AC 2012-3129: A NOVEL APPROACH IN TEACHING STEM SUBJECTS THROUGH CROSS-DEPARTMENTAL COLLABORATION IN CAPSTONE COURSES

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A Novel Approach in Teaching STEM Subjects Through Cross-Departmental Collaboration in Capstone Courses

Abstract

In today's higher education, use of state of the art technology in the classroom and laboratory plays a vital role in hands-on cross-disciplinary activities and demonstration for students to learn the interconnection of STEM (Science, Technology, Engineering and Mathematics) concepts. To implement these activities, the capstone courses present an ideal opportunity for cross-departmental collaboration. The hands-on robotic design project is introduced in the capstone courses to teach interconnected STEM concepts. This type of project, which has proven very effective in engaging students, is used in many areas of technical courses as hands-on activities and demonstration and, in addition, lab work. Additionally, the focus of robotic project is on hardware/software interface, data communication, electrical circuits, and mechanisms which reflect actual engineering activities in a company. These areas provide a tight integration of many STEM concepts and activities for capstone course. In general, the capstone course is a parent course that has inherited the knowledge of many feeder (pre-requisite) courses, and is usually offered in the last or second to last semester of the senior term.

1. Introducing STEM Education

STEM education has been a key in producing qualified individuals to work in today's fast paced, highly competitive public and private enterprises. Unfortunately, for the past twenty years, the supply of qualified workforce has been decreasing due to a steady drop of enrollment of college and high school students in STEM related fields. 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 a need for all students 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[1].

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[2]. Mathematics, science, technology and engineering are taught in classes with the 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 good STEM knowledge, it is difficult for him or her to become a competent innovator and designer. On the other hand, 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[3]. 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. 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 initiative presents a plan on how to use mechatronic/robotic design projects with engaging activities to inspire and attract young people to study STEM[4] and prepare them for challenging careers in product design and development fields.

The goal is to use the top-down learning-by-doing approach to tie in mechatronic design activities with various elements in STEM and to lead the 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. 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 relevant subjects[5]. The top-down learning-by-doing approach will give students a sense of accomplishment at each stage of their design project. That in turn, will inspire the students to continuously engage 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 New York City College of Technology was involved in this study to address the multidisciplinary natures of mechatronic design and to develop teaching plans and projects to improve STEM education as a whole from product designers' point of view.

Students were first introduce to the relationship between robotic design activities and STEM subjects as demonstrated in the following Figure 1. Figure 1 shows that the robotic design projects provide a clear understanding of the four elements in learning STEM subjects.

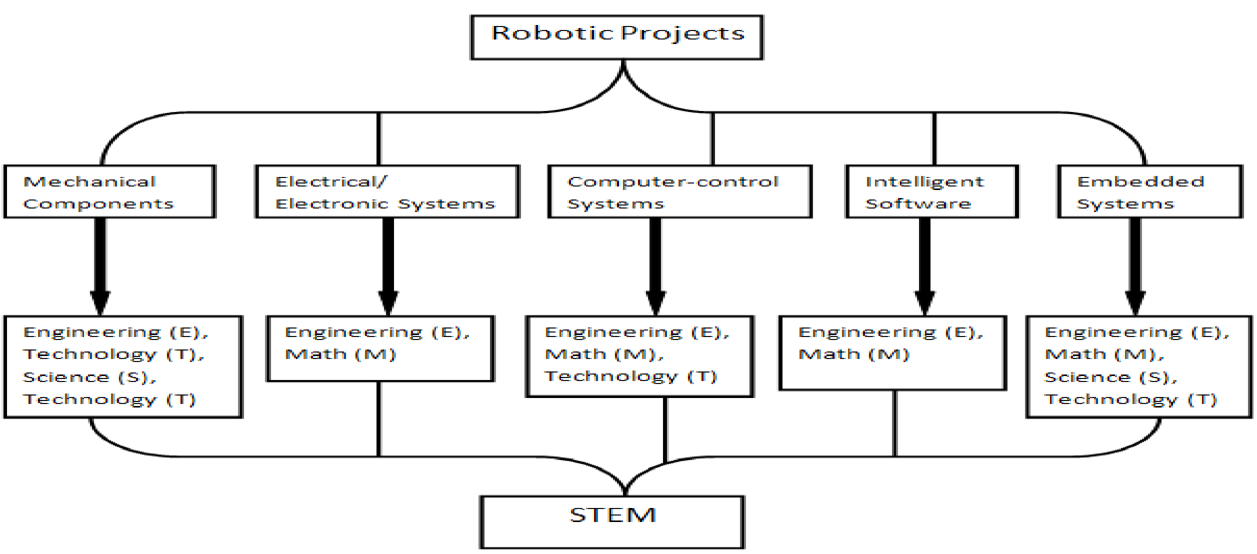

Figure 1: Relationship between Robotic Design Projects and STEM Subjects

2. CET and MET Cross-Departmental Collaboration

The cross-departmental collaboration started when we received an NSF ATE Grant in 2010. The focus of this educational grant is to have a plan to implement cross-disciplinary activities through cross-departmental collaboration between Computer Engineering Technology (CET) and Mechanical Engineering Technology (MET) departments. The Computer Engineering Technology department focuses on the basics of electrical technology, computer hardware, computer software, computer hardware and software interface, networking and how to integrate these technologies to control electromechanical and mechanical devices. Whereas, the Mechanical Engineering Technology department focuses on materials testing, manufacturing, computer aided drafting and design, machine/mechanical design and analysis, and mechanical systems. Thus, it provides a good opportunity for both departments to have the direct hands-on collaboration activities in the field of Computer Engineering and Mechanical Engineering technologies. Through these hands-on collaboration activities between the two departments, students will have an opportunity to learn the fundamental concepts of product design, product lifecycle management and sharpen their teamwork skills[6].

3. Joint Session in Collaborative Lectures and Lab Activities

The CET and MET departments have been conducting joint class sessions in traditional lecture and hands-on lab activities. The following Figure 2 shows a joint session for the traditional lecture in EMT 2461: Electromechanical Systems: Software Interface and MECH 2410: Machine Design. These two courses are comprehensive capstone courses and are required for students to take as part of their major.

Figure 2: CET and MET Joint Class Session

EMT 2461 focuses on how computer hardware, computer software and electromechanical systems control external devices, both electrically and mechanically. This course provides an opportunity for students to build a capstone project and learn the interface of software and hardware for use as a control element.

MECH 2410 focuses on the applications of basic principles, in-depth analysis and design for selected machine elements: brakes clutches, springs, screws, shafts, bearings, cams, gears and gear trains. The students have an opportunity to design simple and complex mechanical components and systems for use in their capstone design project.

Besides the joint class sessions in traditional lecture between CET and MET departments, we also have the joint laboratory sessions where hands-on collaborative multi-disciplinary activities take place. The following Figure 3 shows the students engaged in these multi-disciplinary activities.

Figure 3: Hands-on Activities in CET and MET Joint Laboratory Sessions

4. Comprehensive Design Capstone Project Activities

As discussed in Section 3 on the collaboration activities, it is importance to know that these activities are part of the comprehensive capstone projects. The capstone project presents an ideal opportunity for cross-departmental collaboration. Students from both departments can jointly work together on their capstone project activities.

The students' design projects simulated the actual design activities that occur 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 selected some students as candidates for his or her team, and interviewed each one privately. This selection process made students conscientious about their role in the team. Students were mindful about what skills they possessed that could contribute to the design team. This made them much better members because they would be measured by what they had claimed. Student leaders would later provide a report to the instructor on their reasons for choosing team members. The team leaders performance would be measured later on whether they selected the right members for the team.

In a previous design project, students were required to design robots controlled by custom made robotic controller as shown in Figure 4. These robots are designed by students from both Computer Engineering Technology and Mechanical Engineering Technology departments.

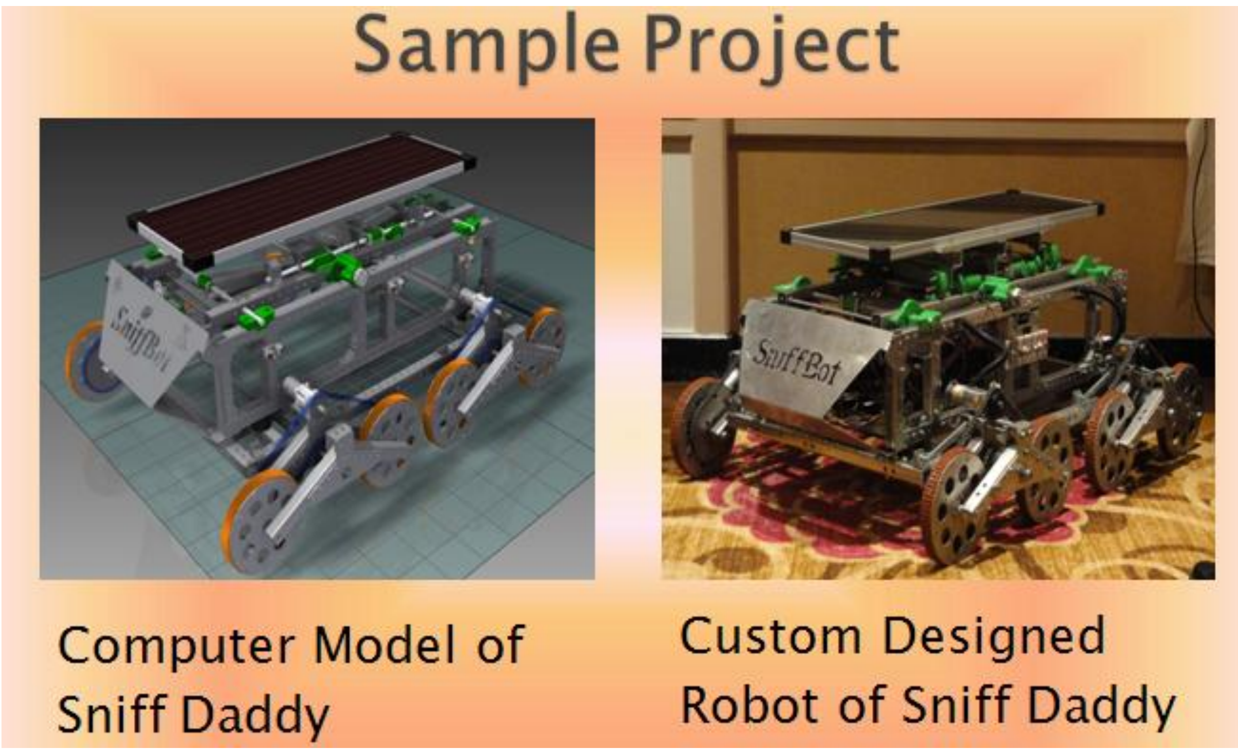

Figure 4: Robot Prototype Controlled by Custom-made Arduino Micro-controller

In this design project, students were asked to design a chassis, steering system, and differential drive system that would meet stated design specifications. The mechanical design should be independent of the electrical design; meaning either custom designed robot controller using Arduino micro-controller[7] or Lego Mindstorm's NXT[8] 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. Each team had a combination of four to six CET and MET students working on their project.

Figures 5 to 7 show a custom designed prototype robot designed by Team One.

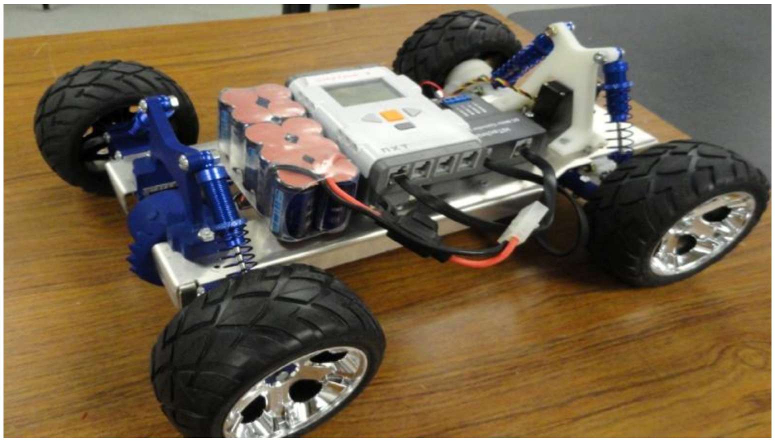

Figure 5: Prototype Robot with Custom Made Suspension System

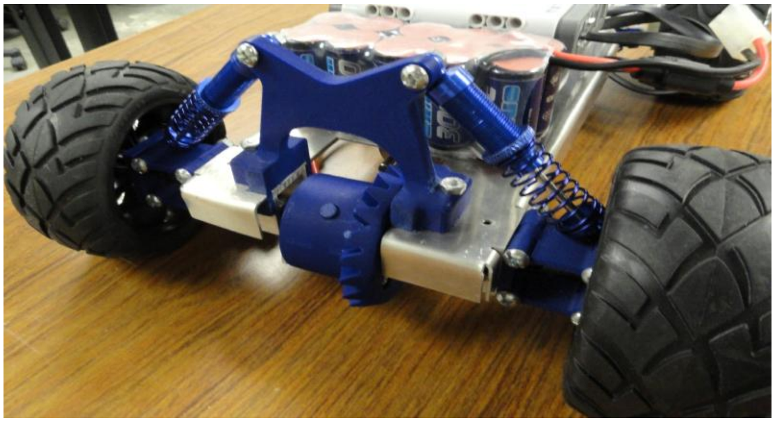

Figure 6: Rear Suspension System and Differential System Built by Team One

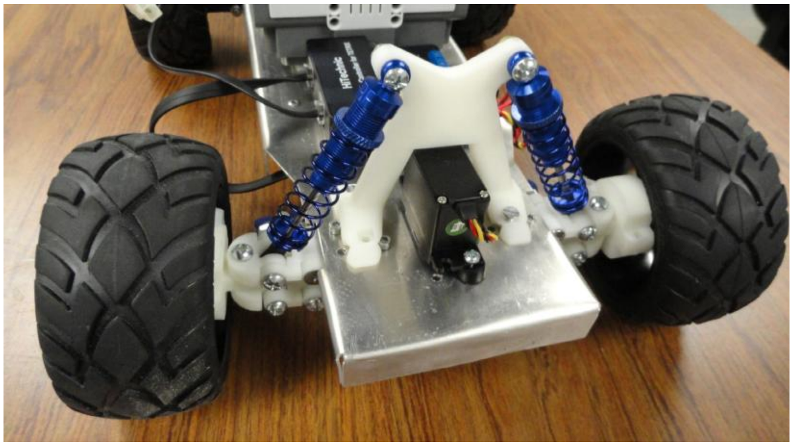

Figure 7: Front Suspension System and Steering System Built by Team One

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

Figures 8 and 9 show the prototype robot designed by Team Two.

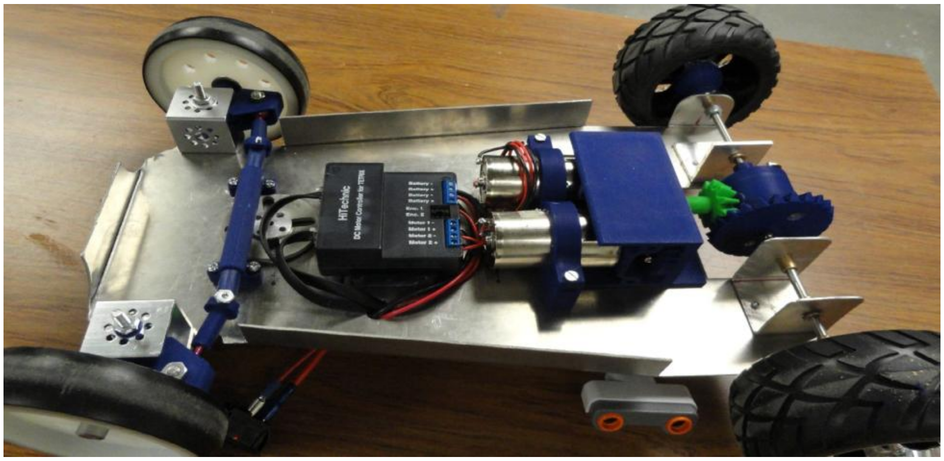

Figure 8: Bottom View of a Robot Prototype Designed by Team Two with 2 Motors to drive the Robot

Although Team Two used two DC motors in their design, 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 torque needed to overcome the resistance was reduced. Another mistake the team made was they did not make the connection properly so the two motors did not run in sync. This is a classical example of how students learn from their mistakes. They won't find anything wrong with their design until they see the test results.

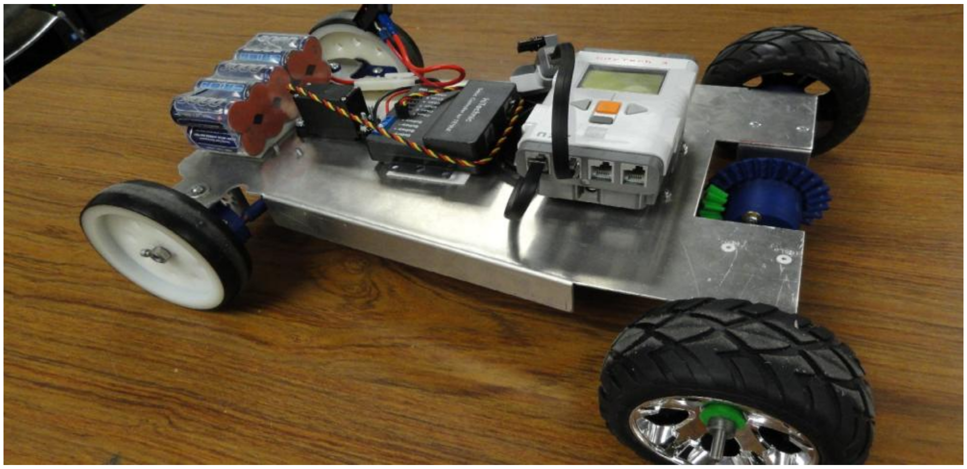

Figure 9: Top View of the Robot Prototype Designed by Team Two with 2 Motors to drive the Robot

5. Conclusions

The hands-on design project helped the students see the big picture of STEM subjects. It helped them make connections among the various STEM courses they take and gave them a new perspective.

The design project made the students 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 project. This helped students with their hands-on knowledge, techniques, and skills in the capstone design project. In addition, it gave students the ability to apply concurrent engineering concepts in product design applications.

Students gained valuable experience in the simulated design project to prepare them for real challenges after graduation. The hands-on project allowed students to learn from their mistakes.

The hands-on engaging design project should be provided every semester to allow students to reinforce their thinking on the practice of concurrent engineering approach in product design. For many students, this was the first time they were exposed to hands-on design project. Many students asked for this type of project to be introduced in freshman year, so they can benefit from the experience early on.

6. Acknowledgement

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