detailed breakdown of the students and their rank.

Students representing various training backgrounds, genders, ethnicities, and cultures provided a variety of different perspectives regarding the use of robotics. Participation from students of varying majors and varying ranks further enriched the classroom dynamic. The participants included 17 students (3 English majors, 5 business majors, 2 computer science majors, 4 psychology majors, 1 nursing major, and 2 undecided). Table 2 shows a breakdown of the students enrolled in the course.

Two students had some programming experience of between 6 months and 1 year, and the remaining students had none. Three students had previously worked with LEGOs, and none had any prior engineering experience or knowledge.

PEDAGOGY AND PRACTICE

Problem Solving Using LEGOs consisted of two parallel instructional components, lecture and open laboratory. The lecture portion of the course met 1 hour per week. Lecture topics included basic robotic principles, creative thinking, problem solving, and elementary programming concepts. The lectures were typically 30 to 40 minutes long and included an in-class activity.

The laboratory sessions enabled students to explore robotics concepts and apply what was presented in the lectures. Students built new robots from scratch for each assignment, producing a new mechanical design to complement the software they would write. Thus, the students obtained hands-on experience with building and programming robots in an informal environment. The course included four laboratory exercises. Each of the exercises required two to three lab sessions to complete. Students worked in groups of three or four and rotated the various roles of programmer, engineer, and researcher.

OPEN LABORATORY: LEGO EXERCISES

We designed the first exercise, "The Tricycle," to introduce students to ROBOLAB and the various pieces of LEGO robotic kits. Students needed to become familiar with the small LEGO RCX unit. See Figure 1.

Table 1. Student Rank Distribution (n = 17)

Freshmen	Sophomores	Juniors	Seniors
21%	22%	23%	34%

Table 2. Student Major Distribution (n = 17)

Major	Percentage of Students
Business	17.65%
English	29.41%
Computer Science	11.76%
Psychology	23.53%
Nursing	5.88%
Undecided	11.76%

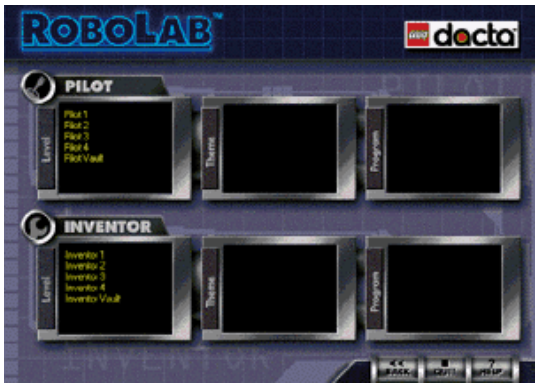
Figure 1. LEGO RCX controller unit

This unit contains the CPU and input/output connections to control the robot actions. The ROBOLAB (see Figure 2) is an icon-based programming environment. It was designed to be easy to learn, even for people who have had no prior programming experience. The ROBOLAB programming software has two levels for programming, the RCX PILOT and INVENTOR. Divided into four levels each, with stepped logical progression from one level to the next, there is a smooth progression from PILOT 1 to PILOT 4 and then from INVENTOR 1 to INVENTOR 4. All of the levels are available through the ROBOLAB Main Menu. PILOT is a very fast template-based programming environment.

The first exercise required students to build a single motor chassis with three wheels and to program the vehicle turn on motor A in the forward direction for 3 seconds, stop the motor, then turn on motor C in the forward direction for 3 seconds, and stop the motor. Repeat this forever. See Figure 3.

The hardest part of this task was building a structurally sound chassis. Affixing the motor and determining the proper gears and axles to connect the motor to the robot wheels to implement a required gear ratio was the next biggest challenge.

Figure 2. ROBOLAB



We developed the second exercise, "Pace NASCAR Race," to reinforce the idea of perceptual affordance and the need of sensors for navigation. For this exercise we allowed each team to join another team and decide which chassis they would use for the race. Students had to construct a four-wheel chassis such that it could turn. The "race track" consisted of one turn. Students could use a touch sensor or a light sensor (see Figure 4) to keep the robot on the track. They also had to enable the robot to accelerate. The most time-consuming aspect of this assignment was programming the robot, as it takes significant trial and error to make the robot turn at the specific angles of 90 and 180 degrees and to resume its direction of motion.

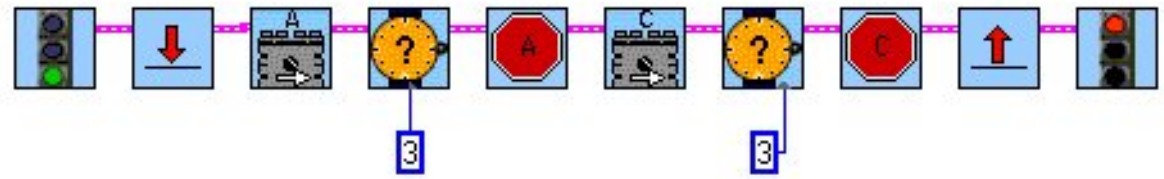
We modeled the third exercise, "Damsel in Distress," after a simulated search and rescue event. For this exercise, students designed robots that were able to navigate through a maze using sensors to aid in their exploration of the area. The goal was to rescue the damsel in the quickest time possible.

In the final laboratory exercise, "Pick-The-Can," we required students to employ previously gained knowledge to solve a fairly sophisticated task of building a robotic gripper that could grasp soda cans. This last exercise reinforced the use of sensors and robotic design.

Impact of Service Learning

Pace University and the various middle schools developed partnerships that provided exchanges of resources and talent in addition to exposing students to new career choices. The Pace students had an exciting time interacting and teaching the middle school students how to construct and program the robots. We placed the Pace students into teams consisting of four or five members. Each team elected a project leader, two designers, and a programmer. The team with five members had two programmers. We explained to the class that each team would be assigned a middle school to assist for the LEGO Tournament as well as give a robotic presentation to the middle school students. The project leader

Figure 3. Sample code in ROBOLAB



for each team picked the middle school that his or her team was to assist out of a hat.

For the first 7 weeks of the course the Pace students completed the four lab assignments discussed in the previous section. The remaining 4 weeks were spent working with the middle school students. They met with the middle school students both in and outside of the class.

RESULTS

Based upon the student and client responses detailed below, we consider the service learning component of the course to be a success. The Pace students achieved many of the learning outcomes set forth at the beginning of the course. They enjoyed helping the middle school students. The Pace students were motivated to excel in their robotic skills and in their mentoring because their middle schools would be competing in a tournament shortly after the conclusion of the course. A total of approximately 50 middle school students participated in the sessions.

THE COURSE

Figure 4. Robot with light sensor

The Seidenberg School of CSIS was able to allocate enough funds to purchase six LEGO robotics kits to support the course. Four area middle schools, including one school which partnered with the course section taught on the New York City campus, participated in the course, and all four formed LEGO robotics teams which competed in the FIRST LEGO League tournament held at Pace. Several Pace students volunteered to participate in running the tournament, and at least one New York City campus student volunteered to participate in the after school mentoring program run by one of the partner middle schools. The course continued to be popular. Within a few days the registration for the Spring 2006 offering of the course on each campus was completely filled, generating wait lists of 16 additional students in New York City and 12 in Pleasantville.

THE STUDENTS

Student evaluations of the assignment were positive. Likert scores were all "agree" or "strongly agree." All students either "agreed" or "strongly agreed" that the service learning activity and labs should be used in future classes. Specific comments from the students included the following: "My favorite part of this course was being able to apply what I learned," "I enjoyed sharing my skills with the middle school students," and "The group labs made me think–yet it was fun!"

The following are some of the "wishes" the Pace students expressed: "I wish that my group could have spent more time with the middle school students," "I wish most of my courses were taught in this fashion," and "I wish that we had video-taped our sessions with the middle school students."

LESSONS LEARNED AND RECOMMENDATIONS

The inclusion of service learning in the curriculum often demands a reconfiguration of traditional methods of learning and teaching. As with any new approach, the instructor has to make changes, and integrating service learning is no different. This transformation in pedagogic methodology poses new challenges for instructors and students. First and foremost is the challenge of obtaining middle schools willing to participate. We found that without sufficient preparation and screening it was difficult to organize and establish the various service-learning partnerships. Secondly, there were middle schools that were interested but lacked the funds to purchase the LEGO kits. We were not in a position to handle these particulars, so we selected those middle schools that had a LEGO club or could afford to purchase the LEGO kits. Presently we are looking into obtaining a grant to provide funding for those schools that do not have the resources to do so. Lastly, we learned to present the expectations of the course and show samples of the students' work to the clients, which was not possible the first time the course was offered.

Important considerations and recommendations include the following:

1. Small class size is probably most feasible for the lab assignments for several reasons. Since each group requires its own equipment, the number of available LEGO kits should be determined before incorporating this tool into a class.
2. Open space and wooden or tile floors are helpful in executing the labs. We found that open space is necessary for the students to test their robots. During the semester students were unable to test the robots in the classroom, so we had to use the hallway outside of the classroom. The New York City course section was taught in a classroom with moveable tables and laptop computers that provided the flexibility to reconfigure the room to create some open space, but even in this case some teams ended up working in the hallway.
3. Time spent setting up the equipment and instructing students must be taken into consideration. All of the equipment had to be transported to the classroom and checked for proper operation before the class began. A dedicated classroom with free hours available for scheduling "open lab" time outside of class meetings would be ideal.
4. Groups of four worked fairly well. The class size and the fact that our school only has four robots dictated the size of the groups. Students reported that it was helpful to have one person operate the robot, another person to observe, and two others working on the design.
5. Sufficient time is needed to complete the lab assignments. Students took approximately 4.5 hours to complete each lab assignment. They said finding the time to experiment was very helpful in understanding.
6. Budgeting should be made available to purchase additional robotics equipment for spare parts. We have not yet encountered this situation, but we are looking for additional funds to obtain extra LEGO kits to plan for this eventuality.
7. The time of day the course is offered is important. Middle school partners are most likely to have LEGO club meetings as part of an after school program in mid- to late afternoon. If the college course is offered as a night class, many of the students may be unavailable for these sessions due to job obligations. To guarantee that students will be able to attend the mentoring sessions, it is best to offer the course starting at 2 p.m. or later.

CONCLUSIONS

Service learning is a teaching model with demonstrated benefits for both the students participating and the community partners being served. Students find value in seeing immediate applications of what they are learning in the classroom. They are given a structured environment to reinforce and augment their power in using their skills and knowledge to better society and their local community.

Our service learning course at Pace University, Problem Solving Using LEGOs, fulfilled the University goals of service learning and civic engagement. In addition, the course curriculum presents computing technology in a way that is approachable, exciting, and easily learned by college students of all majors, meeting the further goal of exposing more students to information technology in a subtle but effective way. In bringing this same excitement to middle school students, the course's most powerful expected outcome is to instill interest and excitement about computing and robotics technology in a future generation of students. In this way we hope to make a difference in the lives of these young students.

We met several challenges in order to make this course successful. We identified funds and purchased sufficient quantities of robotics equipment to allow all students to fully participate in all aspects of designing, building, programming, and problem solving. We recruited school partners with teachers willing and able to offer a LEGO robotics club activity at their schools. The schools additionally needed to secure funding or partnership grants to purchase equipment. Finally, there were logistical issues such as obtaining lab space, scheduling, and coordinating transportation of students between schools.

We know, as well, that this service learning, civic engagement approach can be successful using a variety of technologies besides LEGO robotics. At Pace University several other courses are offered which use a similar approach, such as creating web sites for non-profit organizations unable to afford the services of a professional design company or teaching fundamental personal computing skills such as e-mail and web browsing to disadvantaged communities and the elderly. A wide range of possibilities exist for development of future courses. Regardless of the particular material covered or the particular group served, the same goals can be met: to improve the IT competency and interest of both students and community partners, and to instill in students a strong sense of empowerment to better their community and society through their applied skills.

Note: LEGO®, MINDSTORMS®, and ROBOLAB™ are trademarks or registered trademarks of the LEGO Group.

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