USING LEGO ROBOTS AND LabVIEW TO IMPACT RETENTION

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Abstract

A two week program was initiated in summer 2012 at the University of South Alabama for high-achieving incoming engineering students. The program introduces students to two highly popular areas: robotics and composite materials. The participants are exposed to a graphical programming tool, LabVIEW™, which is widely used in engineering curricula, and use the tool to program LEGO® Mindstorms® robots. This combination provides immediate, visual, verification of project solutions. The students quickly gain skills and facility with both tools, creatively addressing various tasks. The program has been highly successful in capturing the interest of participants and has led to increased retention of these students in engineering.

Introduction

Recruiting and retaining students in engineering programs is a national problem [1] that has been addressed in many, varied ways. Many universities offer bridge programs for incoming freshmen to increase their success in engineering programs. [2,3] These programs are often designed to improve skills in fundamental courses such as mathematics and English as well as academic strategies. In contrast, the University of South Alabama offers Exploring Engineering (E^2) to improve the retention of *high achieving* incoming freshmen. E^2 is designed to:

- Enhance critical thinking and problem solving skills
- Expose students to instrumentation and visual programming tools
- Build community
- Introduce students to campus life
- Increase retention in engineering

Results from the first two summer sessions are encouraging and indicate that similar programs can have a significant impact on graduation rates for engineering students.

E^2 introduces students to two main engineering disciplines: electrical and computer engineering and mechanical and materials engineering. LabVIEW™ and the LEGO® Mindstorms® platform were selected as the tools for the program. LabVIEW is a useful tool, which engineering students repeatedly encounter during their undergraduate careers. LEGO Mindstorms give students an intuitive approach to programming, with immediate, visual results.

As a result of strong teaming experiences in the workshops, the students work more effectively and collaboratively in their coursework. The students also interact one-on-one with undergraduate and graduate engineering students who exhibit their enthusiasm for engineering. These relationships continue into the academic year, providing a support community for the new students.

Highly motivated, inquisitive incoming freshmen are identified for the program based on ACT scores, high school GPAs, and completed high school coursework (math, chemistry, and physics). Admission decisions are based on academic achievement and interest (demonstrated through an essay). In two years, the program has been offered to 130 students (upper 25% of the incoming freshman engineering class). Twenty-four of these students have chosen to participate in the program. Funding for program instruction and materials is provided through Alabama NSF EPSCoR, so there are no costs to participants who live in the area.

Summer Program

Students spend two weeks immersed in interdisciplinary engineering topics ranging from robotics to composite materials. A companion thread for the program is LabVIEW programming, which is integrated into each topic. Robotics and the associated programming are intriguing topics for the students and provide immediate motivation for studying engineering. The students explore instrumentation, sensors, and control using Lego Robots. They use LabVIEW to investigate material properties and behavior for metals, polymers, and composites. The LabVIEW and Mindstorms combination provides immediate, visual, verification of project solutions. Each topic is introduced by a series of short lectures followed by hands-on interactive laboratory sessions. The students quickly gain skills and facility with both tools, using creative approaches to accomplish the various assigned tasks.

Recruitment

The program is advertised during summer orientation sessions for incoming students. Students with ACT scores of 28 or above are individually contacted and given details of the summer program. Additional underrepresented students with high math scores or high school coursework in calculus were also recruited for the 2013 program.

Resources

The program is conducted by two engineering faculty, one in electrical engineering and the other in mechanical engineering. Each faculty member spends one week with the participants, presenting brief lectures and supervising laboratory activities. Undergraduate students, majoring in electrical or mechanical engineering, are hired to assist with laboratory sessions and provide role models for the incoming students. An important resource for the program is LabVIEW Lessons [4] which features activities designed to develop computational thinking and engineering design skills through the presentation of open-ended problems.

Schedule

Each day is divided into a morning and an afternoon session, each 3 hours long. A typical session begins with a brief lecture and is followed by hands-on activities. The two week schedule is given in Table 1. The sessions are deliberately left open-ended to give students creative license. This format results in very different robot implementations and LabVIEW program strategies. It also encourages informal competitions between the groups. The second week introduces applications for the robots in materials testing. At the culmination of the program, the students are assigned an open ended design project encompassing activities from the two week program.

Robotics Sessions

The students spent the first day getting familiar with LEGOs, which were used to illustrate robotics fundamentals. The first exercise was to design and construct a box with a lid, familiarizing students with the LEGO connectors and assembly procedures. The box was to contain a red and a blue ball that were both two inches in diameter. The exercise was deliberately left open-ended to give students creative license. In the second activity, students were to construct a two-motor robotic car from LEGO components, according to construction procedures outlined in the text.

The second day introduced the students to LabVIEW programming and the procedure for developing and downloading applications to the Mindstorm NXT. The main focus was on configuring and acquiring data from sensors: touch, light level, sound level, and ultrasonic distance.

Table 1. E^2 daily schedule.

Week 1 – Electrical and Computer Engineering		
Day 1	Lecture	Getting started, introductory activities
	Lab	Intro to LabVIEW, Lego Mindstorm NXT robots, building and programming a two-motor car
Day 2	Lecture	Sensors and lights, LabVIEW programming concepts
	Lab	Burglar alarm, clap-on lamp controller, light-controlled electric fan, electronic cockroach
Day 3	Lecture	Program loops and iterations
	Lab	Dice game using random number generation, three-speed fan, sound generation
Day 4	Lecture	Robotics and programming
	Lab	Cloverleaf, dancing robot, bug in a box
Day 5	Lecture	Sensor applications and concluding remarks
	Lab	Haunted house, musical instrument, grassfire algorithm, student design project
Week 2 – Materials and Mechanical Engineering		
Day 6	Lecture	Simple and Compound Machines
	Lab	Crane – mass challenge
Day 7	Lecture	Introduction to Mechanics of Materials
	Lab	Build & program robot to determine linear displacement and angular velocity of a rotating wheel
Day 8	Lecture	Light Scattering
	Lab	Turbidity
Day 9	Lecture	Communication, Concluding Remarks
	Lab	”Gauntlet” obstacle course, Generate Presentation
Day 10	Lecture	Critical Thinking retest,, Chemical Engineering Lab Tour
	Lab	Closing Ceremony/Presentations

The students built and programmed a two-motor car to start up when a loud noise was sensed (such as a hand clap). Activities from the LabVIEW lessons text included a driving test. The robots were programmed to travel in straight lines, to steer right and left, to stop after a programmed elapsed time and to spin in circles. At this point, students were becoming comfortable with LEGO construction procedures and with LabVIEW programming.

The final assignment for the day was to construct a two-motor car that could complete a four-lobe cloverleaf pattern, starting and stopping at the same location. During the morning session, students experimented with various motor control strategies to minimize the starting and stopping location offset and to minimize the loop size. The afternoon session evolved into an informal competition between the student groups in which each car executed the cloverleaf pattern on a tabletop. A magic marker was attached to each car and a large pad of paper was used to trace out the cloverleaf pattern. The groups discussed control strategies and refined their navigation algorithms to optimize the performance of their robot. A few groups finished quickly and were assigned the problem of designing an algorithm to complete a three-lobed loop with the loops oriented 120º apart.

The main assignment for the fourth day was a robot obstacle course. A table top was set up with an electrical tape starting line, an electrical tape midpoint line, and a large box at the end of the table. Each group had to design a robot to perform the following sequence of actions:

- Start on a hand clap
- Sense the midpoint line using a light sensor and emit a “beep” sound

- Approach to within one foot of the box and slow to half speed
- Continue at half speed until touching the box
- Reverse direction
- Sense the midpoint line using a light sensor and emit a "beep" sound
- Cross the start line and stop moving

The students again initiated an informal competition between their groups. Each group had very different robots and implemented the design specifications using different LabVIEW program strategies. All groups were successful in completing the obstacle course.

The final day began with a discussion of on-board data acquisition capabilities of the Mindstorm robots. Procedures were covered for configuring sensors, acquiring data, downloading data files, and porting the files to spreadsheets. In the afternoon session, eight strips of electrical tape were placed one foot apart on a table top. The programming assignment was to use a light sensor to acquire data at various motor speeds. The data was then downloaded to Microsoft Excel and was used to calculate the speed of the robot. Data was acquired in triplicate at each of three speeds. The data was graphed and some rudimentary statistical analysis was done to evaluate reproducibility.

Materials Science Sessions

As the students were now comfortable building and programming robots, the initial day of week two reviewed basic physics principles. After lecture and discussion of simple and compound machines (levers, pulleys, gears, etc.), the students designed stationary cranes to lift and hold at least 100 g. The students added an element of friendly competition by determining which crane could lift and hold the most weight or which crane could lift the required weight the highest. Interestingly, the groups chose to use different configurations of worm gears, standard gears, and/or pulleys resulting in decidedly different designs.

The next day, the students were introduced to basic mechanics of materials. Discussion on tests to analyze material properties, as well as methods of monitoring the tests, was followed with the students designing instrumentation for both a tension and a torsion test. A student assistant constructed a uniaxial tension tester with the Mindstorms and programmed it for tension-tension fatigue. This allowed the E^2 students to design either a contact or non-contact sensor to determine axial displacement – akin to a Linear Variable Differential Transformer (LVDT) used in conjunction with a universal test stand. Most groups elected to implement a stationary robot and to use either the light or ultrasonic sensor. These groups calibrated a change in intensity to a change in distance – using the LEGO "moving wall". A second undergraduate student assistant constructed a rotating wheel that had progressively wider indicators 90º apart (Figure 1). The students were asked to determine the angular velocity of this wheel, using the data collection algorithms as well as a light sensor – to differentiate every 90º. There was not much variability in this aspect of the overall design or coding.

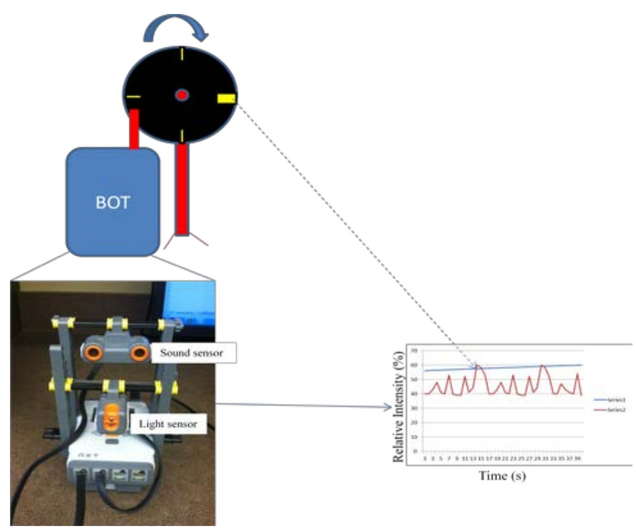

Figure 1: Representative Robot with attached non-contact displacement sensor (sound) and rotation sensor (light). Note: The associated plot illustrates that the width of the tape strip yields a broader peak, thereby allowing the determination of rotations/time.

The third day, after a discussion on basic data analysis and statistics, the groups examined properties for 0/90 fiber reinforced polymer, oriented in different ways, or metal (aluminum and steel). Each group was given a different material and conducted uniaxial tension tests on 5 replicate samples. The change in displacement was recorded by their sensor (designed in day 2), while the group manually recorded the load at specified time intervals. Elastic moduli were calculated for each of the materials and the groups discussed the difference in the moduli between the material systems. A similar exercise was conducted to determine shear modulus from torsion testing. The rotating end of the torsion tester was instrumented as in the spinning wheel. A strip of reflecting tape was placed every 90 degrees with two pieces of tape marking a full revolution. Steel, aluminum and polypropylene were repeatedly tested to illustrate different failure modes as well as different shear moduli. During this test, students manually recorded torque with respect to time, while their robot collected time and revolution information. The participants analyzed the data and calculated various material and mechanical properties.

Day four began with a communications overview, focused presentations of the workshop activities. The students also designed and programmed a robot to complete an obstacle course, The Gauntlet (Appendix), based on the American Gladiators "Eliminator." The students synthesized their knowledge in modifying their robots to complete a series of consecutive activities.

On the final day, the students toured the chemical engineering research laboratories. Parents and engineering faculty were invited for the final festivities. Before the E^2 presentations, civil, electrical and mechanical engineering graduate students briefly discussed their research projects. The students then gave their group presentations and ran "The Gauntlet", illustrating the various capabilities of the robots.

Program Observations

Working closely with the participants in hands-on activities provides ample time to observe individual and team behaviors. One observation is that the personalities of the participants have varied widely. Some are very outgoing, while others are initially very apprehensive and reserved. After the first day, all students are engaged and interested in learning about the robots. The less outgoing students find the environment to be non-threatening and become more collaborative as the workshop proceeds.

The students are organized into groups of three. The group dynamics are interesting – some students pick up the programming very quickly and are eager to try new ideas on their own. Other students "play it safe" using programming algorithms from the text with little modification. In the first year, one group settled into a format with one member doing all of the programming and the other two members managing the hardware construction.

Some students design robots that are functional, but use a minimum number of components. Other students add an aesthetic component by decorating their robots. Again, in the first year, two groups collaborated to teach their robots to "sing" a duet in two-part harmony, which was not a design requirement, but the group members found the exercise to be an interesting challenge. These groups contained two pairs of twins, which were separated into different groups.

Group strategies for meeting design specifications have been strikingly different. Some groups prefer to just start putting parts together and writing code, refining as they go, and other groups do significant planning before beginning to build any hardware. The interesting thing is that both approaches are generally successful.

After the first day, getting the students to leave at the end of the day is difficult. It is obvious that they find working with the Mindstorms to be interesting and challenging. And, it is surprising how quickly all the students learn LabVIEW and how quickly they learn to build and program relatively sophisticated robots. We have found that the open-ended exercises provide additional challenges for motivated students.

Similar hands-on activities are included in the freshman seminar at South Alabama, but do not use the Mindstorm robots or LabVIEW programming. These exercises are similar to those found in many first year engineering seminars and can be easily adapted to these courses. The South Alabama freshman seminar also includes topics intended to enhance academic skills. These are not directly covered in E^2, but are often addressed informally by the undergraduate assistants.

Outcomes

Results are positive, with both faculty and students being highly satisfied with program activities. Participants are genuinely excited about learning new things – and they are able to quickly pick up concepts.

The participants completed evaluation forms at the end of the program that help revise session content and delivery. A focus group with the participants is conducted in the following semester to identify recruitment strategies to attract a larger audience for the program. Comments from the participants include:

- *It is great to make friends even before the first day of classes started.*
- *E^2 incorporated lots of challenges that required a lot of thinking in different ways.*
- *E^2 allowed a lot of innovation*

There are two cohorts for analyzing program outcomes: program participants and the group of students who were invited to the program with comparable ACT scores, but did not participate. Data on program participants for both years of the program are given in Table 2.

This data indicates that E^2 has a significant impact on student success. The difference in composite and math ACT scores for each group is not significant (Table 2); however, the difference in the first semester GPA (Figure 2) is significant ($p = 0.03$ for one tail T Test, unequal variances). And, all of the participants have been retained in a STEM major.

The individual attention during the program may be an important factor in these statistics. Another outcome for the program is the relationships that are formed during the summer program that continue into the academic year. The participants develop study groups and also chose to enroll in the same sections of their courses, essential components of building a community of scholars. The 2013 participants

Table 2: Program Outcomes.

			ACT		**Changed Major**			**Left USA**
		#	Comp	Math	In Eng	STEM	Non STEM	
2012	E^2	11	31.3	29.6	1	1	0	0
	Non E^2	45	29.3	28.3	5	2	3	4
2013	E^2	13	27.3	28.4	0	0	0	1
	Non E^2	69	27.5	27.3	5	3	3	1
Total	E^2	24	29.1	29.0	1	1	0	1
	Non E^2	114	28.2	27.6	10	5	6	5

formed even closer relationships since several were housed in the university residence halls during the program.

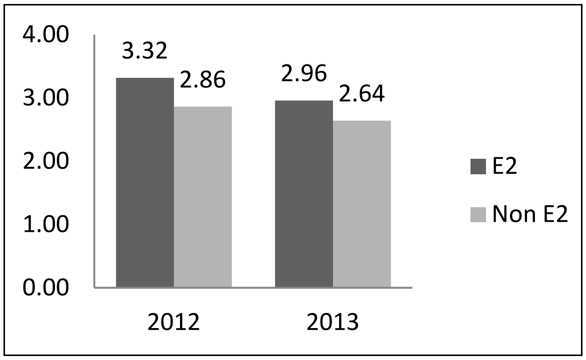

Figure 2: 1st semester GPA comparison.

Obviously as the program is conducted in future summers, larger data samples will provide more conclusive results. However, these initial results are promising.

Future Plans

Funding is available to again offer E^2 this summer, at no charge to the students. Enhanced recruitment efforts will reach more students. A housing option, at participant cost, will be offered so students who are not in the immediate area can also attend the program. Additional funds may be available to attract underrepresented students to the program.

Acknowledgement

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Biographical Information

Gail D. Jefferson earned a B.S. in Mathematics from Spelman College, a B.S.M.E. in Mechanical Engineering from Georgia Institute of Technology, an M.S. in Biomedical Engineering from The Ohio State University and a Ph.D. in Mechanical Engineering from Florida A&M University in 2005. She also served as a postdoctoral fellow at the National Institute of Aerospace. She is an Assistant Professor at The University of South Alabama, where she is also the faculty adviser for the USA Launch Society and the National Society of Black Engineers. Her current research interests include developing models and test methods to examine the behavior of advanced non-metallic, nanostructured material systems.

Sally J. Steadman received a B.S. in Civil Engineering from the University of Wyoming, an M.A. in Mathematics from the University of Denver, and a Ph.D. in Mechanical Engineering from the University of Wyoming in 1994. She served on the UW faculty from 1984 - 2003, where she made use of her interest in engineering computer applications. She is a part-time instructor at the University of South Alabama where she is also a faculty adviser for

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Thomas G. Thomas completed the requirements for a Ph.D. in Electrical Engineering from the University of Alabama in Huntsville in 1997 and joined the faculty at the University of South Alabama in August of 1998. His research interests include image processing, environmental monitoring, robotics, and engineering student outreach. He is a registered professional engineer in the State of Alabama, and currently serves as the Graduate Program Director for the University of South Alabama College of Engineering.

Kuang-Ting Hsiao received his Ph.D. in Mechanical Engineering from the University of Delaware in 2000. He joined the Center for Composite Materials at the University of Delaware as a research associate and worked on projects funded by ONR and NSF. He moved to the University of South Alabama in 2003 and is currently Professor of Mechanical Engineering and a faulty advisor of Pi Tau Sigma mechanical engineering honor society. His current research interests are in multi-scaled composites, nanocomposites, nano-enhanced phase change materials, and sensors for composite materials.

Appendix

THE GAUNTLET
Scoring

Climb Ramp

- There are 4 “lines” – each line you pass in a positive vertical direction is 5 points.
  - if you pass one line more than once, no additional points are given

Identify Ball

- If your robot can identify one blue ball to pass through 10 points.
- If your robot can identify 2 consecutive blue balls to pass through 20 points.

Navigate Maze

- If your robot successfully navigates the maze – 20 points

Stop at Edge

- The style in which you robot stops at the edge is between 0-20 points.
  - if your robot falls over the edge – s=0;
  - if your robot stops “short” or has an appendage over the edge – s=0.5;
  - if your robot stops at the edge – s=1
- Style*s is the “stop at the edge” score

Time

- You will be assigned a t value, based on the relative speed of navigation through The Gauntlet:
  - 1st place (fastest) – t=0
  - 2nd place – t=0.2
  - 3rd place – t=0.4
  - 4th place – t=0.6
  - 5th place – t=0.8
  - Higher - t=1.0
- 20*(1-t) is the “time” score.