

An Engineering Capstone Design Course Taught in a Collaborative University/High School Setting

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Abstract – This educationally-focused capstone design course requires students to design and build one or more educational tools (such as a testing device or a piece of hands-on educational equipment) that will help high school teachers who are working with FIRST Robotics teams communicate to their students the essential elements of the engineering design process while creating an environment to enhance the students' interests in technical fields. This paper will describe how senior mechanical engineering students were placed in a mentoring role in connection with the FIRST Robotics Competition and completed their own design and build project related to this activity. The project is novel in that, unlike other design projects, our engineering students receive significant formal leadership training to facilitate their effectiveness as mentors, which will translate directly to their future professional and outreach activities.

Keywords: Capstone, Design, Mentoring, FIRST.

INTRODUCTION

Senior mechanical engineering students at Virginia Tech are required to take a two-semester engineering capstone design course. Students have many choices including working on industry-sponsored projects, design projects in the context of research problems, national design/build competitions such as SAE Formula and Mini Baja, and a recently established educationally-focused project. This educationally-focused project requires students to design and build one or more educational tools (such as a testing device or a piece of hands-on educational equipment) that will help high school teachers who are working with FIRST Robotics teams communicate to their students the essential elements of the engineering design process while creating an environment to facilitate more interest in technical fields by students. The yearly FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition is a national program for high-school students who are given six weeks and a "kit of parts" to design and build a robot which performs a prescribed set of tasks. This paper will describe how senior mechanical engineering students were placed in a mentoring role and completed their own design and build project related to this activity. The project is novel in that unlike other design projects, engineering students receive significant formal leadership training to facilitate their effectiveness as mentors that will translate directly into their future professional and outreach activities.

BACKGROUND

While the exact numbers are debatable, there is a growing concern that the U.S. is not preparing adequate numbers of students in the fields of science and technology, which will affect the security of the U.S. as well as its economy. Efforts are being mounted by many companies and government agencies directed at increasing the number of engineering and science graduates. Programs are in place that are aimed at interesting young people in science and engineering as early as elementary school. In many of these programs, professional engineers and scientists work

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side-by-side as co-teachers in the classroom.

For the past 7 years, high school students in the Montgomery County Public Schools (MCPS), which serves the county in which Virginia Tech is located, have participated in a year-long robotics course that includes participation in the yearly FIRST (For Inspiration and Recognition of Science and Technology) Robotics competition. In one facet of the program, high-school students solve a common problem in a six-week time frame using a standard "kit of parts" and a common set of rules. More information on this program can be found on the FIRST website¹. The appropriate engagement of trained mentors is an important component of the program. All too often, examples are given of FIRST teams being dominated by professional engineers with minimal interaction of the high school students whom they have undertaken to mentor. One of the goals of the capstone design project described here is to properly train (future) professional engineers to act as mentors to young students.

In the fall of 2006, the first year in which this course was offered, five mechanical engineering seniors (three males and two females) participated in the project. The course began in the fall semester with an orientation to the FIRST Robotics Competition. This, as well as the entire mentoring program, took place in a portion of a former middle school dedicated to the FIRST program which included space where machine tools, computers, workspace, and classrooms were located. (We found that this dedicated space was absolutely critical to the success of this project.) The engineering and high school students were given the task of redesigning a robot from a previous year's FIRST competition. This "mini-goal" requires the application of the engineering design approach to a technical problem, while at the same time allowing the engineering students to familiarize themselves with the students, teachers, and the rules of the FIRST competition which begins in January of each year. The engineering students were immediately placed in leadership positions and assigned the task of running the engineering design process associated with the robot redesign requiring them to understand the design process, to earn the trust of the 25 high school students who were enrolled in the (for credit) TEAM 401 project, and to mentor the students to succeed.

This project replaces an earlier program in which the undergraduate engineering students' roles were limited to only the period (in early January through March) of the actual FIRST competition was run. This year the program began at the beginning of the fall semester and involved two, two-hour meetings per week. High school students can remain in this program over three years, obtaining elective credits in math, science and vocational education. The MCPS program consists of three teachers: the lead robotics instructor, CAD instructor, and safety and machine tools instructor.

Senior mechanical engineering students at Virginia Tech are required to take a two-semester engineering capstone design course, ME 4015-4016, in which this project is offered as one of the many choices students have. Among the other projects that the students were given a choice to work on were industry-sponsored projects, design projects in the context of research problems, and national design/build competitions such as SAE Formula and Mini Baja.

This capstone design project has two separate, but connected, phases:

- 1) A fall semester (ME 4105) re-design component in which the capstone students learn to mentor the high-school students in an authentic design experience focused on rebuilding a robot used in a previous FIRST Robotics Competition.
- 2) A spring semester (ME 4016) design and build component in which the capstone students design, build, and test one or more educational tools (such as a testing device or a piece of hands-on educational equipment) that will teach students about engineering and enhance the abilities of the high-school students to design and build a winning robot for a future FIRST Robotics Competition.

In addition, engineering students receive significant formal leadership training to facilitate this process and their mentoring skills, which is not a typical component of a capstone design experience.

APPROACH/COURSE COMPONENTS

Teaching and Mentoring Skills

Teaching and mentoring students successfully is challenging and requires specific skill sets. There is mounting evidence to show that facilitative learning^{2,3} is an important engagement tool. The engineering students are

introduced to the principles of facilitative learning by the second author. Facilitative learning is a process where the mentors acting as facilitators use certain criteria to guide scientific investigations. The facilitator actively engages the learners motivating them to ask questions and consider new ideas. The facilitators motivate the learners to apply content knowledge to understand and solve problems using technology, teamwork and other valuable skills. This process, having direct ties to the business world, provides the engineering students with experiences developing their abilities to conduct meetings and set goals using effective communication techniques. Periodically, throughout the semester the engineering students are engaged in activities designed to develop: 1) mentorship and leadership skills, 2) skills and strategies for facilitating and monitoring group/team processes, 3) skills in planning, implementation and assessment, and 4) the background and specialty skills necessary for participation in the regional and national FIRST competitions. The engineering students' skills are actualized through field based applications in the high school robotics laboratory.

Focusing and then building on others' strengths and talents (both peer undergraduate students and the high school students that they are working with) is the central responsibility of good leadership and contributes to building positive, constructive and long-lasting relationships that change people and their institutions in positive, productive ways.

The project's leadership component is partially based on the appreciative inquiry⁴ foundation of identifying and aligning strengths in order to contribute to undergraduate engineering students' increased sense of self-efficacy and empowerment as effective leaders. The appreciative inquiry based approach is not about pretending there are no problems. Rather its focus is to identify strengths that will help learners move ahead in their development. Undergraduate engineering student leaders will learn the appreciative inquiry approach as a tool to work with peers and the high school students under their mentorship. Ultimately, one of the goals is to master building relationships with students to attract them to science, engineering, and math, and to continue to facilitate the FIRST Robotics positive, effective and innovative science, engineering, and math learning community. This learning will include the importance of positive language, positive mind-sets, creating shared meaning with others, and developing inclusive environments.

Throughout the leadership components, engineering students have been actively engaged in practical, hands-on experiences. These include:

- A. Management of large and small sub-teams of high school students.
- B. Individual consultations with the facilitators (faculty advisors) when engineering students have specific issues or scenarios that they want help with.
- C. Focus on individual development of their action plans.
- D. Development of strong sense of community with the goal of on-going support of the high school FIRST program once the initial robot redesign activity is completed.
- E. Practice in professional presentations.

This additional training is novel but professionally relevant to the education of engineering students. The students who will graduate from this program will be exceptionally well-prepared to facilitate meetings, manage multi-disciplinary teams, and step into management positions. In addition, they will be motivated and well prepared to successfully continue their outreach work by supporting such programs as FIRST Robotics beyond their undergraduate years.

Robot Redesign

The goal of the redesign of a previous year's robot was to: 1) apply engineering design principles to enhance the technical performance of the robot platform, 2) work with and mentor the high school students to give them an appreciation of what the engineering design process consists of, and 3) understand how an educational tool might be designed and built which would facilitate the way in which the high school students go about the engineering design process.

Initially, the plan was for the engineering students to work with only 16 "veteran" MCPS students during the fall semester to improve the design of an existing FIRST robot. However, as time progressed, the less experienced "rookie" high school students were quickly incorporated into the process. Although this change was motivated by simplifying the scheduling, the participation of the rookies quickly exhibited an educational benefit by creating an

important team/community building experience for the *entire* team of 25 high school students. The rookies also felt empowered by this approach as was determined by anecdotal evidence gathered during meetings, and observations made by engineering students, MCPS teachers, and faculty advisors. Photographs of typical student interactions are shown in Figures 1 and 2.



FIGURE 1: At Work



FIGURE 2: The Re-Designed Robot

Throughout the robot redesign, both the engineering and high school students were required to keep formal engineering logbooks and design notebooks. MCPS teachers were especially helpful to the undergraduates in their efforts to teach the design process to the high school students by agreeing to grade their students' assignments and logbooks at the request of the engineering students. In addition, the engineering students were periodically required to generate progress memos, a mid-semester report, and a final design report as part of their requirements for ME4015. At the conclusion of the robot redesign at mid-semester, the engineering students made a 30-minute professional presentation to faculty advisors, teachers, and high school students. After this event, time was dedicated to self-reflection by the engineering students on the process including several meetings and a written memo detailing their experience was assigned. The engineering students also chose to buy pizza for the high school students and spend the next meeting teaching them about buoyancy in preparation for a foil boat building contest during the second half of the meeting.

Educational Tool Design Project

The educational tool design is the ultimate goal for the senior engineering students. At mid-semester the engineering students begin to work concurrently on the design of an educational tool that will aid the high school students in carrying out the design process more efficiently, or will develop a better understanding of the engineering principles on which design aspects are based. As the engineering students work with the students and robot, they are instructed to begin looking for opportunities to improve the engineering learning process for the high school students (identifying customer needs), and to be prepared to discuss their ideas for educational tools during the "Concept Generation" phase of the project. During "Concept Selection" the engineering students will use formal decision-making tools choose one or more projects to pursue further. For the remainder of the fall and spring semesters the engineering students are mentored through the rest of the design process, including design for manufacturing, prototype testing, and final product build. At the end of the semester the devices the engineering students design and build are presented to the high school for use in preparing for the next year's competition.

WHAT WORKED AND WHAT DID NOT

The robot redesign was a success on many levels, particularly for team building for all students, and the leadership experiences of the engineering students. The engineering students were initially intimidated by the prospect of

mentoring, teaching, and working with high school students (as were the engineering faculty advisors!). However, with the facilitation of their mentoring and leadership skills by the second author in particular, the engineering students became empowered over time and developed strong mentoring relationships with the high school students. High school students clearly looked to the engineering students for guidance and all of the engineering students successfully facilitated various aspects of the process in leadership roles. The positive energy of this component was absolutely tangible, and invaluable leadership and community-building lessons have been learned.

In retrospect, the engineering faculty advisors needed to spend more time reviewing the design process with the engineering students. These students were introduced to the design process in their sophomore year and while some time was spent reviewing concepts, this appeared to be inadequate. The engineering design approach was not always applied as formally as it could have been and there was a little more “seat of the pants” engineering going on than was preferable. Of course, this is not exclusive to this design project based on the experience of one of the authors and two other ultimately successful design projects. Future plans include more writing assignments to help students understand various aspects of the engineering design process and the addition of lectures on implementation of design process components in this atypical application.

CONCLUSIONS

A new educationally-focused design project was offered as an option for Virginia Tech senior mechanical engineering students in connection with their two-semester senior capstone design course. The project was integrated into the FIRST robotics program in the Montgomery County Public Schools (MCPS).

In the first phase of the course, the Virginia Tech students worked as leaders and mentors to facilitate a pre-competition robot redesign and rebuild process in order to teach high school students the engineering design process to enhance their prospects of designing and building a competitive entry in the 2007 FIRST Robotics competition. During this process, the engineering students were taught how to be successful mentors and leaders by using the inquiry-based and appreciative inquiry based approaches by the second author. In the second phase of the course, the engineering students will be required to apply the design process to develop an educational tool (or tools) to help the MCPS teachers facilitate teaching of engineering practices and principles in connection with future FIRST Robotics competitions. At the time of this writing, the fall semester is nearly complete, and the engineering students have shown tremendous growth in their leadership and mentoring skills which will translate well into their professional engineering careers.

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