Novel Program for Engineering Student Retention

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Abstract

Since many students leave engineering without experiencing the excitement of engineering design, a two week program was initiated summer 2012 at the University of South Alabama for high-achieving incoming engineering students. The program introduced students to two highly popular areas: robotics and composite materials. The participants were exposed to a graphical programming tool, LabVIEW™, which is widely used in engineering curricula, and used the tool to program LEGO MINDSTORM® robots. This combination provided immediate, visual, verification of project solutions. The students quickly gained skills and facility with both tools, creatively addressing the various assigned tasks. Preliminary assessments indicate that the program was highly successful in capturing the interest of the participants and should lead to increased retention of these students in engineering.

Introduction

Recruiting, teaching and retaining students in engineering programs is a national problem that has been addressed in many, varied ways.[1] The University of South Alabama has implemented a novel program to improve retention in engineering, especially among high achieving students. A pilot program, Freshman Research Experience in Engineering (FREE), was conducted last summer with extremely successful outcomes. Funding for program instruction and materials was provided through Alabama NSF EPSCoR, so there were no costs to the participants.

Students spent two weeks immersed in interdisciplinary engineering topics ranging from robotics to composite materials. LabVIEW™ programming was integrated into each topic. The students explored instrumentation, sensors, and control using Lego Robots. They also used LabVIEW to investigate material properties and behavior for metals, polymers, and composites. A series of short lectures introduced the topics and were followed by hands-on interactive laboratory sessions, culminating in an open ended design project.

A companion thread for the program was critical thinking which is fundamental to excelling in an engineering curriculum. Following a brief exposure to basic concepts, the students took an on-line test to evaluate their critical thinking skills before beginning the workshop activities. The same test was administered as a post test, with more than a 10 % increase in their skills. The maximum increase was over 30%; interestingly, this was an underrepresented minority student, whose score dramatically improved from the lower end to the high end of the group. This suggests that these types of activities may be quite successful for underrepresented populations, and should be investigated further.

The research activities were conducted in a team environment, hence the students had strong teaming experiences and are able to work more effectively and collaboratively in their engineering coursework. The students also interacted one-on-one with both undergraduate and graduate students majoring in computer, electrical, and mechanical engineering.

Highly motivated, inquisitive incoming freshmen were identified for the program, based on ACT scores, high school GPAs and completed high school coursework (math, chemistry, and physics). Admissions decisions were based on academic achievement and interest (demonstrated through an essay). The program was offered to 60 students (27% of the incoming freshman engineering class) and 12 were accepted for the program. Due to cost constraints and unknown demand, the program did not include a residential component. While the initial assumption was that most of the participants would be from the local area, half of the students came from distant cities and stayed on campus or with relatives.

Formal assessment of the program is underway. However, preliminary results are extremely positive, with both faculty and students highly satisfied with the program activities. FREE participants were genuinely excited about learning new things – and they were able to quickly pick up the concepts. In fact, they requested a challenging last task. Their parents were also exposed to their activities, through demonstrations on the final day. It was obvious that the program ignited interest in engineering. Initial data also indicates that FREE has a positive impact on student success and on student retention in engineering. The program will be expanded for coming summers.

Summer Program

FREE was designed to introduce students to two main engineering disciplines: electrical and computer engineering and mechanical and materials engineering. LabVIEW and the LEGO MINDSTORMS® platform were selected as tools for the program. LabVIEW is an especially useful tool, which engineering students repeatedly encounter during their undergraduate careers. LEGO Mindstorm robots give students an intuitive approach to programming, with immediate, visual results.

Recruitment

Funding for the program was identified late in the spring semester, so there wasn't time to reach out to high school students who might be encouraged to major in engineering. It was decided to advertise the program during the summer orientation sessions for incoming students. Students with ACT scores of 28 or above (60 students / 27 % of freshman class) were individually contacted and given details of the summer program. Additional underrepresented students with high math scores or high school coursework in Calculus were also contacted about the program.

Resources

The program was conducted by two engineering faculty, one in electrical engineering and the other in materials engineering. Each faculty member spent one week with the participants, presenting brief lectures and supervising laboratory activities. Five undergraduate students, majoring in electrical or mechanical engineering, were hired to assist with laboratory sessions. An important resource for the program was LabVIEW Lessons[2] which features activities designed to develop students' computational thinking and engineering design skills through the presentation of open-ended problems.

Program Costs

The cost of the program is about $1000 per student:

Personnel	$9,600
Lunches	1,200
Supplies	200
Transportation	400
TOTAL	**$11,400**

A one-time cost for the LEGO MINDSTORM® robots was $3,000.

Schedule

Each day was divided into a morning and an afternoon session, each 2 ½ hours long. A typical session began with a brief lecture and was followed by hands-on activities. The two week schedule is given in the following table.

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	Instrumentation for Mechanics of Materials and Data Analysis
	Lab	Tension Test (LVDT), Torsion Test (Troptometer)
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

Critical Thinking

The workshop started with a presentation, based on the keynote lecture[3] by Dr. Richard Paul, Director of Research and Professional Development at the Center for Critical Thinking and Chair of the National Council for Excellence in Critical Thinking. A PowerPoint presentation summarized main points from the keynote lecture and also introduced planned activities for the two-week workshop.

Following the presentation, the students took an on-line test to evaluate critical thinking skills[4] before beginning workshop activities. The on-line test took the students about an hour to complete. When the students returned to the classroom, a “fun” test in critical thinking was given, which was followed by a general discussion on creative and critical thinking. The students took the on-line test again at the end of the program. Student scores on the critical thinking skills pre and post tests improved 13%, from 52% to 59%.

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.

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. Different groups 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 FREE students to design either a contact or non-contact sensor to determine axial displacement – akin to an 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.

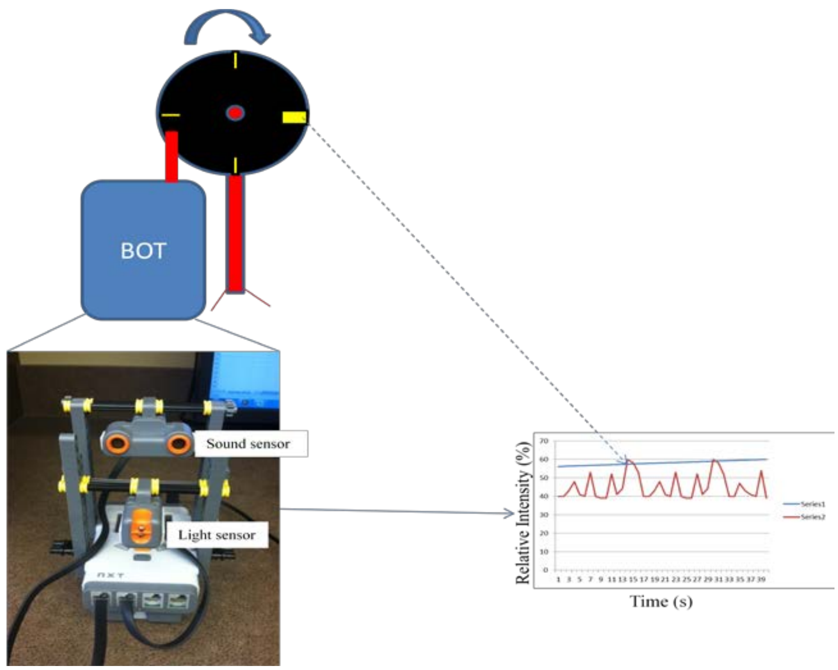

Figure 1: Representative Robot with attached non-contact displacement sensor (sound) and rotation sensor (light). The associated plot illustrates that the width of the tape strip yields a broader peak, thereby allowing the determination of rotations/time.

The third day, after a discussion on basic data analysis and statistics, the groups examined properties for either 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 polypropolene 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 retook the critical thinking exam. They also toured the chemical engineering research laboratories. Parents and engineering faculty were invited for the final festivities.   Before the FREE 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.

Observations

The personalities of the participants varied widely. Some were very outgoing, while others were initially very apprehensive and reserved. After the first day, all of the students appeared to be engaged and interested in learning about the robots. The less outgoing students found the environment to be non-threatening and actually became more collaborative as the workshop proceeded.

The students naturally organized themselves into groups of three. The group dynamics were interesting – some students seemed to pick up the programming very quickly and were eager to try new ideas on their own. Other students "played it safe" using programming algorithms from the text with little modification. One group settled into a structure where one member did all of the programming and the other two members did all of the hardware construction.

Some students designed minimalistic robots that were functional, but used a minimum number of components. Other students added an aesthetic component and decorated their robots. 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.

Group strategies for meeting design specifications were strikingly different. Some groups preferred to just start putting parts together and writing code, refining as they went, and other groups did significant planning before beginning to build any hardware. The interesting thing was that both approaches were generally successful.

After the first day, it was difficult to get the students to leave at the end of the day. It was obvious that they found working with the Mindstorms to be interesting and challenging. It was surprising how quickly all the students learned LabVIEW and how quickly they learned to build and program relatively sophisticated robots.

These exercises are similar to those found in many first year engineering seminars and can be easily adapted to these courses. We have found the exercises to be open-ended, providing additional challenges for students who are motivated.

Assessment

Since this is a pilot program with a limited number of students, assessment data cannot be viewed as conclusive. However, these results can be used to formulate future offerings and preliminary information indicates that the program was highly successful.

The participants completed evaluation forms at the end of the program that will help revise the session content and delivery. A focus group with the participants was conducted in the spring to identify recruitment strategies to attract a larger audience for the program.

There are two cohorts for analyzing outcomes for the program. The 11 students who completed the program form one group; 12 students were selected for the program, but one student dropped out after the first day (due to personal conflicts with the session times). The students who were invited to the program, but did not participate, form a control group.

				Changed Major		
	Number	GPA	ACT	In Eng	At USA	Left USA
Participants	11	3.32	30.9	1 / 9%	1 / 9%	0
Non Participants	48	2.89	29.4	7 / 15%	5 / 10%	6 / 12.5%

This data indicates that FREE had an impact on student success. The participants had a higher combined GPA and were retained in their majors and at the university in much higher percentages. The difference in both composite and math ACTs is not significant; however, the difference in the first semester GPA is significant ($p = .02$ for 1 tail TTest, unequal variances).

The individual attention during the program may be an important factor in these statistics. Obviously as the program is conducted in future summers, larger data samples will provide more conclusive results. However, results from the pilot program are extremely promising.

Future Plans

Funding is available to again offer FREE to students this summer, at no charge. 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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References

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[2] Bratzel, Barbara, *LabVIEW Lessons: Classroom Activities for Learning and Using LabVIEW with LEGO Mindstorms*, College House Ent., Knoxville, TN, 2011

[3] Critical Thinking in Every Domain of Knowledge and Belief, the 27th Annual International Conference on Critical Thinking, July 23-26, 2007

[4] The Foundation for Critical Thinking, Critical Thinking Basic Concepts and Understanding Test http://www.criticalthinking.org/pages/online-critical-thinking-basic-concepts-test/679

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 Eliminator:
    - o 1st place (fastest) – t=0
    - o 2nd place – t=0.2
    - o 3rd place – t=0.4
    - o 4th place – t=0.6
    - o 5th place – t=0.8
- 20*(1-t) is the "time" score