Using Hands-on Robotic Projects to Engage and Strengthen High School Students Participation in STEM Education

Andy S. Zhang, Iem Heng, Farrukh Zia, and Sidi Berri
New York City College of Technology of CUNY

ABSTRACT

This paper discusses the work that the Mechatronic Technology Center (MTC) in the School of Technology and Design of New York City College of Technology (City Tech) has done in the past two years to actively engage high school students in STEM education through hands-on robotic projects. Project-based hands-on robotic design activities are introduced at various levels. MTC offered these hands-on robotic design activities through after-school program, weekend workshops, and summer programs to maximize participation.

Keywords
STEM, Conference Proceedings, K-12 Outreach, Hands-on Learning, Engineering Education

1. INTRODUCTION

STEM education has been the key in producing college graduates capable of working in today's fast paced, highly competitive public and private enterprises. Unfortunately, the supply of qualified workforce has been declining for the past twenty years due to the steady drop of college students majoring in STEM related fields. Of those who were admitted to study STEM fields in colleges and universities, a significant number were underprepared to take regular STEM courses. To find a solution, the National Science Board suggested that all students develop their capabilities in STEM to levels much beyond what was considered acceptable in the past, with an increased emphasis on technology and engineering at all levels (Beering, 2009). The Board gave two priority recommendations: (1) Ensure Coherence in Nation's STEM Education System; (2) Ensure that Students Are Taught by Well-Prepared and Highly Effective STEM Teachers. This paper aims to encourage and help local high school students to engage in STEM studies, and thus strengthen the STEM education in high schools.

In this country currently, only 5% of college degrees are in engineering, compared to the 20% in Japan and Germany, and 40% in China (Barr, 2006). This is partly due to the lack of hands-on opportunities in high schools in which students can actively participate, and the lack of pre-engineering programs in high schools that can produce long lasting interests (Brown, 2006).

In New York City, there are currently more than 700 public high schools, but only a fraction of them have hands-on engaging STEM programs such as the FIRST Robotic Competition (FRC) and the FIRST Tech Challenge (FTC). Many schools do not offer their students the opportunity to be exposed to this wonderful FRC and FTC experience that can inspire them to study STEM in colleges and universities. To maintain US superiority in science, engineering, and technology, it is crucial that more pre-engineering programs be available to high school students to inspire them to pursue careers in science, engineering, and technology.

There is a need to change the perception of STEM education. STEM education cannot be viewed as teaching four unrelated subject matters. STEM education should be treated as an integral education. Mathematics, science, technology and engineering are taught in classes in the hopes that students will use these subjects simultaneously to make new discoveries, explore new ideas, make new products and provide better services. As such, more project-based activities that enable students to apply the knowledge and skills they learn from STEM courses should be implemented into curricula. Practical hands-on learning-by-doing activities go hand-in-hand with STEM education. They complement each other. If a person does not have a good STEM knowledge, it would be difficult for him/or her to become a competent innovator and designer. On the other hand, even if a person demonstrates excellent STEM knowledge on exams, he or she will not necessarily become a competent designer or engineer. Any successful designer or engineer would agree that it takes many years of experience and setbacks for him or her to reach that level.

Many studies have indicated that students learn well in teams, in project-based activities, and in collaborative environments. The hands-on activities strengthen students' skills in critical thinking, communication, collaboration, and creativity/innovation. They have been identified by top U.S. companies as priorities for employee development, talent management and succession planning (Fadel, 2010, Higdon, 2010). It is only natural for STEM education to incorporate hands-on applications at every stage of a student's education. This connection should be made earlier during a student's high school years and be reinforced for many years to allow the student to reach a level of maturity expected by companies for entry level or junior level positions. This paper presents some projects aimed at inspiring and attracting young people to study STEM. The goal is to use the top-down "reversed engineering approach" to tie in robotic design activities to various elements in STEM and to lead the students to focus on their STEM education. The top-down learning-by-doing approach will give students a sense of accomplishment at each stage of their design projects. That in turn, will inspire the students to continuously engage in and focus on the subject matter when dealing with STEM related courses. Faculty members from the Mechanical Engineering Technology and Computer Engineering Technology Departments in City Tech were involved in this study to address the multidisciplinary natures of robotic design.

2. USING ROBOTICS TECHNOLOGY TO CREATE ENGAGING ACTIVITIES

Robotics technology is very popular among all age groups, especially among young people. Robotic technology has the potential to lead another industrial revolution and has been identified as the next disruptive technology (Barrett, 2009). Robotic technology is a multidisciplinary field that required collaborations among mechanical engineers, electrical engineers, and software engineers to create products as results of tight integration of mechanical components, electrical/electronic systems, industrial design ideas, computer-control systems, embedded systems, and intelligent software into the product design and development processes. It provides an opportunity for the high school students to be exposed to various STEM fields. It also allows students to learn concurrent engineering concepts and sharpen their collaboration and communication skills.

The top-down learning-by-doing approach was adopted to teach students the state of the art hardware and software. National Instrument's CompactRIO (cRIO) programmable automation controllers, considered to be one of the preferred robot controllers in the market, were used to make robotic prototypes. Arduino micro-controllers were also used by students to design and build these products when size and low cost were concerns. Programming languages such as Java, LabVIEW, Matlab, and C/C++ were used. Computer Aided Software packages such as Autodesk Inventor, Creo Element Pro were also used in the projects.

3. BRINGING ROBOTIC TECHNOLOGY TO HIGH SCHOOL STUDENTS

To bring robotic technology to high school students, we adopted two approaches. One was to support the existing Pre-engineering programs such as FIRST Robotic Competition (FRC), FIRST Tech Challenge (FTC), and Science and Technology Entry Program (STEP). The other was to create new pre-engineering projects that address environmental issues in the neighborhood.

To maximize participation, the trainings were offered on weekends in conjunction with our FIRST partners, in afterschool programs, and in summer programs. Weekend classes make it possible for interested students, their parents, and high school teachers to attend. Training modules include: robotic programming, mechanical principles and design, electrical/electronic principles and design, and solid modeling using 3D computer design software such as Autodesk Inventor and PTC's Creo Elements/Pro.

Through various robotic projects, faculty members try to instill the 21st century skills to the students. In 2009, the Partnership for 21st Century Skills Framework for 21st Century Learning identified the following as the 21st Century Skills that each students must have: 1) Learning and Innovation Skills, which include creativity and innovation, critical thinking and problem solving, and communication and collaboration; 2) Information, Media, and Technology Skills, which include information literacy, media literacy, and information and communications technology literacy; and 3) Life and Career Skills, which include flexibility and adaptability, initiative and self-direction, social and cross-cultural skills, productivity and accountability, and leadership and responsibility (Bellanca and Brandt, 2010; Thomas and Brown, 2011).

3.1 Support the Existing Pre-engineering and technology Programs

Since October 2010, we have hosted more than 20 weekend workshops for robot programming, mechanical design, and electronic design to high school robotic teams each year. We have also created after school programs and summer robotic programs for local high school students.

3.1.1 Working with FRC Teams

Besides offering workshops to many local high schools' FRC teams, in January 2012, we started sponsoring two Rookie FRC teams to build robots in the Mechatronics Technology Center at the College. College students serve as mentors to help two rookie teams to build their robots for the annual FIRST Robotic Competition which is held in March every year. Figure 3.1 shows a robot prototype built by Team One. Figure 3.2 shows a robot built by Team Two. Over 20 high school students were exposed to the various elements of STEM through the hands-on projects.

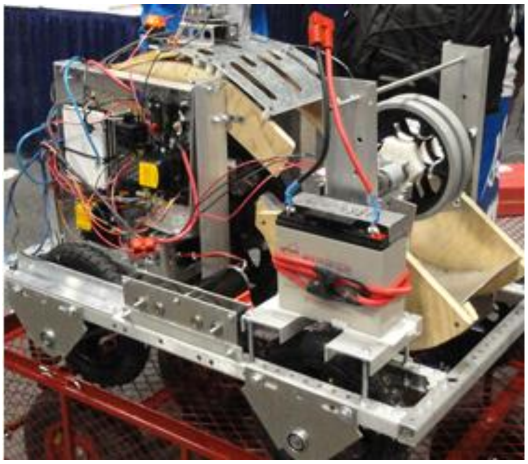

Figure 3.1: FRC Robot Built by Team One

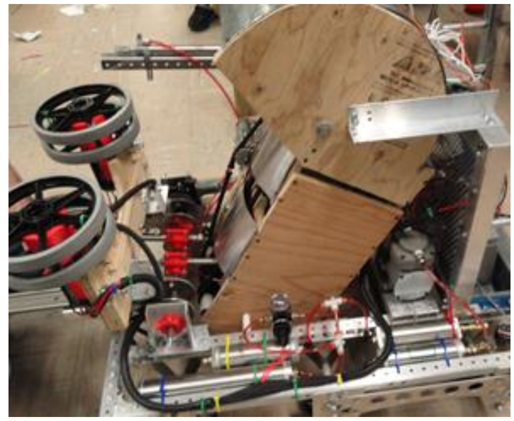

Figure 3.2: FRC Robot Built by Team Two

3.1.2. Working with FTC Teams

FIRST Tech Challenge (FTC) is another division of FIRST. It allows high school students to build much smaller robots at an affordable cost. Mechatronics Technology Center (MTC) organized numerous workshops on programming, solid modeling, and mechanical design. Figure 3.3 are some of the FTC robots built by high school students along with the posters.

Figure 3.3: FTC Robots and Posters Made by High School Students

3.1.2. Working with STEP Team

In 2012, New York State's Science and Technology Entry Program (STEP), a program aimed at introducing high school students the wonders of STEM, introduced robotic competition in its annual meeting. High school students were required to build a smaller robot using Lego Mindstorm NXT 2.0 Robotic kit. MTC was contacted to provide technical guidance for a local high school team of four students. Additionally, two faculty members from MTC mentored the team. Each student was assigned a special role (mechanical engineer, electrical engineer, computer engineer, and industrial engineer/designer). The idea was to help the students to realize the multidisciplinary nature of product design. The high school team won the third place in the 2012 STEP Robotic Competition held in Albany, New York. Figure 3.4 shows the robot built by the team.

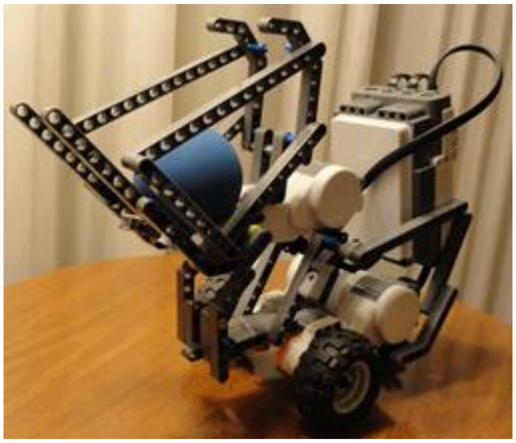

Figure 3.4: NXT Robot Built for STEP Program

3.2 Create New Hands-on Training Programs

In addition to the robotic training that has attracted hundreds of students, the MTC has created some new hands-on projects to enhance its offering. In 2011, we developed low cost chemical detection robots using an Arduino micro-controller and commercial gas sensors. We are currently in a process of creating a handheld device called the "Mobile AirCasting Device" so the high school students can use them in conjunction of new curriculum development.

3.2.1 Chemical Detection Robot (CDR)

CDR is capable of detecting harmful gas in the environment. This CDR teaches the students how to use a low cost micro-controller to construct a robot. It also addresses the issue of protecting the environment. Thus, this would encourage students to learn and to foster a clean planet.

Figure 3.5 is a prototype of the chemical detection robot. Figure 3.6 is a remote control unit which communicates with CDR through XBee wireless communication module. Figure 3.7 shows a computer model of the remote control unit and the CDR.

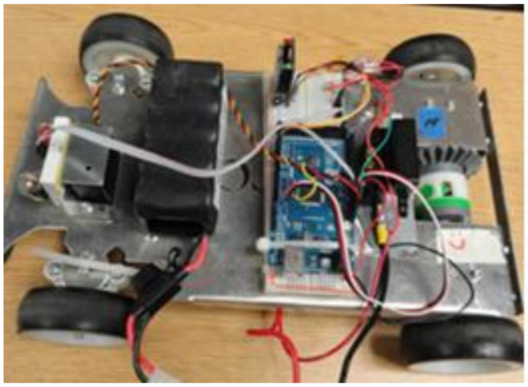

Figure 3.5: Chemical Detection Robot

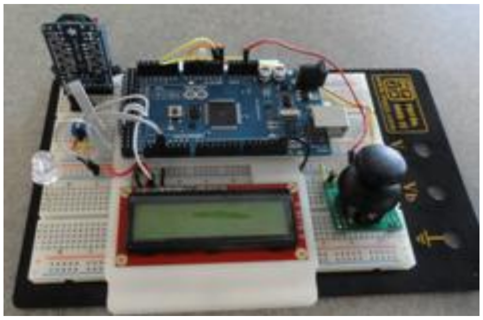

Figure 3.6: Remote Control Unit

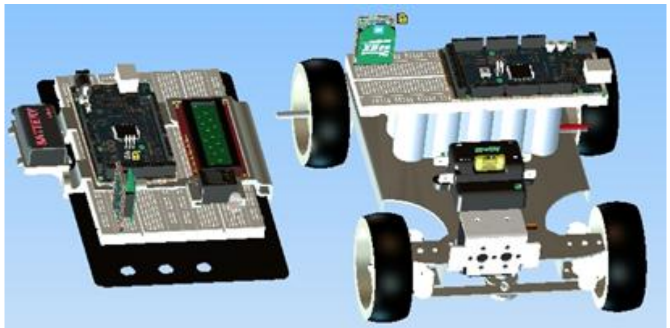

Figure 3.7: Computer Models for the Remote Control Unit and the CDR

3.2.2 AirCasting Device

Another project that is being developed is a handheld device called the Mobile AirCasting Device (MAD). The device can detect the existence of chemicals and broadcast the information to the internet through smart phones or tablets. Figure 3.8 shows an assembly of the MAD. Figure 3.9 is a physical prototype of the Mobile Aircasting Device.

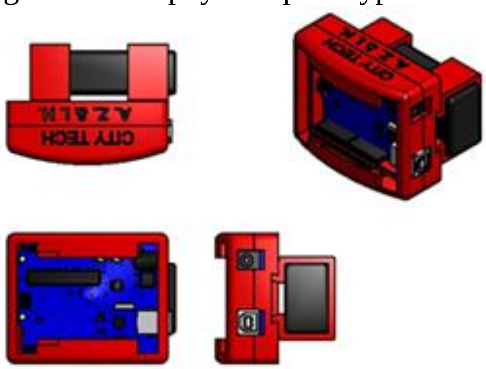

Figure 3.8: AirCasting Assembly

Figure 3.9: A Physical Prototype of MAD

3.3 Organizing Competition Events and Conferences

We organized mini robotic competitions to allow the students to compete and have fun. Figure 3.10 and Figure 3.11 show a scene of mini competition held in 2011 and 2012, respectively.

Figure 3.10: Mini FTC Robotic Competition Held in 2011

Figure 3.11: Mini FTC Robotic Competition Held in 2012

After school robotic programs were also offered to high school robotic teams who wanted to participate in regional robotic competition but could not come to the weekend workshops.

Last summer, we offered a one-month robotic training class for students from more than 10 high schools. To make sure potential applicants for the summer program were serious about the course, we interviewed each candidate before enrolling them. As a result, we had almost perfect attendance for our summer program. The summer program gave us more time to implement the various components related to product design. Students also learned teamwork, time management, and leadership skills. At the end of the summer program, students presented their work at a NASA Students Conference held in City Tech.

Figure 3.12 is a photo showing the FTC robots that students made in the summer program and the posters they presented at the NASA Student Conference. Figure 3.13 shows students taking a photo with the FRC robots they programmed.

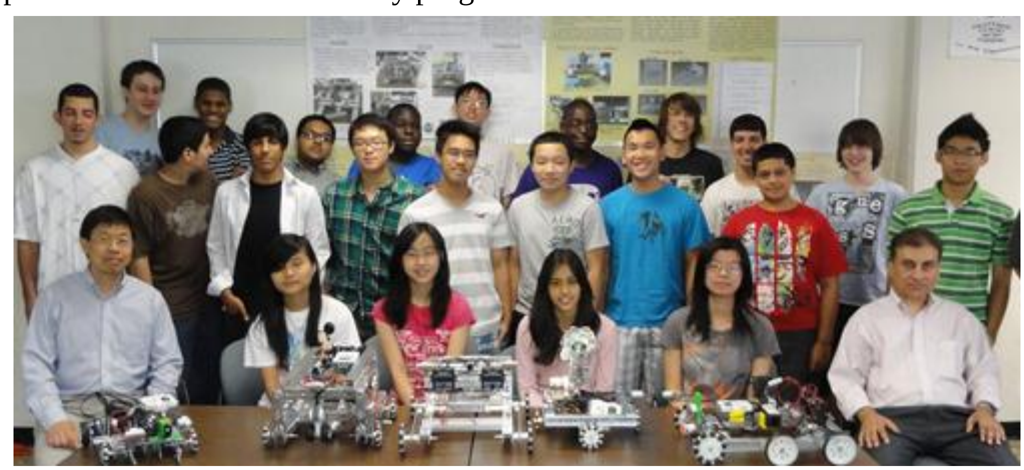

Figure 3.12: Students Taking a Photo in Front of the FTC Robots They Made.

Figure 3.13: Students taking a Photo with the FRC Robots

4. CONCLUSIONS AND FINDINGS

The outreach robotic training program helped answer many questions that parents and students often ask at college and university open houses: What is mechanical engineering? What is electrical engineering? What is computer engineering? If students were not exposed to any engineering activities, they would not be able to tell the difference among various engineering fields.

This explains why significant number of students change major after one or two semesters. Another reason would be that many students do not have enough STEM preparation at high school that allows them to understand the contents taught in college level courses.

Connecting high school students to STEM education is crucial for the colleges and universities in the U.S. to guarantee steady enrollment of high school students in STEM fields.

The hands-on engaging robotic design activities are the tools to really help high school students gain perspective on STEM education and become interested in it. The hands-on design project helps the student to see the big pictures. It help student to make connections among the various STEM courses they take and gave them a new perspective.

It has been reported by NSF (NSF Press Release, 2007), students who participated in pre-engineering activities such as the FRC have higher tendency to major in engineering, science, and technology in colleges. In a study conducted by Brandeis University involving high schools students in New York City and the Detroit area, it was found that when compared to other high school graduates with similar preparation in mathematics and science, FIRST participants were (1) nearly twice as likely to major in science or engineering than comparison students (55% vs. 28%); (2) more than three times as likely to major in engineering (41% vs. 13%) than the comparison students, and seven times the average among US college students overall (New York City/New Jersey First Annual Report, 2007).

Our internal survey conducted on students who attended the summer robotic program revealed that 70% of the students rated the robotic activities as a challenge but doable. Majority of students reported issues on teamwork, collaboration, and cooperation. This indicates that teamwork and collaboration do not occur naturally. It takes time and guidance for the students to work together effectively. Almost all students indicated an increased interest in taking STEM courses when return to high school.

Participants came from diverse backgrounds. Over 50% of the students were female who attended the weekend and afterschool programs. However, only one 6th of the female students attended the summer program. About 40% of the participants were Asians in all programs. About 25 % of the participants were from underrepresented minorities (URM) who attended the weekend and afterschool programs. Although, a priority was given to underrepresented minorities, only 15 % of the summer program applicants were from the URM.

In summary, the design projects help students to realize the multidisciplinary nature of product design and appreciate the importance of teamwork and time management, and how to work with other members in a team. They gained leadership skills as well. The top-down learning-by-doing approach gave students a sense of accomplishment at each stage of their design projects. The hands-on projects allowed students to learn from their failure and they provided opportunities for the students to gain valuable experience that prepared them for the real challenge after they graduate.

ACKNOWLEDGEMENTS

The work is funded by a grant from the National Science Foundation (NSF) Advanced Technological Education (ATE) Division. The award number is DUE #1003712. The authors greatly appreciate the support from the NSF.

REFERENCES

Beering, Steven C. 2009. "National Science Board STEM Education Recommendations for the President-Elect Obama Administration" National Science Board, NSB-09-1 January 11.

Barr, Ronald E. Barr, 2006. "Current Status of Engineering Education and ASEE", *ASEE Mid-Atlantic Spring Conference, Brooklyn, NY, April 28-29.*

Brown, Alan S. 2006. "Engineers Focus on Education", *Mechanical Engineering, Vol. 128/No.10 October*.

Fadel, Charles. 2010. "21st Century Skills - From Industry to Education and Back" October 26-28, NSF ATE Principal Investigator Conference.

Higdon, Ann. 2010. "The Art of Enlightened Self-Interest", October 26-28, NSF ATE Principal Investigator Conference.

Barrett, David. (2009) "Robotics: The Next Disruptive Technology", NIWeek 2009 Keynote Presentations, http://zone.ni.com/wv/app/doc/p/id/wv-1709, August 12.

Bellanca, James and Brandt, Ron. (2010). "21st Centtury Skills – Rethinking How Students Learn" Solution Tree Press, 2010, ISBN 978-1-935249-90-0.

Thomas, Douglas and Brown, John Seely. (2011). "A New Culture of Learning – Cultivating the Imagination for a World of Constant Change", ISBN-13 978-1456458881, ISBN-10 145658884.

NSF. (2007). " Can a Robot Get High School Students Interested in Studying Science and Engineering in College?", September 11, 2007, NSF Press Release 07-120..

New York City / New Jersey FIRST Annual Report, 2007.

Authors Information

Dr. Andy S. Zhang is an associate professor in the Mechanical Engineering Technology Department of NYC College of Technology. Dr. Zhang obtained his Ph.D. from the Graduate Center of City University of New York. His research area includes materials testing, composite materials, CAD/CAE, engineering animation, and mechatronics. He is a member of New York City/ New Jersey FIRST Planning Committee.

Dr. Iem Heng is an assistant professor in the Computer Engineering Technology Department of NYC College of Technology. Dr. Heng obtained his Ph.D. in computational and applied mathematics from Old Dominion University His research activities include embedded systems, software development for embedded systems with real time simulation, real time gamming simulation programming, and web application programming.

Dr. Farrukh Zia is an assistant professor in the Computer Engineering Technology Department of NYC College of Technology. Dr. Zia earned his Ph.D. in computer engineering from Syracuse University. His current research activities include applications of neural networks and fuzzy logic in industrial control systems and robotics.

Dr. Sidi Berri is a professor in the Mechanical Engineering Technology Department of NYC College of Technology. Dr. Berri obtained his Ph.D. from Polytechnic University. His areas of expertise include: machine condition monitoring using digital signal processing, machine design, nanotechnology, bioengineering, and computer aided design/computer aided manufacturing (CAD/CAM). Dr. Berri is the author of several conference and journal research papers.