

## **AC 2007-1354: TEACHING CAPSTONE DESIGN IN A SERVICE-LEARNING SETTING**

### **Mary Kasarda, Virginia Tech**

Mary Kasarda is an associate professor in the Department of Mechanical Engineering at Virginia Tech. She specializes in magnetic bearing, rotor dynamic, and health monitoring research topics. She has six years of professional engineering experience and her background is in various aspects of turbomachinery engineering. She is a member of the VT Rotor Dynamics Laboratory and the VT Center for Intelligent Materials and Smart Structures. In 2003-2004, she acted as an education consultant through Virginia Tech to Sweet Briar College to help facilitate a new engineering program at this all-women liberal arts college. She received an NSF CAREER award in 1998 and the VT College of Engineering Outstanding New Assistant Professor Award in 2000.

### **Brenda Brand, Virginia Tech**

Dr. Brenda R. Brand is an assistant professor of Science Education at Virginia Tech. She received her Masters and Doctorate degrees in Curriculum in Science Education from Virginia Tech. Prior to joining Virginia Tech, Dr. Brand was the science supervisor for Montgomery County Public Schools. As the science supervisor, Dr. Brand co-developed a year-long robotics program, working with the lead teacher to develop a course description and syllabus that incorporated participation for the FIRST robotics competition. Currently, Dr. Brand and Dr. Mary Kasarda, a colleague in mechanical engineering, are conducting a study on factors influencing girls' participation in robotics engineering.

### **Eugene Brown, Virginia Tech**

Eugene Brown is Professor of Mechanical Engineering. He is a computational fluid dynamicist with a special interest in computational nano-fluidics. His research is diverse and has ranged from the numerical simulation of fire extinction by water mist to the development of methods for predicting the performance of aircraft propulsion nozzles. For the past two years, he has been the technical advisor to the Virginia Demonstration Project, an ONR funded middle-school focused educational outreach project. His research has been published in many journals and conference proceedings. Dr. Brown is an Associate Fellow of the American Institute for Aeronautics and Astronautics. He has served the University and the profession as Virginia Tech's Associate Provost for Program Development and as Program Manager of the Graduate Research Fellowship Program at the National Science Foundation.

# Teaching Capstone Design in a Service Learning Setting

## Abstract

This service-learning-focused capstone design 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 and mentors who are working with FIRST Robotics teams communicate to the students the essential elements of the engineering design process, while creating an environment to enhance the high-school 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 while working to complete their own design-and-build project related to this activity. The project is novel in that, unlike other design projects, the engineering students receive significant formal leadership training to facilitate their effectiveness as mentors and to aid them in their future professional lives. The project serves not only as a capstone design experience, but also as a mini-internship with a service-learning component where students experience working as both leaders and mentors.

## Introduction

For almost a decade, undergraduate engineering students at Virginia Tech have volunteered as mentors to TEAM 401, a group of local high-school students taking part in the annual FIRST Robotics Competition. To prepare them for these responsibilities, the second author, a faculty member in the School of Education, has offered a for-credit education course focused on developing mentoring skills in the context of problem-based learning.

This year, the authors have joined forces to offer a mechanical engineering capstone design project that encompasses the service learning and mentorship components of the earlier program and adds a new mechanical engineering capstone design-and-build feature. Specifically, our senior mechanical engineering capstone students first mentor the members of TEAM 401 through a rigorous product design and development experience based on the re-design and re-building of a robot originally constructed for a previous FIRST Robotics Competition using their knowledge of engineering tools and the engineering design process. Following the robot re-design phase, the capstone students apply the formal design process to develop and build a “facilitating educational product or device” to enhance the abilities of educators (including themselves) to 1) communicate to the high-school TEAM 401 members the nature of a properly conceived design process, 2) demonstrate one or more difficult-to-understand physical principles, and/or 3) assist the TEAM 401 students in the building or testing of their robot.

Conceptually, this design project has two separate, but connected, phases:

**Phase 1. Mentoring and Robot Redesign.** This comprises most of the fall semester portion of the capstone design course, ME 4105, where the capstone students learn to mentor and lead the high-school students in an authentic design process experience focused on the redesign and rebuilding of a robot used in a previous FIRST Robotics Competition. There is close (almost one-on-one) interaction with the Team 401 students as the capstone students play the dual roles of mentor and role models guiding the

students through the rebuilding process, pointing out not only the usefulness of the engineering design process but also the application of other tools in engineering, science, and mathematics.

**Phase 2. Designing and Building an Educational Tool.** This begins late in the fall semester and continues on into the spring semester portion of the capstone design course, ME 4016, 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 high-school students about engineering, and enhance their ability to design and build a winning robot for future FIRST Robotics Competitions. During the first half of this phase of the project, Team 401 is fully consumed with the design and build of the robot for the spring competition. While informal mentoring activities continue, the interaction between the capstone and the high-school students is minimal. At the completion of the FIRST robotics competitions, the capstone students will utilize TEAM 401 members for prototype testing of their product.

The two-phase approach is used to achieve multiple goals. One of the goals of the first phase is aimed at immersing the capstone students in the environment of a FIRST robotics team so that they can learn about the process and be prepared to adequately identify customer needs. Another goal of Phase 1 is to formally train students to be leaders and mentors in a real-world situation effectively creating an internship experience while enhancing the experience and skills of TEAM 401. A result of the two-phase approach is that the capstone students benefit from running through the entire design process twice – once for the robot redesign and once for their final product. In addition, the capstone students are sequentially exposed to the design process at two different and complementary levels--one in which the students are called up to apply and teach the design process, and another one in which they are called upon to use what they have learned in the first phase about their customers and the design process to design and build a product of their own creation.

## **Background**

### Origins of the Project

For the past eight years, high-school students in the Montgomery County Public Schools (MCPS), which serves the county in which Virginia Tech is located, have taken part in a year-long robotics course that includes participation in the yearly FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition. In FIRST Robotics, high-school students solve a common problem in a six-week time frame starting in January of every year using a standard "kit of parts" and a common set of rules. More information on this program can be found at <http://www.usfirst.org/>.

The TEAM 401 robotics course starts at the beginning of the fall semester and involves a minimum of two, two-hour meetings per week, supplemented by additional meetings on weekends and other evenings to meet deadlines, particularly during the six-week FIRST design and build period in the spring. High-school students can remain in this program for three years, obtaining elective credits in math, science and vocational education. The MCPS program is

served by three teachers: the lead robotics instructor, a CAD instructor, and a safety and machine tools instructor.

The appropriate engagement of trained mentors is an important component of the program. All too often, well-meaning mentors do more than just coach FIRST teams, they *run* them. One of the goals of the capstone design project described here is to assure that this doesn't happen in this and future FIRST Robotic teams in which these engineering students mentor.

#### Outline of the Capstone Course

In the first year (AY 2006-2007) in which this capstone design project was offered, five mechanical engineering seniors (three males and two females) participated in the project. Much of the first semester of the capstone design course occurs concurrently with the MCPS FIRST Team 401 meetings. All of these meetings take place in a portion of a former middle school dedicated to the FIRST program which includes space where machine tools, computers, workspace, and classrooms are located. All involved found that this dedicated space was absolutely critical to the success of this project. The fall semester (Phase 1) begins with all students (capstone and high-school) attending an orientation to the FIRST Robotics Competition, followed by some short team-building exercises and group meetings. After the initial meetings, the capstone engineering and high-school students were given the task of redesigning a “moth-balled” robot from a previous year's FIRST competition. This goal required 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. The capstone engineering students were immediately placed in leadership positions and assigned the task of guiding the robot redesign process. This required them to understand the engineering design process, to earn the trust of the 25 high-school students who were enrolled in the TEAM 401 project, and to lead and mentor the students to success. In addition, this phase of the project also significantly enhanced the high-school student's prospects of designing and building a competitive entry in the 2007 FIRST Robotics Competition.

In Phase 2, the capstone engineering students apply the design process to the development of their educational tool/device which will be their final product. In this phase, the capstone students follow conventional steps of a design process including process planning, identification of customer needs, product specification, concept generation, concept selection, concept/prototype testing, product architecture, industrial design, design for manufacturing, and conclude with the building and delivery of a final product. More details associated with Phases 1 and 2 are presented below.

#### **Capstone Design and Service Learning—Bringing It All Together**

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

The Virginia Tech Undergraduate Course Catalog describes the ME 4015-4016 capstone design course in this way:

## 4015-4016: ENGINEERING DESIGN AND PROJECT

Team oriented, open-ended, multi-disciplinary design projects focused on industrially relevant problems. A specific, complex engineering design problem is normally taken from problem definition to product realization and testing. Emphasis is placed on documenting and reporting technical work, idea generation and selection, application of design and analysis tools developed in previous courses, project management, selling technical ideas and working in teams.

The project which we describe in this paper is unique in that not only does it have the required characteristics of a capstone design project, but it also has the characteristics of an internship and a service-learning project. As identified by the U.S. National and Community Service Trust Act of 1993, the term “service-learning” means a method under which students or participants learn and develop through active participation in thoughtfully organized service. Our project meets that definition and in addition fulfills the Act’s requirements that it:

- i) is conducted in and meets the needs of a community;
- ii) is coordinated with a secondary school, institution of higher education, or community service program, and with the community; and
- iii) is integrated into and enhances the academic curriculum of the students.

In addition, this project meets the goals of the Purdue University founded Engineering Projects in Community Service (EPICS) program<sup>1</sup> in that it:

1. Broadens the students' education to include experience with design as a start-to-finish process by defining, designing, building, testing, deploying, and supporting real systems, and
2. Brings affordable engineering expertise to community service and education organizations.

The case is clear. This project satisfies the requirements of a capstone design course in that the students are exposed to a fully-configured design experience which proceeds from the collection of customer needs (in ME 4015) to the completion, testing, and re-design of a prototype (in ME 4016), and it is done in the spirit of service in which the skills of the capstone students are used to benefit the community.

Finally, the project has another unique feature and that is the inclusion of a leadership training program that not only enables the capstone students to more effectively mentor the high-school students, but also provides them with the management skills which will be of use to them throughout their professional lives. The leadership training aspect is unique also in that capstone students immediately apply their leadership skills in a real-world scenario working with a diverse group of students.

### **Phase 1. Mentoring and Robot Redesign**

#### Mentoring

Teaching and mentoring students successfully is challenging and requires specific skill sets. There is mounting evidence to show that an ability to use facilitative learning<sup>2,3</sup> is one of the most important of these skills. An important part of the leadership training provided by the second author is focused on imparting this skill to the capstone students.

The basic premise of this training is that learning will occur by the educator acting as a facilitator, that is, by establishing an atmosphere in which learners feel comfortable to consider new ideas and are not threatened by external factors. 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 inquiry<sup>4</sup> 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 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 the capstone 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 and written reports and memos.

This additional leadership 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

In this portion of the project, the capstone students apply their mentoring and leadership skills to direct and mentor the high-school students as they redesign a previous year's FIRST robot in order to enhance its ability to perform based on the criteria from that robot's respective competition. This provided an "authentic" experience which the capstone students used to demonstrate both the principles of the engineering design process and the usefulness of the tools of engineering, mathematics and physics to the TEAM 401 students. The capstone students were also directed to use this experience as an opportunity to gather customer needs leading to the design an educational tool which, if it were available, would improve the way in which the high-school students go about the engineering design process.

The original plan was for the engineering students to work with only the 16 "veteran" MCPS students. However, as time went on, 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.

Throughout this process, the capstone students were advised by the authors in a step-by-step fashion as they proceeded through the design process, and given suggestions on how to teach the elements of the engineering design process to the high-school students. All aspects of the robot redesign process were completed by high-school students mentored by the capstone design students. The process began with project planning including development of a Gantt chart, identification of customer needs (i.e. what did the robot need to do to be more competitive in the previous competition?), target specifications including ideal and marginal values and associated units, the development of a House of Quality, concept generation, concept selection, and build and test phase. Multiple approaches were used during the process including the capstone students working with smaller sub-groups, large group meetings including group voting for concept selection, and meetings with faculty advisors and capstone students to clarify difficult concepts such as the House of Quality. Photographs of typical student interactions and the re-designed robot are shown in Figures 1 and 2.

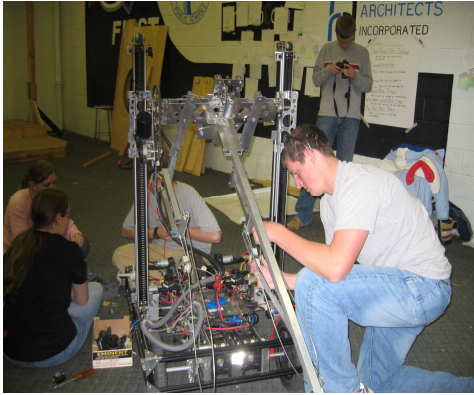


Figure 1: At Work



Figure 2: 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 (some of which were conceived and assigned by the capstone students) 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 ME 4015. 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 capstone engineering students on the process including several meetings, and a written memo detailing their experience was assigned. At this point, the capstone students took the initiative to buy pizza for the high-school students and spend the next concurrent meeting teaching them about buoyancy in preparation for a foil boat building contest during the second half of that meeting. Clearly, the capstone students became invested in the experience and education of the high-school students. The faculty advisors had hoped that this would be the result, but expectations were pleasantly exceeded!

## **Phase 2. Designing and Building an Educational Tool**

### Identifying Customer Needs

In this phase of the project, the capstone students used well-known design tools (see, for example, reference 5) to continue the collection of customer needs which they began in Phase 1. As a first step, the capstone students prepared a comprehensive quiz which was administered to the Team 401 students to determine their areas of weakness. The capstone students found the results of the quiz, which covered the areas of strength of materials, pneumatics, dynamics, motors, kinematics, and the design process, showed similar areas of weakness in all areas. The students took from this result the conclusion that the TEAM 401 students needed help in all areas, and in a sense, they couldn't go wrong regardless of the curricular area which they choose to concentrate on. In order to put these needs in a hierarchy, additional tools were used. For example, personal interviews by the capstone students were conducted with high-school teachers and one veteran mentor who had volunteered his time to the high school for several years. Students also took into account their own observations from the Phase 1 robot redesign. The



results were used to provide a better definition of the curricular areas where the students needed the most help. From here, they assigned an importance to each of these needs and their results are shown in Table 1.

No.	Need	Importance
1	The educational tool emphasizes electricity/torque/power	1
2	The educational tool emphasizes forces/moments	3
3	The educational tool emphasizes material selection	2
4	The educational tool emphasizes traction	4
5	The educational tool emphasizes pneumatics	3
6	The educational tool emphasizes kinematic/Potential Energy	5
7	The educational tool emphasizes linkages	3
8	The educational tool emphasizes center of Mass/ Acceleration/Speed	4
9	The educational tool emphasizes fastener selection	2
10	The educational tool emphasizes stress/moment diagrams/ stress concentration	5

Table 1. Importance of specific customer needs for the educational tool. “1” indicates the highest level of importance.

### Concept Generation and Target Specifications

The capstone students then began the concept generation stage by laying out a functional diagram as shown in Figure 3, which contains their view of the elements of their educational tool consisting of a curriculum with associated mini design projects that feed into a robot design support tool. The capstone students identified the need for the mini design projects primarily from their experiences in Phase 1 which told them that students learn much more quickly when they participate in a hands-on experience. They anticipated creating between 3 and 5 curricula-mini design project lessons along with the design and building of the robot design support tool.

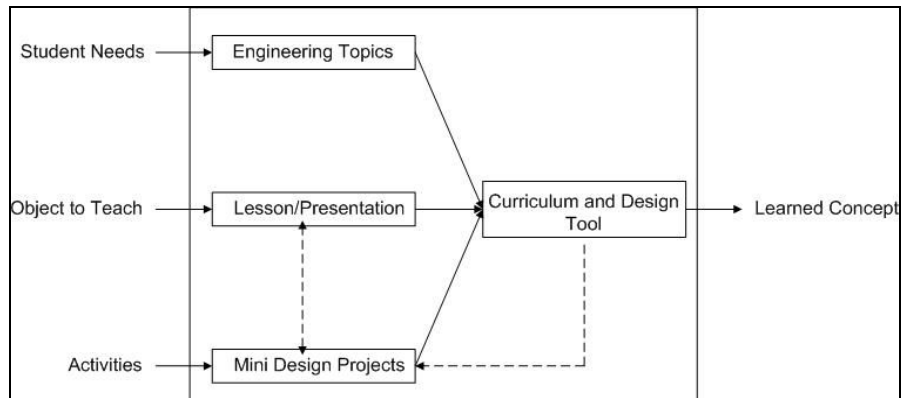


Figure 3. Functional Diagram

The next step was to develop a framework for the Curriculum. For this the capstone students used a concept classification tree to subdivide the various technical areas into more fundamental physical concepts. Figure 4 is the Concept Classification Tree which the students developed.

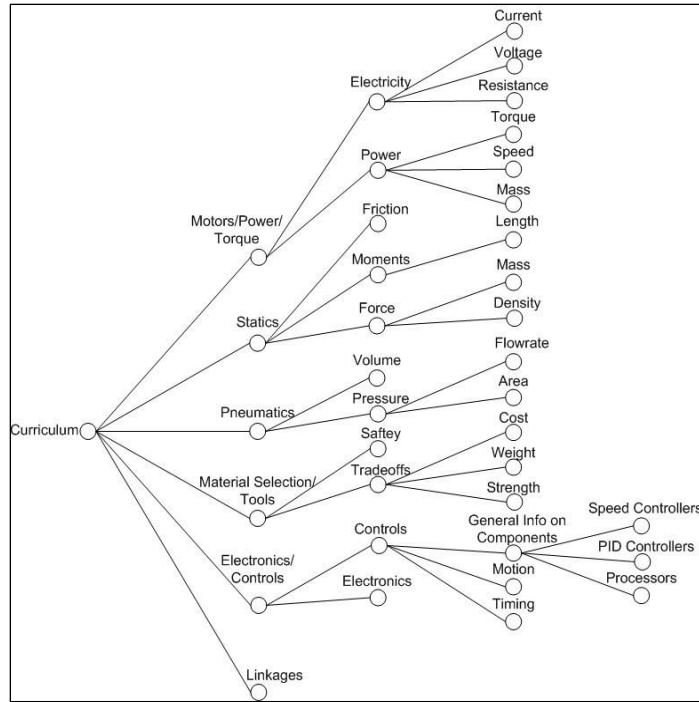


Figure 4. Concept Classification Tree

Finally, a concept scoring and concept screening tools were also developed by the capstone students which led them to select the combined topics of motors/power/toque as the concept around which they would build the robot design support tool and at least one of the associated curriculum and mini design projects.

Their rough concept chosen for the robot design report tool is shown in Figure 5 which is a general concept of a dynamometer for testing and understanding motor performance and basic principles. The students next launched into a more detailed concept generation and selection process to refine the details of this motor test bench.

The remaining portion of the semester will be devoted to the remaining design considerations including product architecture, industrial design, Design For Manufacturing (DFM), prototype testing, and final product build. As part of this process, the curriculum and mini design projects, along with the motor testing device prototype capstone will be presented to the high-school students for testing and re-design refinements for the final product. Additional details about the final stages of this work will be included in the presentation of this paper.

### Lessons Learned—Do's and Don'ts

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, as their mentoring and leadership

<b>Motor dynamometer:</b>		
The purpose is to be able to load a small DC motor and see the effects of loading on speed, current, torque, power, etc. Hopefully, data acquisition will be possible and allow torque curves and speed to be plotted to teach the fundamentals of motor theory/selection.		
<b>Description of unit:</b>		
The unit will have several components. Below is the functional breakdown of the various components.		
<b>Electrical:</b> voltage, current, and power consumption meters will display real-time readings		
<b>Data Acquisition:</b> The computer, DAQ card, loadcell, and rpm sensor will measure inputs and allow the computer to plot the torque vs RPM curve and subsequently calculate power.		
<b>Motor stand:</b> The stand will hold motors and components in place. The stand must allow for swapping out of various motors. The stand includes a coupler to connect the motors to the dynamometer.		
<b>Dynamometer:</b> This will be a type of power absorption device (brake) that also contains a device to measure torque.		
<b>Target Specs:</b>	<b>Marginal</b>	<b>Ideal</b>
Size	25 sq ft	15 sq ft or less
Weight	200lb	100 lb or less
HP capacity	0.5 HP	1 HP
Voltage range	0-12v	0-24v
Current capacity	40amps or greater	80amps or greater
Torque capacity	25 ft lb	50 ft lb or greater

Figure 5. Dynamometer Specifications

skills increased, the engineering students became gradually empowered 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 early in the fall semester. Students had not been exposed to the design process since their sophomore year, and the advisors needed to better facilitate review of that subject matter with them. This was also partly due to the fact that there was a more acute need than with other senior capstone projects because our students not only had to understand the material and application of the material, but also needed to teach it to the high-school students. This lack of familiarity resulted in a situation where the engineering design approach was not always applied as rigorously 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 uncommon, based on the previous experience of the first author with two design projects which ultimately proved to be very successful in National competitions.

Another important aspect of the project is scheduling. Since this was the pilot year for the project, the advisors were a bit too flexible with students in the early fall semester in terms of them meeting design process milestone target dates to allow for uncertainty associated with capstone student/TEAM 401 dynamics. This resulted in some relief for the capstone students involved in an intimidating situation (working with a large group of high school students) and is not necessarily a bad thing (particularly for a pilot year), but this may have contributed to a marginally less successful robot redesign. Only one of the chosen two major design changes to the robot was completed, but, nevertheless, the rebuilding experience was considered a success by both the TEAM 401 students and high-school teachers. Now that advisors better understand what to expect in terms of the educational dynamic and how to better mentor students through this, stricter schedule milestones in the fall semester will be implemented in the next iteration of the project. Additionally, in future years, early meetings will be devoted to team-building exercises before a comprehensive schedule of design process milestones will be implemented. Future plans also include more writing assignments to help students understand various aspects of the engineering design process, and requirements to communicate stronger analytical justification for their decisions. Faculty advisors will also include the addition of lectures on implementation of design process components in atypical applications such as our students encountered here.

Also, in future years, students will be required as a condition of enrollment to commit to attending a minimum of four hours per week of mentoring time with the high-school students, return from their Christmas break early in January for the FIRST robotics kickoff, and will be required to attend the regional FIRST competition in March. While this was generally not a problem with our dedicated group of capstone students this year, it was recognized that this could be problematic in the future. Also, these additional requirements are no more stringent than many other design project requirements, particularly when a national competition is involved.

## **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).

This project has achieved two objectives. It not only reinforced the principles of a thoughtfully conceived design process at multiple levels, but it also equipped the capstone students with the life-long skills that will enable them to be effective mentors and role models for the engineers of the future.

In Phase 1 of the course, the capstone students learned how to successfully work as leaders and mentors in a service-learning context. In this manner, the capstone students facilitated a pre-competition robot redesign and rebuild process in order to teach high-school students the engineering design process in order to both educate high-school students about engineering, but also to enhance the high-school student's prospects of designing and building a winning entry in

the 2007 FIRST Robotics Competition. During this process, the engineering students were taught how to be successful mentors and leaders by using an appreciative inquiry based approach by the second author. In Phase 2 of the course, the engineering students were 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 teams.

The capstone students have shown tremendous growth in their leadership and mentoring skills which will translate well into their professional engineering careers. Here, at the mid-point of the spring semester, our students have demonstrated they understand the design process and associated tools by successfully applying them to the development of their educational tool. Our students have determined that their final product will consist of 3-5 curricula lessons on engineering fundamentals with associated mini-design projects, and a motor test station complete with a dynamometer for supporting the teaching of motor fundamentals and for use as a design support device for future FIRST competition robots.

We have been extremely impressed with how well our students have applied the design process to an unusual scenario, and have been able to justify their chosen concept using the analytical design process tools. The faculty advisors have learned much from their observations and insights. We continue to anticipate great things from our students as they complete the development of their educational tools designed to help high-school teachers and mentors who are working with FIRST Robotics teams communicate to the students the essential elements of applying engineering principles, while creating an environment to enhance the high-school students' interests in technical fields.

### **Bibliographic Information**

- [1] Coyle Edward J., Leah H. Jamieson, and William C. Oakes, "EPICS: Engineering Project in Community Service," *International Journal of Engineering Education*, Volume 21, No. 1, February 2005, pp. 139-150.
- [2] Wittmer, Joe and Robert D. Myrick, *The Teacher As Facilitator*, Educational Media Corporation, 1989
- [3] <http://www.educationaldividends.com/lt3/business/facilitative.asp>, *Facilitative Learning Model*, Educational Dividends, December 6, 2006
- [4] Cooperrider, David L, and Dianna Whitney, *Appreciative Inquiry: A positive Revolution in Change*, Berrett-Koehler, 2005.
- [5] Ulrich, Karl T., and Steven D. Eppinger, *Product Design and Development*, Irwin McGraw-Hill, Second Edition, 2000.