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## **AC 2012-3515: UTILIZING PROJECT-BASED MULTIDISCIPLINARY DESIGN ACTIVITIES TO ENHANCE STEM EDUCATION**

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# Utilizing Project-Based Design Activities to Enhance STEM Education

## 1. Abstract

This paper discusses the use of project-based interdisciplinary design activities to enhance the STEM education system in New York City College of Technology's (City Tech) School of Design and Technology. A top-down "reversed engineering approach" is used to tie design activities to various elements in STEM. Currently, most traditional STEM projects aimed at improving the STEM education address only one or two elements of STEM education and lack suitable activities to keep students engaged. Project-based design activities have proven to be very effective in attracting and motivating young people to study. The top-down learning-by-doing approach gives students a sense of accomplishment at each stage of their course work. That in turn, inspires the students to continuously engage and focus on the STEM subject matter. Faculty members from multiple engineering technology departments at City Tech are involved addressing the multidisciplinary nature of product design and to develop teaching materials to improve STEM education from a practical application point of view. Project-based projects are parts of capstone courses at the associate degree level as well as to high school students.

## 2. Introduction

STEM education has been key in producing qualified individuals to work in today's fast paced, highly competitive public and private enterprises. Unfortunately, the supply of qualified workforce has been reduced due to the steady drop of enrollment of college and high school students in STEM related fields for the past twenty years. To tackle the dwindling enrollment of STEM students and low quality of STEM graduates, the National Science Board submitted a report to Congress in 2009 suggesting all students need to 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 in the Nation's education system [Bee01].

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 hope that students will use these subjects simultaneously to make new discoveries, to explore new ideas, to make new products and to 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 curriculums. 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 is difficult for him/or her to become a competent innovator and designer. However, if a person demonstrates excellent STEM knowledge on exams, it does not mean this individual can be a competent designer or engineer overnight. Any successful designer or engineer would agree that it takes many years of experience and setbacks for him or her to reach that level.

In his keynote speech called "21st Century Skills - From Industry to Education and Back" at 2010 NSF ATE Principal Investigator Conference, Mr. Charles Fadel, Global Education Research Lead at Cisco Systems, presented a study which indicates that students learn well in teams, in project based activities, and in collaborative environments [Fad02]. The hands-on project based activities will also strengthen students' skills in critical thinking, communication, collaboration, and creativity/innovation. These skills have been identified by top U.S. companies as priorities for

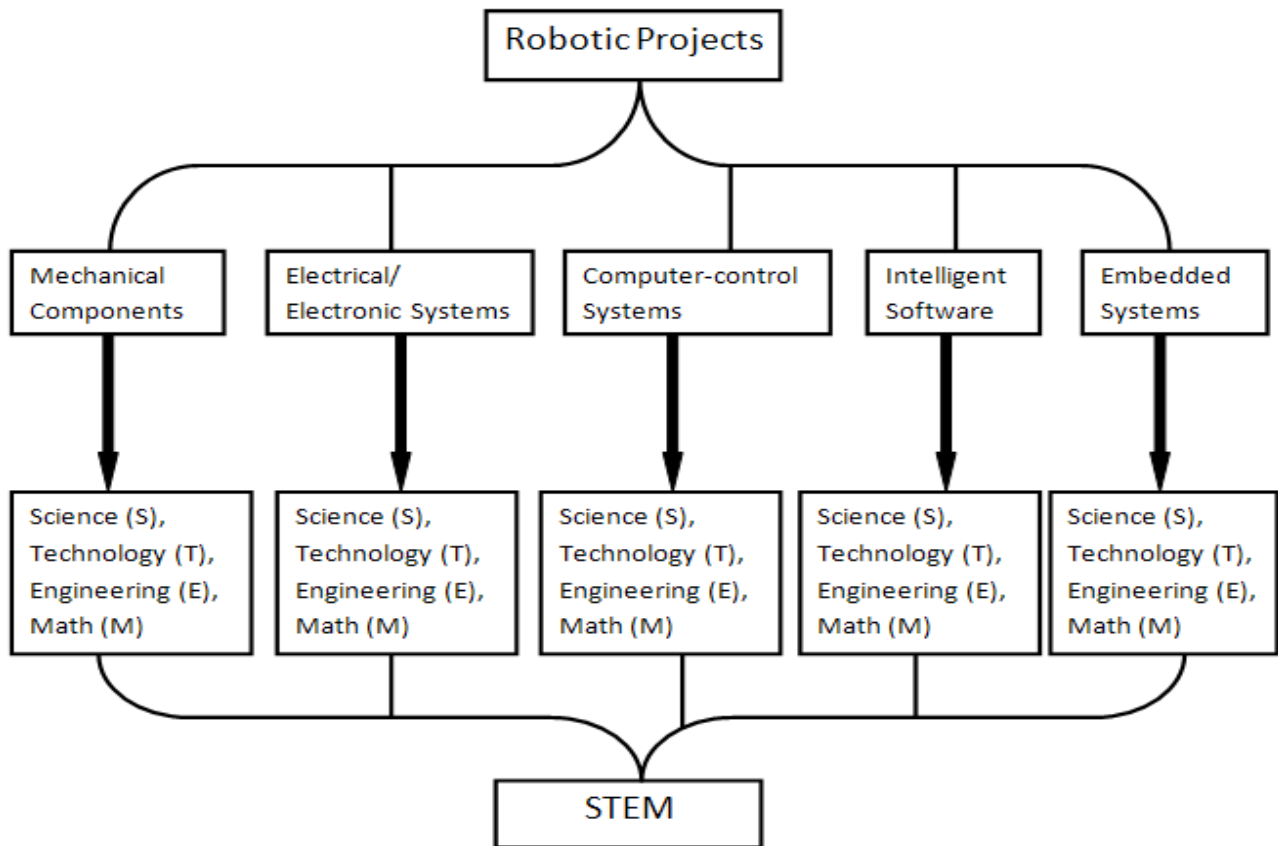
employee development, talent management and succession planning [Dag01, Bar01, Nat01, Nat02]. It is only natural for STEM education to incorporate hands-on practical applications at every stage of a student’s education. This connection should be made earlier during a student’s high school years and be reinforced every semester during student’s college years so as to allow the student to reach a level of maturity expected by companies for entry level or junior level positions. This project presents a plan on how to use mechatronic/robotic design projects with engaging activities to inspire and attract young people to study STEM and prepare them for challenging careers in product design and development fields.

Hands-on Mechatronic design activities such as FIRST Robotic Competition in high schools have proven to be very effective in attracting and motivating young people to study [Col01, Hig03]. The top-down learning-by-doing approach will give students a sense of accomplishment at each stage of their design projects. That in turn, inspires the students to continuously engage and focus on the subject matter when dealing with STEM related courses.

### 3. Innovative Pedagogy and Innovative Facility

A top-down “reversed engineering approach” is used to tie mechatronic design activities to various elements in STEM and to lead students to focus on their STEM education. Currently, most traditional STEM projects aimed at improving the STEM education address only one or two elements of STEM education and lack suitable activities to keep students engaged.

Students were first introduced to the relationship between robotic design activities with STEM as demonstrated in Figure 2.1



**Fig2.1 Relationship between Robotic Design Projects and the STEM**

Joint sessions are conducted by faculty members from mechanical engineering technology and computer engineering technology. Emphasis is placed to help students to understand the intrinsic relations between the four subject areas and multidisciplinary nature of product design. Students learn the importance of STEM working in interdisciplinary groups from both departments. They understand the importance of mathematics and physics by solving strength of materials problems, designing group projects, and fabricating and assembling final parts.

When students are designing mechanical elements, they need to perform force analysis, stress analysis, selection of materials, and finalize the design. This requires students to use the theory of statics (Science) and stress analysis (Engineering), select materials based on mechanical and chemical properties (Science), determine geometric properties using integrals (Math), derive equilibrium equations (Math), solve various algebraic and differential equations using computer software (Technology), and develop a blue print of the final product using CAD/CAM tools (Technology).

When working on electrical or electronic design, students have to perform circuit analysis (Science), choose various electrical and electronic components for their design (Engineering), derive equations based on electrical and electronic principles (Math), analyze the performance of the design using computer software (Technology), and present the design work using computer tools (Technology).

Faculty members from the mechanical engineering technology and computer engineering technology departments at City Tech were involved in this study to address the multidisciplinary nature of mechatronic design and to develop teaching plans and projects to improve STEM education in general.

Besides using the core content of knowledge of STEM to solve engineering design problems, the hands-on multidisciplinary design projects also inject the important 21<sup>st</sup> century skills to students such as information and communication skills, collaborative skills, synthesizing and problem solving skills, interpersonal and self direction skills [Bel01].

The Mechatronics Technology Center (MTC) established in 2010 serves as the platform for students to actively engage in various design and training activities. State of the art hardware and software used in the projects expose students to the latest technology used in the industry and in academia. In the hardware side, at the high end is the National Instruments' Real time I/O Controller called Compact RIO used by many companies in product design. In the middle is the Arduino Micro Controller which is an open source low cost robot controller. At the low end is the Lego Mindstorm's NXT brick used as the robot controller. In the software side, various programming languages such as LabVIEW, C/C++, Java, and Matlab are being used. In addition to programming software, CAD and CAM packages such as Autodesk Inventor, Solidworks, Creo/Elements Pro, and MasterCAM are being used. Students also have access to a CNC milling center, a water jet, and rapid prototyping machines. The technology infrastructure is very crucial for the faculty to teach the latest robotic technology and 21<sup>st</sup> century skills [Pea01]. This is to make sure that students are exposed to the latest technology and technical skills in their fields.

#### **4. Reaching out to High School Students**

One of the key problems related to the dwindling number of students enrolled in STEM programs in colleges and universities is the lack of preparation of high school students in STEM. To fill the gap and to help high school students to realize the importance of STEM education, hands-on engaging training programs are developed to help and encourage high school students to be exposed to

various STEM areas through robotic design activities that tie to existing pre-engineering programs such as FIRST Robotic Competition (FRC) and FIRST Tech Challenge (FTC). To maximize participation, the trainings were offered 1) on weekends in conjunction with our FIRST partners, 2) in afterschool programs, and 3) in summer programs. Weekend classes make it possible for interested students, their parents, and high school teachers to attend. Training modules include: robotic programming using RobotC, a C programming language developed by Carnegie Mellon University's Robotics Academy, Java, and LabVIEW, 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.

Figure 4.1 to 4.2 showed some of the workshops we conducted on the weekends.



**Fig4.1 Weekend Robotic Classes Attracted a lot of Students**



**Fig4.2 Solid Modeling Weekend Class Using Creo Elements/Pro**

We also organized mini robotic competition to allow students to compete and have fun. Figure 3.5 shows a scene of mini competition held during a weekend.



**Fig4.3 Mini Robotic Competition for FTC Teams**

After school robotic programs were also offered to high school robotic teams who want to participate in regional robotic competition but cannot 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 are serious about the course, we interviewed each candidate before enrolling them. As a result we had almost perfect attendance for our summer program. Summer program gave us more time to implement the various components related to product design. Students also learn 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 4.4 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 4.7 shows students taking a photo with the FRC robots they programmed.



**Fig4.4 Students Taking a Photo in Front of the FTC Robots They Made.**



Fig4.5 Students taking a Photo with the FRC Robots

## 5. Making The Connections

The outreach robotic training program helped answer many questions that parents and students often ask at colleges and universities' open houses: What is mechanical engineering? What is electrical engineering? What is computer engineering? Etc. If students were not exposed to any engineering activities, of course 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 semester. The other reason would be that many students don't have enough STEM preparation at high school that allows them to understand the contents taught in college level courses.

The hands-on robotic project put students on a discovery path. It can spark and nurture students' interests. It provides opportunities for students to mess around the robotic technology and find something useful and engaging. Making the connections to high school students on STEM education is so 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 helped high school students to gain perspectives on STEM and become interested in them.

## 6. Design Activities For College Students

College students' design projects simulate the actual design activities occurred in industry. It started with selection of team leaders. Team leader candidates were first interviewed by instructor. All students then filled out the survey questionnaire that asked about the important attributes about team leaders and team members. Based on the interview and the survey questionnaire, the instructor selected the team leader for each team. The team leader then picked up some students as candidates for his or her team, and interviewed each one privately.

This selection process made students conscientious about his or role in the team. Students were mindful about what skills he said he has that can contribute to the design team. This made him a much better member because he will be measured by what had claimed. Student leader would later

provide a report to the instructor on reasons he chose his team members. The team leader would be measure later on whether he selected the right members for the team.

In previous design project, students were required to design robots controlled by custom made robotic controller as shown in Figure 5.1 designed by students from the computer engineering technology department.

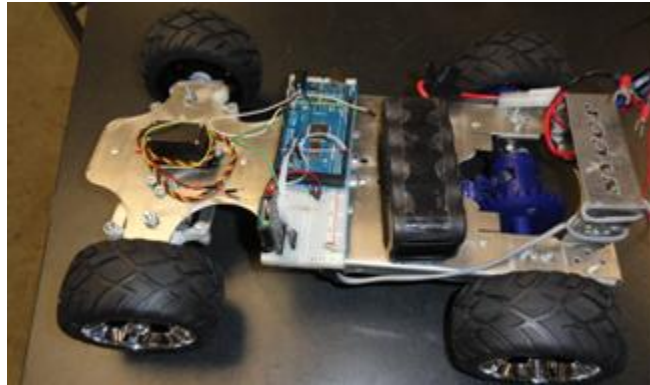


Fig6.1 A Robot Prototype Controlled by Custom Made Arduino Micro-controller

In this design project, students were asked to design a chassis, steering system, differential drive system that meet stated design specification. The mechanical design should be independent of the electrical design. Meaning either custom designed robot controller using Arduino micro-controller or Lego Mindstorm's NXT robot controller can be used in the project.

Each team was required to follow a time line and the team leaders were required to submit a progress report each week to document their work.

Figure 6.2 to6.4 show a custom designed prototype robot designed by Team One.

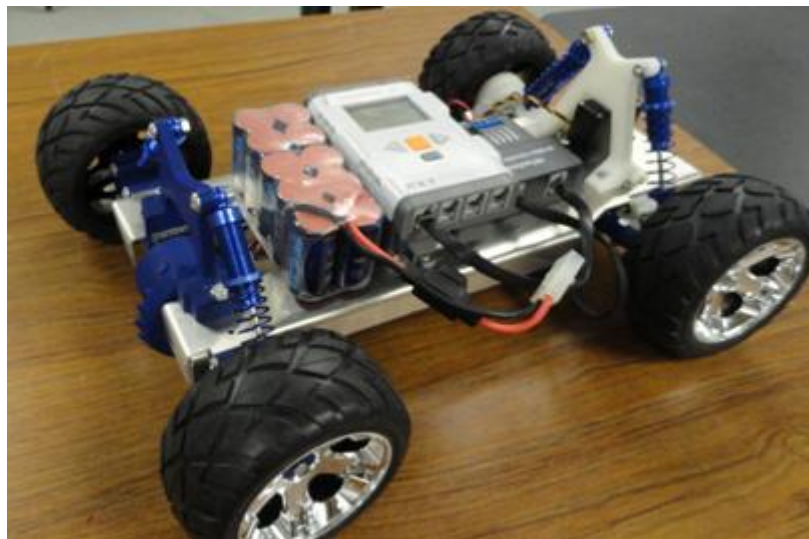


Fig6.2 A Prototype Robot with Custom Made Suspension System



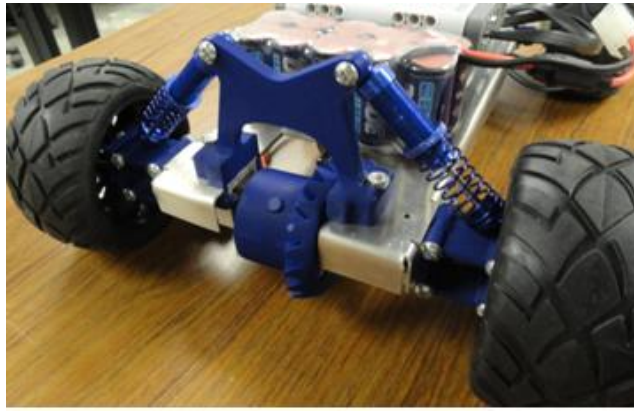


Fig6.3 Rear Suspension System and Differential System Built by Team One

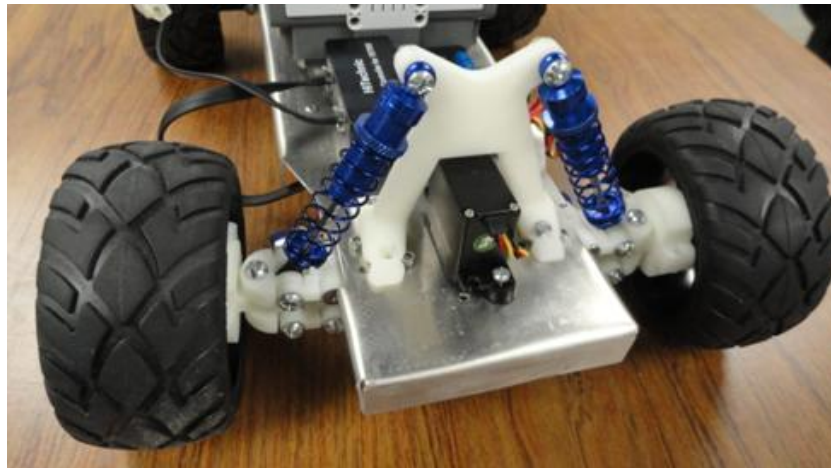


Fig6.4 Front Suspension System and Steering System Built by Team One

Team One has demonstrated a good design with custom made suspensions systems in both and rear wheels. The strong leadership and competent team members made it possible for the team to finish the project on time.

Figure 6.5 and 6.6 show the prototype robot designed by Team Two.

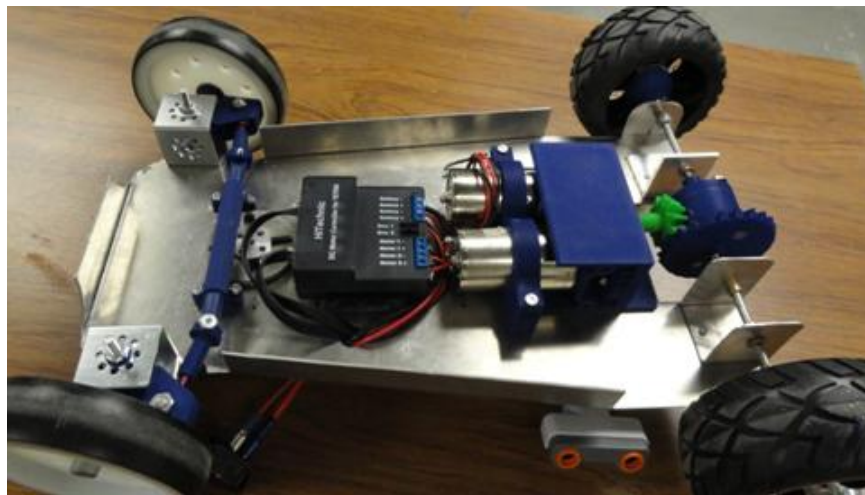


Fig6.5 Bottom View of a Robot Prototype Designed by Team Two with 2 Motors to drive the Robot.

Although Team Two used two DC motor in their design, but it failed to climb a one-inch ramp under slow speed. One reason for the robot failing to climb the ramp was that the gearbox they designed to connect to the two motors used reversed gear ratio intended to increase the speed. As a consequence, the torsion needed to overcome the resistance was reduced. Another reason the team believed was they did not make the connection properly so the two motors did not run in sync. This is a classical example that students learn from their mistakes. They won't find anything wrong of their design until they saw the test results.

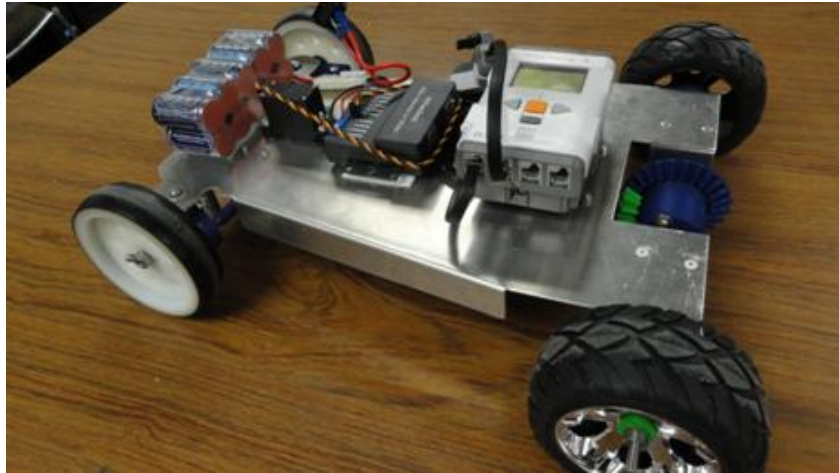


Fig6.6 Top View of the Robot Prototype Designed by Team Two with 2 Motors to drive the Robot.

## 7. Assessment and Conclusions

The project was conducted in capstone courses of two associate degree programs. For most students, this is the first time they were exposed to this type of hands-on design project. Pre and post surveys were conducted. Although most students said they learn a lot from this fresh experience, majority asked that this type of hands-on design project be given much early in their freshman years. Most students realized they lack certain STEM components for them to successfully finish the project. It takes time for students to gain synthesizing and other skills for them to apply STEM to solve real problem.

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.

These design projects help students to realize the multidisciplinary nature of product design and appreciate the importance of teamwork, time management, and how to work with other members in a team. They learned leadership skills as well.

The top-down learning-by-doing approach gave students a sense of accomplishment at each stage of their design projects.

Students gained valuation experience in the simulated design projects that prepare them for real challenge when graduate. The hands-on project allows student to learn from his failure.

The hands-on engaging design project should be provided every semester to allow students to reinforce their mind on the practice of current engineering approach in product design and slowly and steadily build problem solving and synthesizing skills [Mil01]. This type of project should be introduced at freshman years, so they can benefit from the experience early. This will provide opportunities for the students to make early connection of STEM to the future work that they will

be engaging. It will make students more consciousness on what they should learn on various STEM courses.

## 8. Acknowledgements

The work is funded by a grant from the National Science Foundation Advanced Technology Education Division. The award number is NSF ATE No 1003712. The authors appreciate greatly the support from the NSF.

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