Teaching Basic Engineering Concepts in a K-12 Environment Using LEGO® Bricks and Robotics

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Abstract

This paper explores the impacts of basic engineering concepts of LEGO® Bricks and Robotics in Coral Academy of Science in Reno, Nevada - a Science, Math and Technology Middle and High School - collaborated with the Mechanical Engineering Department, University of Nevada, Reno (UNR). A team from middle school students designed and developed a LEGO® Robot and has competed, for the first time in the State of Nevada, in FIRST LEGO® League (FLL) using LEGO® Mindstorm technology. On the other hand, a high school robotics team built an actual robot and participated in FIRST Robotics Competition (FRC). The teams had partnership through NASA Nevada Space Consortium grant and some local sponsors. The school, at the beginning of the first year, set up Middle School LEGO and High School Robotics clubs where various basic engineering concepts were covered. The Robotics club eventually transformed to an elective Robotics class. Several local engineers, graduate students, and parent volunteers contributed to these projects. At the end of the academic year, the projects provided a great success in the following five areas; (1) Student achievement and inspiration, (2) Creating a pipeline for the Science, Math, Engineering and Technology workforce, (3) Public-private partnerships and institutional collaboration, (4) Involvement of women and racial/ethnic minorities in this very valuable experience, (5) An excellent recruitment tool for engineering colleges. This paper will present the details of these implementations and current assessment results.

1. Introduction and Background

Math and science are described as the most difficult classes by middle and high school students. Concepts in these classes are not intuitive and traditional lecturing may not always provide complete understanding of the subject matter. Because the emphasis at Coral Academy of Science[1] (CAS) is mainly on math and science, there is a continuous effort to enhance the teaching by means of specific clubs and electives where hands on projects are implemented. LEGO® is deemed as an excellent tool to attract students on some real world experiments. FIRST LEGO® League[2] is a competition for middle school students to design a robot using LEGO® bricks to accomplish a series of missions. CAS has participated FLL in 2003 and 2004. Whereas, FIRST Robotics Competition[3] is a high school competition to design a larger scale high-tech robot to do a series of tasks while competing with other teams. CAS has competed in FRC both

in 2004 and 2005. CAS administration and staff are very much supportive of both of FLL and FRC because these projects inspire, challenge and educate the students in the areas of science, math and technology and that is what the school is founded for.

Coral Academy of Science is a science, math and technology oriented college preparatory school with 25% of the students on the free and reduced lunch program. It is a public charter school, funded by tax dollars, but operated by an independent board. In spite of all difficulties so far, the school is managed to be successful locally. Last year, the Nevada Department of Education recognized CAS as a 'High Achieving School', first to a charter school in Northern Nevada. The school encourages its students to get involved with science, math and technology competitions. CAS teams rely heavily on grants and contributions because of its small size.

Educators have used LEGO® Mindstorm to teach robotics[4,5], computer science[6,7], design[8], soccer playing[9], race car[10] and incorporation with LabView[11,12]. Wang et.al[13], (2004) have utilized LEGO® Mindstorm technology in their freshman classes to keep students in engineering discipline. IEEE and SME student chapters have extensively used FLL and FRC in their regional or national meetings.

2. FIRST LEGO® League for Middle School Students

FIRST LEGO® League is an international program that combines a hands-on, interactive robotics program with a sports-like atmosphere for children ages 9-14. Teams consist of up to 10 players with the focus on such things as team building, problem solving, creativity, and analytical thinking. Each September, a new Challenge is unveiled to FLL International teams across the world. Over the course of 8 weeks, they strategize, design, build, program, test and refine a fully autonomous robot capable of completing the various missions of the FLL International 'Robot Game' using the LEGO® MINDSTORMS™ technology. They also search the web, talk to scientists, visit the library and develop compelling presentations based on the FLL International 'Research Assignment', which relates to a problem or opportunity facing the world today.

Coral Academy of Science's LEGO Club consisted of 19 members in 2003. The club worked on the competition by meeting regularly since the beginning of the school year. Then, near to the competition, the team members met at least twice a week and some weekends. They also received external consulting and support from UNR. The team designed and developed an FLL robot to accomplish the missions on the playing fields. The theme for 2003 was 'Mission Mars'. Some of the missions were; to release the rover stuck on the sand hill, to connect the habitation modules, to clear the dust from the solar panel, etc. The hard work was paid off and the team was placed among three teams to go to Northern California State Tournament. The regional qualifying competition was held on November 15, 2003 in Sonora, CA. The Coral RoboRats as the only Nevada team was awarded the 'best research project' among the other participant schools and advanced to the next round. In 2004, there were 10 students in the club. The theme was to find ways to help people with different levels of physical ability. The specific missions to be accomplished by the robot included putting the CD away, playing the ball, climbing the stairs, feeding the pet, reading the bus stop signs, etc. The regional qualifying tournament was on

November 20, 2004 in Sacramento, CA. The team could not advance the state championship that year

During meetings, some engineering concepts in rigid body dynamics like gears, gear ratios, speed calculations, combination of pulleys, force, friction, torque, momentum, inertia, equilibrium, structural stability, sensors, etc. were covered. In addition, some club members worked on other aspects of the competition like writing a research paper, presentation, fundraising, web design, etc.

3. FIRST Robotics Competition for High School Students

The FIRST Robotics Competition is an exciting, multinational competition that teams, professionals and young people to solve an engineering design problem in an intense and competitive way. The program is a life-changing, career-molding experience and a lot of fun. In 2004, the competition has reached more than 20,000 students on over 900 teams in 27 competitions. The teams come from Canada, Brazil, Ecuador, Mexico, Great Britain, and almost every U.S. state. The competitions are high-tech spectator sporting events, the result of lots of focused brainstorming, real-world teamwork, dedicated mentoring, project timelines, and deadlines.

The CAS Robotics Club[14] was first established by 11 very interested students to meet the challenge for 2004 Competition. The team met regularly every week since the beginning of the school year. Before the competition started, some science and engineering principles like; Statics, Kinematics, Dynamics, Hydraulics, Pneumatics, Strength and Structures, Design Structures and Mechanisms, Electricity and Programming were covered in a lecture format. Then related examples were demonstrated using the engineering kits at hand, showing downloads from certain websites and watching available video cassettes/CDs. The computer teacher and one of the engineers helped the team with the AutoCAD design. A graduate student from UNR assisted in the Web Design. Besides regular club meetings, team members were exchanged ideas through online forum at Club's website. A machining facility at International Game Technology[15] (IGT) as one of the Engineer Mentor's workplace has been used during the fabrication process. Financial support for the club was mainly through NASA Nevada Space Consortium. The team was awarded $10,000 as a partner. The competition was held on March 31 through April 2, 2004 in San Jose, CA. As being a rookie team and not experienced in the other aspects of the competition, the team could not qualify for the finals among the other 45 teams.

This endeavor was continued in Spring 2005 with 12 students. This year, the team was in close contact to get some corporate sponsorships; secured $6,000 from the local companies for FRC and then NASA matched this donation. The team got help from professional engineers (3 mechanical and 1 electrical), graduate students from UNR, parent mentors, professors, teachers and students. The team members split up in the meetings to various committees such as fundraising, mechanical, web design, presentation etc. and followed their agendas. Then, the team came all together and shared the committee outcomes with each other. The meeting minutes and decisions were posted in the forum on the club's website. In the fabrication process, IGT was committed to help this year, too. The mechanical committee met in IGT for fabrication as needed. The team was also capable of doing some woodworking and metalworking in the

school. The team used the school for main meetings for all other committees. Finally, the team finished the robot by the deadline on February 22, 2005. The competition is going to be held between March 30 and April 2 in Las Vegas, NV.

4. Implementation and Results

The school's science teacher has developed a post-competition survey (Appendix A) which was conducted to the most participants (Table 1) of both competitions for two consecutive years. The two-page long survey consisted of about 30 items in Likert Scale[16]. The major categories in the survey were demographics, the intent of involvement with the programs, the impact of programs, evaluation of the partnership and other areas. The respondents were asked statements to which they were expected to answer whether they Strongly Disagree, Somewhat Disagree, Somewhat Agree or Strongly Agree and the responses were coded from 1 to 4, respectively. The mode of each item from Section 3 of the survey was taken to analyze each item as shown in Fig. 1. The mode of each item was determined as 4 with the exception of 'inspired' item which was calculated as 3.

Table 1: The surveyed participants

	FLL	FRC	Total
First year	**11**	**5**	**15**
Second year	**10**	**6**	**17**
Total	**21**	**11**	**32**

Results have shown that most of the students had fun, challenged and learned in Science, Technology, Engineering and Math (STEM) and wanted to get into a better college. Majority of students expressed that they have enjoyed and had a better understanding in STEM as shown in Fig. 1. The survey also implies that they inspired and increased their self-confidence about engineering concepts. Participants think that the competitions will help them to find a STEM related job. The students were all motivated and wanted to do it again. Total of four women have been involved as 13% of all the participants. Fig. 2 shows the ethnic distribution of the participants.

Students established positive and productive interaction among themselves through team building and brainstorming activities. These activities most often resulted in development of new and useful ideas. For example, some of the FLL team members solved the problem of having limited slots for downloading programs by intelligent use of sensors as triggering different parts of the program when needed.

In 2004, several teachers incorporated different aspects of the FRC in school's curricula. One of the major enhancements was to open up an elective Robotics class where Carnegie-Mellon's Robotics Academy[17] curriculum was taught along with others that support FRC. The curriculum enabled students to apply the math, science and technology concepts and skills during the elective class. The computer science teacher also assigned and taught FRC related projects such

as web site development and web maintenance, AutoCAD drawing, C programming language. The students in the web design committee also met with another UNR graduate student for this year's 3DS-Max animation. For the second straight year, FRC team was successful to get a NASA grant and multiple donations from local companies.

Involving in the FIRST Robotics Competition has helped the students, school and community at large in many ways; for instance, teachers have increased their communication with the parents and other community members. The team has been building a lot of self-confidence as a result of this experience. They have learned how to work in a team with diverse background and interests. They learned from the knowledge, skills, experience and expertise of the other adults namely the engineers and university mentors in the group. Students started to like math and science classes and they wanted to stay in school longer. More high school students recently have registered to CAS due to this competition. The students have learned more about the resources in the community when they looked for the competition funding. The partnership with local companies not only brought human resources but also provided the team with funds and access to facilities which would be out of reach otherwise.

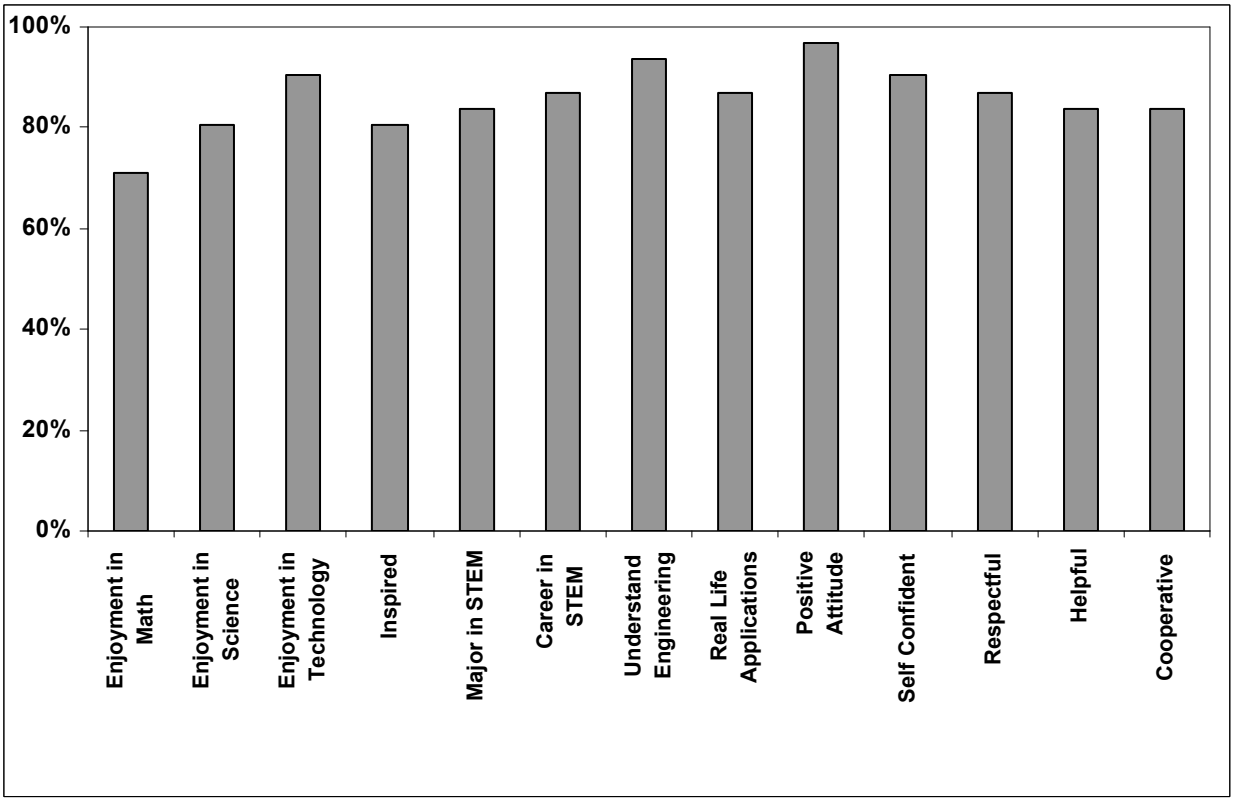

Fig. 1 Majority of students expressed that they had a better understanding in STEM.

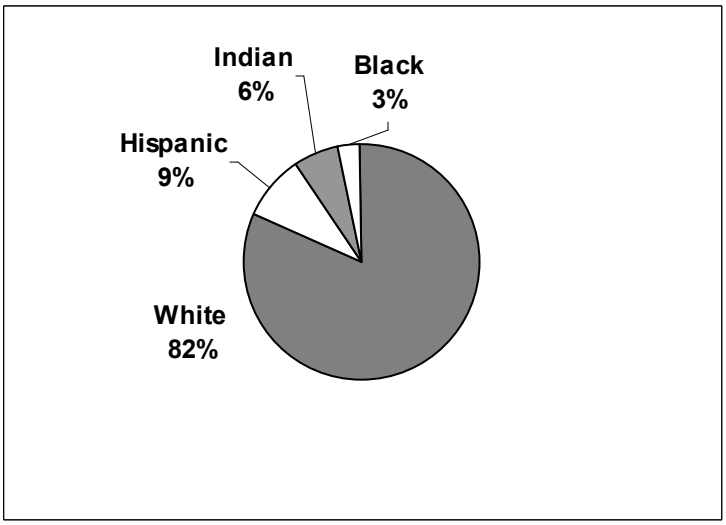

Fig. 2 Ethnic distribution of the participants

5. Discussion

Because Science Olympiads, Advanced Math, Math Counts, SimCity etc. are among other attractive clubs at CAS for STEM oriented students, the participants were not that many as anticipated initially. As a result, some of the data collected from the survey turned out to be not statistically significant for each club due to the small number of the participants. Therefore, some of the assessment results presented herein are anecdotal. This can be avoided in the future by attracting more STEM oriented students to those clubs by offering limited number of clubs or by increasing the overall enrollment of the school to have a larger student body. There were always scheduling conflicts for those who wanted to get involved with more than one club. Another challenge was to keep the student's attention and motivation steady during the season.

Table 1 shows a mere increase of the participants for the second year. Also, the students involved with FLL are almost twice as much compare to FRC. About 7% of the school was interested in either FLL or FRC. Total of only six diverse students involved in the projects due to the school demographics. Some of the second year participants were performed better since they were already exposed to LEGO and Robotics projects from previous year.

The difference between number of club participants and the surveyed participants came from the fact that some students involved in a club for both years. Also some students could be reached to do the survey.

6. Conclusion

In this paper, we are presenting the data for both FLL and FRC competitions for two consecutive years. Both projects were wonderful opportunities for the students to learn and apply STEM related concepts in the school. Everybody greatly benefited from the projects. The students are now more self confident in their classes. They are enthusiastic to learn more about math, science and technology. More importantly, they are willing to implement what they have learned in the

projects. They are getting prepared for leadership roles within their team and community. They show professionalism and responsibility in what they are doing. They also show development in life skills such as; team work, community involvement and academic success. The majority of the participants also agreed strongly that the partnership between the school, university and corporations created interest for them to work for the partner.

After the school administrators have decided to incorporate FRC into the curriculum, an elective Robotics class is introduced in the second year for high school students. LEGO and Robotics have been used in all Open Houses, Fairs, and Expositions etc. to attract more students this year and following years to come. Display robot in the school speaks by itself everyday.

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APPENDIX A

LEGO and Robotic Clubs Survey

Age: _____ **Sex**: ☐ Male ☐ Female

Ethnicity: ☐ White ☐ Hispanic ☐ Asian ☐ African-American ☐ Indian-American

1. How many years did you involve with the LEGO/Robotics Club?

☐ One Year ☐ Two Years

2. Which one of the following best describes your involvement with LEGO/Robotics Club?
Select more than one if applied.

	Strongly Disagree	**Somewhat Disagree**	**Somewhat Agree**	**Strongly Agree**
To have fun.				
To be challenged in math, science and technology.				
To learn more about science, math and technology.				
To get into a better college.				

3. My involvement in LEGO/Robotics Club made a positive impact in the following areas. Select more than one if applied.

	Strongly Disagree	**Somewhat Disagree**	**Somewhat Agree**	**Strongly Agree**
I started to have greater enjoyment in Math.				
I started to have greater enjoyment in Science.				
I started to have greater enjoyment in Technology.				
I got inspired as outlined in the he FIRST mission: "To inspire young men and women to pursue studies and careers in scientific and technological fields."				
I started to think of majoring in Science, Math, Technology, or Engineering related field in college.				
I am very like to pursue a Science, Math, Technology or Engineering related field in the future as a result.				
I started to have a better idea of what engineering is and how it is used.				
I saw how skills learned in class can be applied to a real-world setting.				
I started to have more positive attitudes about the working world.				
I am more self-confident.				
I am more respectful.				
I am more helpful.				
I am more cooperative.				

4. The Robotics Club has partnership through NASA, UNR, IGT and some other local businesses and companies. What are your opinions about this partnership?

	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Club builds relationships between their students and their sponsors.				
Club has created an interest in working for one of the team sponsors after completing my education.				
I have plans to work for one of the team sponsors in a summer internship or a part-time job.				
Club has created a great mentorship with volunteers from local businesses and companies.				

5. How likely are you to participate in LEGO/Robotics Club next year?

☐ Not likely ☐ Somewhat likely ☐ Very likely ☐ Don't know

6. CAS offers an Elective Robotics class as a result of involvement with FIRST. How likely are you to enroll in this class?

☐ Not likely ☐ Somewhat likely ☐ Very likely ☐ Already enrolled.

7. Please rate your overall experience with LEGO/Robotics Club:

☐ Poor ☐ Fair ☐ Good ☐ Excellent

8. How did you feel after you completed the robot?

9. How did you feel after the competition was over?

10. At times, did you feel that you stuck somewhere and then find out an immediate alternate solution?

11. The one aspect of LEGO/Robotics Club that I like the best is:

12. The one aspect of LEGO/Robotics Club that I would change is:

13. Any other comments and suggestions.