AC 2008-625: THE VIRGINIA TECH FIRST ROBOTICS PROGRAM PARTNERSHIP: TECHNOLOGICAL LITERACY THROUGH SELF-EFFICACY

Mary Kasarda, Virginia Polytechnic Institute and State University

Brenda Brand, Virginia Polytechnic Institute and State University

Michael Collver, Montgomery County Public Schools

Gabriel Goldman, Virginia Polytechnic Institute and State University

Gabe Goldman is a Ph'D candidate in the Department of Mechanical Engineering at Virginia Tech

The Virginia Tech FIRST Robotics Program Partnership: Technological Literacy through Self-Efficacy

Abstract

This paper describes a partnership between Virginia Tech (VT) and the Montgomery County Public Schools (MCPS) FIRST robotics high-school team which includes undergraduates from a two-semester mechanical engineering senior capstone design course. The FIRST robotics program at MCPS was developed nine years ago by one of the co-authors, Dr. Brand, to facilitate STEM literacy by creating experiences to promote self-efficacy of high-school students in STEM areas. Unlike most FIRST programs around the country, the MCPS program was set up in the context of a two-semester robotics course that high-school students take for credit. This FIRST program at MCPS was developed using approaches which are based on Bandura's [1,2] four sources of efficacy: mastery experiences, vicarious experiences, social persuasion, and stress reduction. In this manner, high-school students achieve a level of familiarity and literacy in engineering and other STEM topics, such as design and manufacturing, in the context of robotics. VT engineering capstone design students working with the high-school students are taught mentoring and leadership skills in order to effectively interact and promote self-efficacy with the high-school students. Through their experiences of mentoring, the VT students also achieve an additional level of their own self-efficacy with technical subjects, and an understanding of how to facilitate STEM learning and literacy in others. This paper discusses the structure of the partnership which supports self-efficacy to foster technological literacy in *both* the high-school and undergraduate students. This approach is also preparing engineering undergraduates for success in professional practice as well as facilitating future successful outreach and mentoring strategies for these students to further technological literacy in future generations.

Introduction

In the ITEA Standards of Technological Literacy, the author's [3] state that "…One of the great benefits of learning about technology is also learning to do technology, that is, to carry out in the laboratory-classroom many of the processes that underlie the development of technology in the real world…" The partnership program described here accomplishes this concurrently for high-school students and undergraduate students but at different levels. For almost a decade, undergraduate engineering students at Virginia Tech have been able to take a course offered through the VT School of Education focused on developing leadership and mentoring skills in technical problem-based scenarios. A large component of the course requires the students to volunteer with the Montgomery County Public School (MCPS) high-school FIRST robotics course. Recently a second collaborative course was added where a VT Mechanical Engineering Capstone Design Experience which is based on designing and building educational tools for the high-school program, while giving undergraduates in this design experience, leadership training to allow them to work successfully with the high-school population. Kasarda [3,4] described service learning and outreach aspects associated with the pilot year of the new capstone design course. Now in its second year, the authors have recognized, and have enhanced, aspects of the capstone design project that facilitate the self-efficacy of both the undergraduates and the high-school students in technological and STEM literacy.

Of all of the ITEA Standards of Technological Literacy [3] Standard 8: Students will develop an understanding of the attributes of design; Standard 9: Students will develop an understanding of engineering design; and Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving, are particularly well demonstrated in this program. That is, the high-school students obtain a level of mastery of technological literacy by designing, manufacturing, and operating real hardware systems in a supportive community of faculty and well-trained mentors who are undergraduates in an established engineering program. This program applies the old adage, "you don't really understand something until you teach it," to the experiences of the engineering undergraduate students. The engineering undergraduates obtain an additional level of self-efficacy on technical subjects through their completion of their own capstone design project, their work in leading the high-school students through technical processes, and by seeing the results of their own contributions in mentoring high-school students in achieving new levels of technical mastery and literacy.

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/. In recent years, the need to advance the numbers of individuals pursuing science, technology, engineering and mathematics fields has been gaining much attention. FIRST is devoted to this cause in that it seeks to motivate students' interests and participation through an exciting "edge of the seat" robotics competition. This program capitalizes on the excitement of FIRST; however, pedagogically, it targets students' competence and self-efficacy beliefs. In most school systems, FIRST is a club activity which is active during the six-week build season and into the subsequent regional and/or national competitions. However, MCPS has established a two-semester course, Robotics, around this activity.

Structure of the MCPS/VT collaborative

The overall collaborative built around the FIRST program involves students and faculty from MCPS's four high schools, VT undergraduate and graduate students from engineering and related fields, and faculty from VT Science Education and the VT Department of Mechanical Engineering. What facilitates the collaborative is the structure of the MCPS course. The MCPS high-school course, Robotics, is offered as a one credit "local elective" to 10th through 12th grade students that meets at a centrally located shop facility from 6-8PM on Mondays and Wednesdays. The evening time slot facilitates a university collaborative, and university students and faculty are able to attend the class and become integrated members of the classroom community. In addition, the shop facility offers a co-location of useful resources and consists of a computer lab, workshop complete with machine tools and welding equipment, and a classroom. High-school students can take the course up to 3 times, and underrepresented groups are targeted in the application process for the course. For example, participation of female students has grown from 5% to 38% over the nine-year period of the program, including a 90% rate of retention of female students over the maximum three-year period that students may sign up for the course. The enrollment of the course is approximately 25 high-school students in a given year.

The university piece of the collaborative involves two courses as mentioned earlier: A one-semester Leadership and Mentorship course, and a two-semester Mechanical Engineering Capstone Design course. The leadership course, in particular, is generously supported financially by the VT School of Education including the support of a graduate teaching assistant. The goal of the undergraduate leadership course is twofold: to teach skills for participating in and leading teams, and also to teach strategies for facilitating problem solving activities. As facilitators, the VT undergraduates engage students by posing questions and encouraging discussions, analysis and explanations of problems. The mentors are taught to support learning without giving answers. As mentors, they lead high-school student groups in developing plans and prototypes that are implemented and tested as required by both the mini-design challenges assigned in the robotics course as well as the actual FIRST competition design challenge. These mentors act as "middle management" working with sub-teams of high-school students which results in more one-on-one attention to students. There are typically 8-10 undergraduate mentors enrolled in the course in a given semester. The mentors always have access to faculty, and faculty visit each sub-team periodically to give feedback or guidance. Based on the success of this leadership course for educating undergraduates in professional leadership and team-building skills, this course is currently being expanded to include some specific design process content in preparation for submitting it as a technical elective for Mechanical Engineering students as well as students in other departments. While some formal design process content will be added, the focus of the course will remain on the development of leadership skills in team-based technical scenarios. These skills are directly transferrable to a professional setting as students begin their careers. The subject matter of the course directly mirrors workshops and short courses offered to professional engineers on professional and team-building skills.

The second university piece in the partnership is the two-semester Mechanical Engineering Senior Capstone Design course where mechanical engineering students are charged with designing an educational tool to aid the MCPS FIRST robotics class. This course is generously supported financially by the VT College of Engineering and the VT Department of Mechanical Engineering. The VT capstone design students are also charged with incorporating high-school students into their capstone design project, and receive leadership training components during the first semester of the project which have been extracted from the content of the original one-semester leadership course. There are typically 4-5 students enrolled in the capstone design course, and these students are initially expected to individually mentor sub-teams of the high-school students in mini-design challenges (such as a "Rube Goldberg" competition) in order to "identify customer needs" as the VT students begin their design process. This phase of the class is also designed for relationship and community-building between the VT and high-school students. Following a couple of weeks of this type of activity, the VT students jump into the next phase of their design process in which they incorporate the high-school students.

This year, the capstone design project is titled "Farmbot." The goal of the capstone project is to re-design a donated lawn tractor for autonomous operation. The as-received tractor, without the cowling, is shown in Figure 1. Ultimately, the Farmbot will be used as a tool to help teach high-school students aspects of autonomous robot operation which is directly related to one component of the FIRST robotics competition. Initially, the VT capstone design students and high-school students worked collaboratively to get the donated tractor into operating condition and prepped for

autonomous operation. This included a mini-design project for a new gas tank mounting system, a project for design of remote control operation of the tractor, and tutorials on the C programming language. During the "identification of customer needs" process, the VT students identified the lack of programming skills and developed their own "short course" in order to educate their "customers" with the skills necessary to operate the "product." Shown in Figures 2 and 3 are pictures from an active learning assignment on flow charting developed for high-school students by the VT mechanical engineering undergraduates as part of this activity. As the Spring semester and FIRST build season approaches, the capstone design students will continue to work on this project to fully automate the tractor, while working in parallel on their new duties as "upper-level managers" of the new undergraduate mentors joining the program who have registered for the one-semester leadership course. The Farmbot at the end of the fall semester, including modifications for remote control operation, is shown in Figure 4.

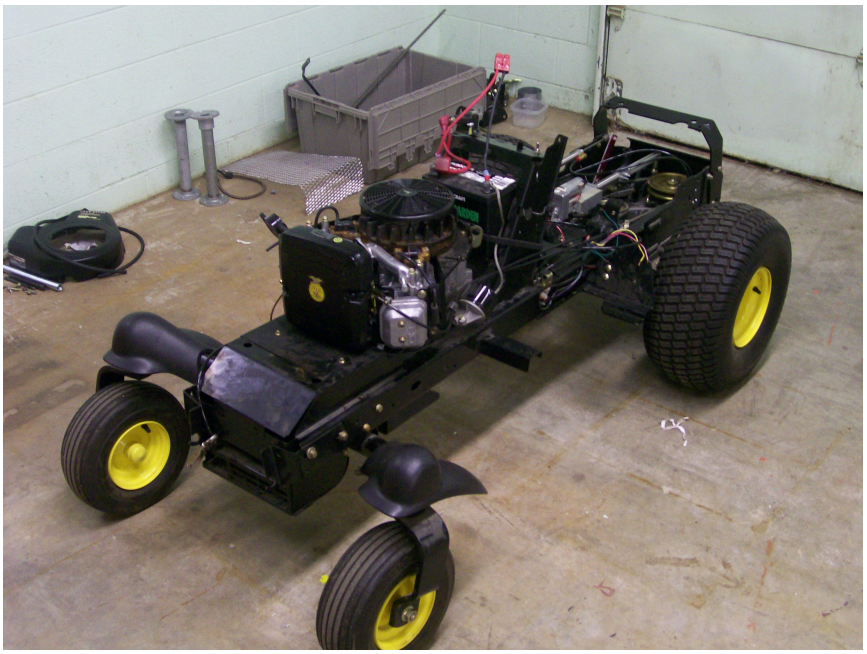

Figure 1: Donated tractor at beginning of Farmbot project.

Figure 2: Tom Daley, VT Mechanical Engineering senior (on stool in back) leading a small group of high-school students in an active learning assignment on flow charting.

Figure 3: One of the high-school students presents an explanation of flow charting to his peers during the active learning assignment designed by Tom Daley.

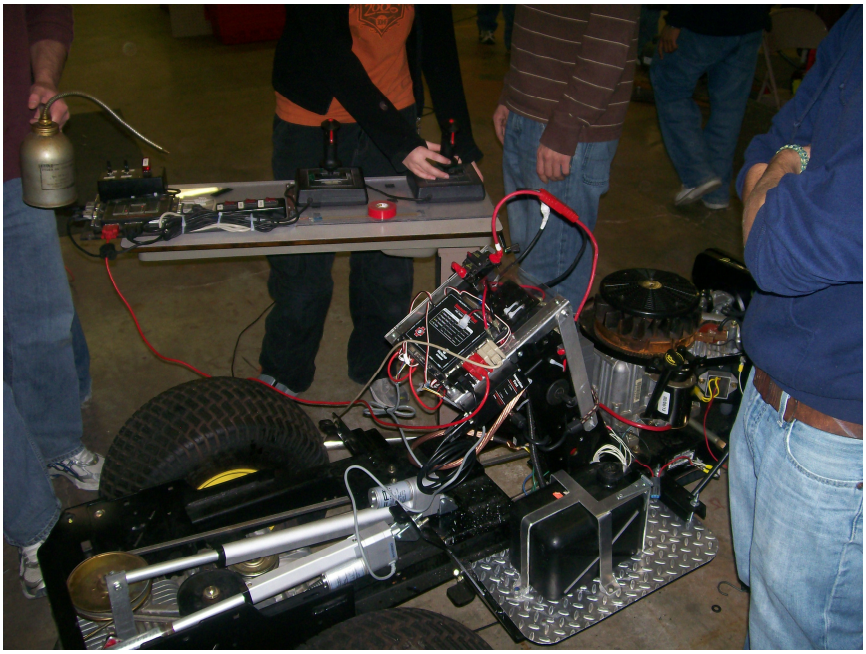

Figure 4: Farmbot at end of fall semester. Note new gas tank support in bottom right, actuators for control in bottom left, and controller in center.

At the start of the Spring semester the senior capstone design students are now considered as experienced mentors and are assigned roles as "upper-level managers" of the new undergraduate students entering the leadership course during the spring semester. These upper-level managers report directly to a "Vice President" who is one of the co-authors and a graduate teaching assistant from the Department of Mechanical Engineering. The "CEOs" in this corporate structure are the other co-authors who are university and MCPS faculty. Basically, the capstone design students spend part of their first semester mastering their roles as managers/mentors of the high-school students, and are quickly promoted at the start of the second semester to face distinctly new management challenges, requiring additional professional skills. In this trickle-down approach, the successful win-win model of undergraduates mentoring high-school students is taken one step further, with the individual experienced undergraduates now mentoring sub-teams of the undergraduates who are new to the program and stepping in as manager/mentors of the high-school students. The capstone design students are still involved directly with the high-school students, but are given additional responsibilities associated with the new mentors and subteam tasks assigned under them. All levels of mentors are supported by the faculty who meet with these students regularly for guidance including lectures on professional leadership topics, and to help them sort out details of their experiences during oral reflections. In addition, faculty are always available for impromptu consultations so that while students are challenged by new situations, they also know that they are fully supported for working through issues when needed.

Technological literacy through self-efficacy

The authors believe that an important foundation for achieving technological literacy in students is to focus on their self-efficacy beliefs, that is focus on student's beliefs that they are able to

participate in, and contribute to technological issues. One of the main motivations for the structures of the courses developed here is to develop self-efficacy and confidence of multiple levels of students in order to achieve functional levels of technological literacy in addition to additional specific STEM knowledge and skill sets. To achieve the self-efficacy and confidence component, the authors have based the design of all of their educational structures in the MCPS/VT partnership on Bandura's [1,2] four sources of efficacy: mastery experiences, vicarious experiences, social persuasion, and stress reduction.

Mastery Experiences. Mastery Experiences are characterized by repeated successful experiences. The FIRST robotics program creates the context for mastery experiences by the high-school students by creating places for students to showcase their accomplishments in regional and national competition venues. While the FIRST program is built around a competition, the FIRST organization does an excellent job of focusing on the *experiences* of the students including a spirit of "graceful professionalism" so that contributions of all teams are encouraged and celebrated. Undergraduate mentors working with the high-school students in the MCPS/VT program are specifically trained to be "hands-off" and to let the high-school students actually perform the design and build of the competition robot. Any success of the robot in performing any of the myriad tasks is therefore "owned" by the high-school students as their own experience. The FIRST competition goals, in addition to achievable mini-design challenges (such as egg-launch and foil boat competitions) that occur during the MCPS Robotics class, comprise the mastery experiences for the hig
h school students. These also translate to mastery experiences for the undergraduate students, who see the tangible results of their ability to successfully translate and transfer their own technical knowledge and skills to the younger students that they mentor. In addition, the nature of the capstone design project is in itself a mastery experience, where students conclude their design experience with the physical realization of their design.

Vicarious Experiences. Vicarious Experiences are defined as positive encounters in social models. That is, the experiences of seeing oneself in others and their struggles can improve personal perceptions of inadequacies. In the context of this collaborative, both the high-school students and undergraduates (and faculty!) are faced with new technical challenges that they have not previously encountered. The high-school students watch their mentors struggle with answering questions about myriad technical problems and learn that "even VT engineering students don't know everything." They see parallels with their own struggles, which builds their own self-confidence in tackling challenging technical problems. In addition, high-school students are empowered as part of the structure of this supportive community to contribute to solving technical problems faced by their mentors, as with their support of the Farmbot project. Similarly, the undergraduate students see reflections of their own problem-solving struggles in the high-school students as well as in the faculty who are brought in for consultation on particularly difficult problems. They, too, are placed in situations where they see that struggling with technical issues, and

inadequacy of knowledge, is common at all levels and that they, too, are capable of working through technical challenges.

Social Persuasion. Social persuasion occurs through verbal affirmations and motivation within the setting. A positive classroom environment and supportive community may encourage participation and convince an individual of his or her capabilities. This type of environment is consciously developed for all students in the MCPS/VT collaborative. This culture of social persuasion is not to be mistaken for a lack of "rigor." Students are given high expectations, and continually demonstrate that they are able to rise to the challenge. An environment is fostered where errors and inadequacies are dealt with in a positive context by presenting students with inquiry-based guidance to facilitate their own corrections, while encouraging and affirming their successes throughout the process. Students easily conform to the positive culture of high expectations, facilitated by no hesitancy to point out positive affirmation by faculty and mentors to all students.

Stress Reduction. Stress reduction is characterized by a reduction in stress reactions, and an altering of negative emotional proclivities. In an environment that nurtures positive emotional outcomes, individuals may freely focus and concentrate on what they are learning. Individuals' self-esteem is nurtured in environments that seek to foster and cultivate positive dispositions and attitudes towards learning [6]. The emphasis in the MCPS/VT collaborative for all students is on learning. Risk taking is strongly encouraged, and supported in positive ways as described above. While high expectations are given to students, and while student performance (grades) inevitably vary, the structure of the course focuses on positive reinforcement for learning for students of all performance levels during the process. This aspect is particularly appropriate and critical for the success of courses and experiences focused on achieving technological literacy in young students.

While it can be argued that the application of Bandura's (and other's) educational components for self-efficacy should be applied to all levels of STEM education, the authors believe it is particularly critical in scenarios where one of the major goals is to achieve technological literacy and comfort with STEM subjects in younger students. By achieving self-efficacy of students in technological literacy, the door is opened for many students to pursue STEM careers who would not have considered this path otherwise. Assessment of this hypothesis is underway, but beyond the scope of this paper.

Facilitating future outreach and technological literacy

The immediate goals of the MCPS/VT partnership for the VT undergraduate engineering students are to improve their engineering design skill set, improve their technological literacy by creating an environment where they must understand and figure out new technology in order to mentor and manage effectively, and to give them a professional skill-set, including leadership strategies, for successfully managing technical projects with diverse teams throughout their careers. However, another inevitable and welcome outcome is that this experience is empowering these students to create similar effective outreach initiatives of their own when they begin their professional careers.

While the data is only anecdotal at this point, it is clear by their questions that many of our undergraduate students are already trying to understand how they can contribute and create this type of initiative in the future. While the realities of professional life may not always be conducive to supporting these types of ambitions, we believe that even if students are not able to create new initiatives, they are at the very least well-positioned to confidently and effectively jump into existing opportunities for mentoring that they may encounter.

Conclusions

A successful partnership between Virginia Tech School of Education and Department of Mechanical Engineering, and the Montgomery County Public Schools has been described which includes two undergraduate courses and one high-school course. The undergraduate courses include a one-semester leadership course and a two-semester Mechanical Engineering Capstone Design course. The high-school course is a year-long robotics course. All of these courses have been designed to promote self-efficacy in order to achieve technological literacy based on Bandura's [1,2] four sources of efficacy: mastery experiences, vicarious experiences, social persuasion, and stress reduction. In addition to improving their technical knowledge-base, *all* students improve their level of technological literacy by becoming comfortable with technological issues, and comfortable with tackling and solving technological problems. Undergraduates learn an additional level of professional or social skills which they can immediately apply in professional settings as they begin their careers. They are also well prepared to participate, and even orchestrate, future outreach activities promoting technological literacy in future generations.

Acknowledgements

The authors would like to thank the VT School of Education, the VT College of Engineering, the VT Department of Mechanical Engineering, and the Montgomery County Public Schools for their support of the collaborative described in this paper.

References

1. Bandura, A. (1994). Self-efficacy in V.S. Ramachaudran (Ed.), *Encyclopedia of human behavior, 4*, 71-81. New York: Academic Press.

2. Bandura, A. (1997). *Self efficacy: The exercise of control.* NewYork: W.H. Freeman.

3. Dugger, W.E., and Gilberti, A. F., *Standards for Technological Literacy: Content for the Study of Technology*, International Technology Education Association (ITEA), 2002

4. Kasarda, M., Brown, E., and Brand, B., 2007a, "Teaching Capstone Design in a Service Learning Setting," Proceedings of 114th Annual ASEE Conference and Exhibition, Honolulu, Hawaii, June 24-27, 2007.

5. Kasarda, M., Brand, B., and Brown, E., 2007b, "An Engineering Capstone Design Course Taught in a Collaborative University/High School Setting," Proceedings of ASEE South East Regional Conference, Lexington, KY, April 2007.

6. Brand, B. R., and Wilkins, J. L. M., (2007). "Using Self-Efficacy as a Construct for Evaluating Science and Mathematics Methods Courses," *Journal of Science Teacher Education*, 18:297-317