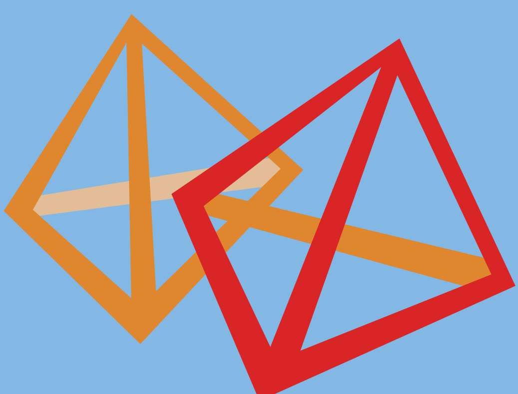
Motivating Students With Robotics

Students increase science skills and confidence through a robotics course and international competition

Brenda Brand, Michael Collver, and Mary Kasarda

In recent years, the need to advance the number of individuals pursuing science, technology, engineering, and mathematics fields has gained much attention. The Montgomery County/ Virginia Tech Robotics Collaborative (MCVTRC), a yearlong high school robotics program housed in an educational shop facility in Montgomery County, Virginia, seeks to motivate students' interest in these fields. Through this program, students have the unique opportunity to apply their science and math skills to robotics design through a series of short courses and to participate in an international robotics competition, For Inspiration and Recognition of Science Technology (FIRST) (see "About FIRST").



The high school robotics program capitalizes on the student excitement generated by participation in FIRST while providing an avenue for students to increase science-related skills (e.g., critical thinking) and self confidence.

The MCVTRC program is a collaboration between students and faculty from Montgomery County Public Schools' four high schools, undergraduate and graduate students from engineering and related fields at Virginia Polytechnic Institute and State University (Virginia Tech), and faculty from the university's School of Education and Department of Mechanical Engineering. While this article describes a countywide robotics program and its impact on student understanding, it also can serve as a model for other schools and districts that wish to implement similar programs.

Student engagement

According to Bandura (1986, 1994), students' perceptions of their abilities play a major role in determining their accomplishments and defining what they consider to be an attainable goal. Bandura discusses the nature of the learning environment in terms of encouragement and motivation, peer interactions, repeated successes, and supportive risk taking as factors having the potential to positively impact students' self confidence, as well as their behaviors and attitudes toward learning (Bandura 1997). In the MCVTRC program, all students are encouraged to participate in the activities and are supported in their application of science, mathematics, and technology concepts to solve problems.

Similarly, the National Science Education Standards (NRC 1996) call for students to be actively engaged in solving problems that allow them to realize applications beyond the scope of the classroom. Ideally, students should be engaged in designing, constructing, analyzing, and proposing solutions to problems (AAAS 1993; NRC 1996). To accomplish these objectives, and also to open the world of science to those from nonmainstream backgrounds, nontraditional approaches can be particularly effective (Brown 2002).

Along these lines, the robotics program engages students in science through a nontraditional approach, as students explore the field of robotics as a real-world discipline in which the fundamentals learned are put to practical use. Over the course of the year, students construct various robot prototypes in addition to the human-sized robot specifically designed for the FIRST competition. Having the opportunity to work with peers and mentors from the university and to participate in FIRST motivates students, which can increase their interest in pursuing careers in science, technology, engineering, and mathematics.

Students explore the field of robotics as a real-world discipline in which the fundamentals learned are put to practical use.

About FIRST.

As stated on the organization's website, FIRST was founded in 1989 to inspire young people's interest and participation in science and technology. Based in Manchester, New Hampshire, the nonprofit public charity designs accessible, innovative programs that motivate young people to pursue education and career opportunities in science, technology, engineering, and mathematics, while building self-confidence, knowledge, and life skills.

For more information, visit *www.usfirst.org*.

The program

Now in its ninth year, MCVTRC is a one-credit "local elective" offered to 10th- through 12th-grade students that can be taken up to three times during their course of study. Through this program, high school students, undergraduate mentors, graduate students, and high school and university faculty meet twice a week in a centrally located shop facility consisting of a computer lab, workshop, and classroom. The high school course is cotaught by high school faculty and a graduate student from Virginia Tech—who is advised by faculty from the School of Education and the Department of Mechanical Engineering.

Mentorship is vital to the robotics program. Students complete their assignments and projects under the guidance of undergraduate student mentors—primarily from engineering, but also from other majors such as computer science and business—who receive course credit at Virginia Tech for their participation in the program. (**Note:** In preparation for working with high school students, the undergraduates take a mentoring course cotaught by faculty in the School of Education and the Department of Mechanical Engineering. The goal of this course is two-fold: to teach skills for leading and participating in teams and to teach strategies for facilitating problem-solving activities.)

As facilitators, undergraduate mentors engage high school students by posing questions and encouraging discussions, analysis, and explanations of problems. The mentors are taught to support learning without giving answers. Acting as "middle management," they work directly with high school students organized in subteam structures to provide more one-on-one attention. Mentors also lead student groups in developing plans and prototypes to be implemented and tested as required by

FIGURE 1

First semester short courses.

Short Course	Description	Objectives
Safe Shop Behaviors and Machining	This three-week unit challenges students to safely fabricate simple aluminum components to be used in later lessons.	◆ To foster team-building ◆ To acquaint every student with every tool ◆ To develop reflexive safe shop behaviors
Machines and the Design Process	This three-week unit challenges students to work through a formal, cyclic design process to create a unique machine. The machine will be constructed from a robotics design kit and will employ three or more simple machines to accomplish a predetermined "task."	◆ To distinguish between *machines* and *robots* ◆ To learn how to create an original device through the engineering design process ◆ To learn project management skills, including attention to "critical path" ◆ To identify personality traits as they relate to functioning in a group
Computer-Aided Design (CAD)	This three-week unit introduces students (working in small groups) to another robotics design kit. Students use CAD applications to design and virtually assemble a motorized platform.	◆ To create a detailed sketch with enough clarity to allow the creation of a three-dimensional (3-D) vector-based scale drawing ◆ To be able to assemble several drawings into one complex mechanism within a software program ◆ To be able to predict the mass and center of gravity of an assembled machine ◆ To render and animate an assembled machine using a 3-D software program
Programming and Logic	This three-week unit introduces students to object-oriented and textual computer languages used to control a machine—ulitmately a *real* robot. The C-programming language will be used to create logical feedback relationships between the inputs and outputs of their robots.	◆ To introduce students to the concept of teleoperated control ◆ To introduce students to the concept of autonomous control ◆ To create a logic diagram and then translate into a C-based instruction set
Rapid Prototyping	This final six-week unit challenges the whole class to create a robot through the combination of the engineering design process with the concept of prototyping.	◆ To challenge students to identify the function that will drive their eventual design ◆ To model functioning components with space-filling wooden models ◆ To solidify the concept of subsystem integration

both the weekly design challenges assigned in the short courses—which comprise the yearlong robotics course—and the FIRST competition. They are responsible for setting deadlines and overseeing the process to ensure completion of the assigned tasks.

Short courses

The first semester of MCVTRC is presented as a series of short courses at the centrally located shop facility (Figure 1). From simple machines to C-language programming to the creation of a simple robotic arm, all of the tools students will need to effectively participate in a team-oriented design process and to construct robots are imparted by way of design challenges. In a design challenge, a problem is posed to students, who must then use an arbitrary set of raw materials to design machines that will complete the task or solve the problem.

The first four short courses—Safe Shop Behaviors and Machining, Machines and the Design Process, Computer-Aided Design, and Programming and Logic—are three-week courses; the final course—Rapid Prototyping—is six weeks long. These courses are outlined in the following sections and are completed in the order listed.

FIGURE 2

The 2005 competition robot lifting a tetragonal game piece.

PHOTO COURTESY OF THE AUTHOR

Safe Shop Behaviors and Machining

At the beginning of the first semester, high school and university students must attend a series of safety presentations that emphasize proper attire and general safe behaviors. These presentations are led by a high school shop teacher, who also demonstrates the proper use and maintenance of specific shop tools, such as a bandsaw, drill press, and miter saw. After each presentation, there are separate written and practical examinations. Students are allowed to operate shop equipment only after identifying and demonstrating the proper use of tools. The unit on safety ends with a multiple-choice exam, on which students are expected to score 90% or better. If students do not pass the exam, they must retest with a different exam.

CAUTION

Machines and the Design Process

This three-week course challenges students to work through a cyclical design process to create a device that solves a specific problem. Initially, the discussions revisit simple and compound machines. (**Note:** It is assumed that students have been exposed to these ideas in other courses prior to enrollment in the program.) At the end of the unit, students understand that robots are classified in a unique category of compound machines that are capable of acting on either predefined or sensed information.

Using only the components found in a robotics design kit, students—typically working in groups of four—apply concepts of stability, accuracy, speed, power, robustness, and elegance as they build and rebuild a robotic machine to solve a specified problem. One problem addressed in this class required the removal of a "tumor" from a patient—a laboratory "rat" constructed entirely from LEGOs. Each team had to devise a robot that would stand alone and then insert an instrument into the patient to "treat" the tumor. Success was achieved when the students' robot successfully pushed a button located in the rat that caused its tail to rotate.

After working on design problems, the class is then asked to scrutinize groups' models for efficiency. Students are asked to identify the best models and are prompted to define the constructive functions particular to each design challenge. These could include such things as speed, robustness, or accuracy. Finally, groups are encouraged to complete their robot with a renewed focus, attending only to the design elements that must be modified to achieve success in addressing the problem.

Computer-Aided Design

In this course, students are presented with a design problem and are required to solve it using a robotics design kit. Parts in the kit include construction pieces, motors, sensors, and controllers. Students are encouraged to use computer-aided design (CAD) software to draw the side view of a robot that could theoretically solve the problem.

A professional software program for sketching and drawing is also supplied in the kit for FIRST participants. With this program, students can click and drag to create shapes representing individual components of the robot. Once drawn, these shapes can be constrained to match the actual part measurements. These components can be "attached" to one another and their movements limited to match those of the real robot parts. Each virtual robot must demonstrate on the computer screen that it can indeed perform the task.

Programming and Logic

Programming and Logic introduces students to the use of computer programming languages. By the end of this three-week unit, students will make use of the C-programming language to control a machine of their own design, thereby elevating it to the status of a *real* robot. The problems typically presented in this unit require a robot to be created that will both perform a sequence of scripted actions, as well as execute actions in response to sensor input.

From brainstorming and sketching to modeling a mock-up of their solution to a design challenge, this course results in a final robot that is programmed using C-programming language. Throughout the brainstorming, modeling, and programming stages, a machine must be visualized and a set of logical behaviors must be organized to ensure proper functioning.

Rapid Prototyping

For the last six weeks of the first semester, the entire class embarks upon a final project together. Using spare parts from the kits and robots of previous competitions, students must design and build a prototype. *Prototype*, in this case, is defined as a robot made to demonstrate functionality but not of a finished quality.

In a prototyping challenge from a previous year, students were required to build a remotely controlled robot capable of pneumatically launching a rolled-up t-shirt at least 12 m horizontally. The class' finished prototype was ultimately capable of launching a shirt 24 m and had two powered wheels operated by remote control. It was made of wood and ceased to function after only three demonstrations, but showed that the gearboxes and firing mechanism would work if one were to proceed with a more robust version of the machine.

FIRST robotics competition

The second semester begins with the FIRST competition. The first six weeks of the second semester are designated as "build season," the period of time that FIRST gives to all participating teams to complete their robots. All of the skills learned during the year, and in previous years, are applied to the FIRST engineering project. Using the basic kit of parts provided by the FIRST organization to participating teams, the robots are designed to perform specified tasks for accomplishing the year's competition challenge (Figure 2, p. 47).

Students are divided into subteams according to their preferences and strengths, their previous subteam assignments (if they are returning students), or the need to balance the numbers in groups. Students work collaboratively to construct a robot according to specifications and strategies decided upon as a whole, and craft their robots in subteams facilitated by their undergraduate mentors. Using the strategies learned during the first semester of the program, mentors lead each subgroup in goal setting and in completing the tasks of the competition challenge, which could include planning, designing, and building select parts of the competition robot.

During build season, extended shop hours are typically needed for completion of the competition robot. Subteams schedule work sessions in addition to designated class time for planning and building their designated components. Once the robot is shipped to the FIRST competition, the semester resumes with students polishing up their technical reports, along with other class assignments and new design activities.

Assessment

In addition to student presentations and demonstrations of varied designs, performance is assessed using two major assignments: portfolio logbooks and technical reports. Portfolio logbooks are ongoing assessment instruments that are used over the course of the school year. Technical reports, on the other hand, are completed in the second semester of the course and are maintained throughout the six-week build season. For faculty evaluation of course effectiveness, end-of-the-year interviews are also conducted.

Portfolio logbooks

Students receive a grade at the end of each six-week term on all assignments completed during that period. Five-sixths of their entire year's grade is based on the portfolio logbook submitted at the end of the fifth week. Logbooks are working repositories of all handouts, completed scoring rubrics, sketches, drawings, and team update bulletins distributed by FIRST during the build season. Portfolio items are scored against a rubric.

Technical reports

During the six-week build season, students are required to log their activities each day by responding to six standard questions:

- When did you arrive?

- With whom did you work?
- On what aspect of the project did you work?
- What was accomplished?
- What is the next thing that needs to be done?
- When did you leave?

For example, below is an excerpt from one student's report:

February 17, 2007, 4:00–8:00 p.m.
- *Designed and measured aluminum bracket to secure omniwheels*
- *Cut out bracket with Lindsey*
- *Bent edges with Lisa, Carrie, and Mr. Carlton*
- *Tomorrow—measure, mark, and drill holes for brass bushing to support the axle*

At the conclusion of the build period, students are required to reorganize their daily log entries into a week-by-week account for their technical reports. Students are required to fill in missing details and add sentence structure to create a narrative of their experience as illustrated in the following student excerpt:

During the sixth week of construction, I worked on the 14th and 17th of February. I primarily worked with Lindsey on the shop floor, fabricating elevator and drive-train parts. I gained experience with a thread tapping tool, sheet metal bender, and band saw. Ten to 24 threads needed to be cut in the blank bolt holes of the extruded aluminum columns of the elevator mechanism. This had to be done carefully, with roughly one turn backward for every two turns forward. The tap had to be frequently removed and cleaned to prevent the dulling of the threads. The bender can be used to form angles in malleable sheet metal or polycarbonate.

Components for success

Each year, during end-of-the-course interviews, students convey the value of mentorship and teamwork and the relevant applications of science, mathematics, and technology to their learning. During one end-of-the-course interview, a graduating senior who began taking the robotics course as a junior said that she regretted not taking it her sophomore year. This reflection is quite common for students participating in the yearlong robotics program. Overwhelmingly, students also stress the importance of participating in FIRST, often reflecting on how rewarding it is to see their contributions perform on the competition floor. Approximately 75% of participating high school students return each year, some as undergraduate mentors.

There are many aspects of the robotics course that contribute to its overall success. First, it is a countywide program that meets in the evenings, from 6:00–8:00 p.m., at a central location—allowing a school district to pool its resources by conducting one robotics program for all county students rather than a separate program for each of the four high schools. Because it meets at night, the class also facilitates a university collaborative by allowing university students and faculty to attend and become integrated members of the classroom community. In addition, funding each year is obtained through fundraising events and corporate sponsorships organized by faculty, parents, and students.

Conclusion

Now in its ninth year, the outcomes for the MCVTRC program have been consistently positive. These results are evident in students' discussions of increased comfort level with the science, technology, engineering, and mathematics applications in the course and in their consideration of these programs beyond high school.

Currently, there is a national push for university science and engineering programs to participate in K–12 outreach. School districts should not hesitate to be proactive in contacting department heads and deans of local community colleges and universities to coordinate collaborative projects. ■

Brenda Brand (bbrand@vt.edu) *is an associate professor of science education and Mary Kasarda* (maryk@vt.edu) *is an associate professor of mechanical engineering, both at Virginia Polytechnic Institute and State University in Blacksburg, Virginia; Michael Collver* (mcollver@mcps.org) *is the lead teacher of robotics for Montgomery County Schools in Blacksburg, Virginia.*

References

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy: Project 2061*. New York: Oxford University Press.

Bandura, A. 1986. *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice Hall.

Bandura, A. 1994. Self-efficacy. In *Encyclopedia of human behavior, Vol. 4*, ed. V.S. Ramachaudran, 71–81. New York: Academic Press.

Bandura, A. 1997. *Self efficacy: The exercise of control.* New York: W.H. Freeman.

Brown, S.W. 2002. Hispanic students majoring in science or engineering: What happened in their educational journeys? *Journal of Women and Minorities in Science and Engineering* 8(2): 123–148.

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academy Press.