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Engagement in Practice: Integration of an Engineering Service Learning Course with a High School Robotics Team

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Abstract

Through service learning, both students and community partners help fulfill each other's needs. A robotics service-learning course teaches the principles of robotics through hands-on activities and requires each student to participate in mentoring high school robotics team. Through these relationships, students gain a deeper understanding of the principles of robotics from the classroom, through teaching those principles to others and helping their mentored team solve problems. Students gain an appreciation for, and capability to, inspire younger generations to engage in STEM activities.

The course integrates STEM outreach into the engineering curriculum as a major elective for all engineering students. The course successfully implements reflection practices to measure attainment of civic learning outcomes, which are essential to true service-learning courses. A rubric measures student achievement of course technical outcomes. Improved team performance demonstrates effectiveness of the university mentors. The mentoring has a demonstrable effect on youth attitudes toward STEM education and careers. The course and mentoring resulted in 85% retention of existing youth team members, plus addition of new youth from 3 additional high schools, expanding the reach of the robotics team in the community. The course has also resulted in the university hosting a district competition, increasing STEM visibility to the ~1200 community attendees.

Introduction

Through the service learning structure, both students and community partners help to fulfill each other's needs. A robotics service learning [1] course at Fairfield University teaches the principles of robotics through hands-on activities and requires each student to participate in a mentoring relationship with a local high school robotics team. These types of programs have been implemented at other universities [2-5]. Through these relationships, students gain a deeper understanding of the principles of robotics from the classroom, through teaching those principles to others and helping their mentored team solve problems. Students gain an appreciation for, and capability to, inspire younger generations to engage in STEM activities.

Engineering technical skills and problem solving are best learned through active practice. Most engineering courses necessitate learning complex mathematical and scientific concepts, and are often unable to incorporate learning through doing, until a significant amount of learning through study has already taken place. However, many students see the requirements for math and science courses as a daunting barrier to entry into the engineering field. Robotics captures the popular imagination, and sparks interest in students of all ages. Robotics can be an enticing introduction to engineering. This course is specifically attractive to both novice and experienced students be they engineers, or non-engineers.

In the community, among many middle and high schools, this excitement for robotics is a key attractor to STEM (Science, Technology, Engineering, and Math) career paths. Many of these schools participate in robotics competitions for novice students to be able to learn scientific and engineering principles through hands-on activity. However, at the high school level there is lack of team mentors to assist those youth with their various projects. Prior to development of this course, Fairfield University had received frequent requests to recruit college students to serve as mentors for those programs. Many of our students found it difficult to dedicate the time, when they did not see themselves as experts, nor have an incentive on campus to encourage their participation.

Through the service learning structure both college students and community partners help to fulfill each other's needs. This course teaches the principles of robotics to interested students in our university community through hands-on activities, and requires each student to participate in a mentoring relationship with a local high school robotics team. Through these relationships our students gain a deeper understanding of the principles of robotics they learn in the classroom, because they teach those principles to others and help their mentored team solve problems. Our students also gain a deeper appreciation for, and capability to, inspire younger generations to engage in STEM activities.

The community partner fills their need for dedicated adult mentorship with technical background to help their students succeed, while having young adult role models interacting directly with the students that they are teaching and encouraging to prepare for university level studies.

Course Design

The course integrates STEM outreach into the engineering curriculum as a major elective for all engineering students. It enhances living and learning communities, community partner sustainability and campus support. The course successfully implements reflection practices to measure attainment of civic learning outcomes, which are essential to true service-learning courses [1].

This introductory course in robotics develops understanding of how robotic systems integrate sensors, actuators, and control systems to achieve specific goals. Principles of autonomy, programming, wireless communications, sensor applications, mechatronics, electrical power, electric motors, pneumatics, structure, and locomotion are understood and applied. Design of robotic subsystems utilizes multiple areas of knowledge. The course involves application of statistical analysis to quantify robot performance. Service learning is an integral part of the course. All students in the course participate in weekly mentoring of a youth FIRST Robotics Competition team to put into practice the principles learned in class, and to learn through community interaction from other students using robots to accomplish different feats.

Student Outcomes Assessment

Our broad outcomes for the course include demonstrating a level of competency with technology, while the service-learning component will enable the students to recognize the importance of STEM education and building a STEM pipeline in the community, as well as providing key opportunities to put their coursework into practice.

Technical Outcomes - Students will be able to...

1) Design and construct robotic sub-systems to fulfill competition requirements and specifications by being able to:
   a) Analyze a complex task and identify subsystems needed to accomplish that task considering the use of commercial off-the-shelf vs. fabricating custom parts
   b) Apply basic concepts of mechanics such as gear ratios, gearboxes, motors, belts, and materials
   c) Compare different methods of manipulating game objects using motors vs. pneumatic actuators
   d) Select the wiring, circuit breakers, and power distribution needed to connect the robot controller, motor encoders, and controllers to meet FIRST specifications.
2) Design an autonomous behavior routine for the robot as they:
   a) Distinguish between open and closed loop feedback control systems
   b) Program, debug, and modify a series of software commands
   c) Connect and operate various sensors such as vision, encoders, limit switches, ultrasonics, etc.
3) Develop a strategic plan by analyzing key features and analyzing performance data

Civic Outcomes – Students will be able to...

4) Apply best practices of service learning team management as they:
   a) Demonstrate co-leadership by guiding youth team members to decide what they can accomplish
   b) Apply teaming skills for conflict resolution, task assignment, scheduling, and cross-cultural communication
   c) Apply problem solving skills to troubleshoot robot failures with the youth team members
5) Discuss their professional responsibility to work for the betterment of society and why it is important to "give back", even at this very early stage of their career, to help youth overcome negative impacts of their “environment”

At the end of the course, students are assigned a final project, to design a new robotics competition, similar to the FIRST Robotics Competition. Another team in the class is assigned to solve that game through a robot concept design incorporating all of the technical outcomes from the course. A rubric, shown in Appendix A, measures student achievement of course technical outcomes.

In the first year of the course, the performance threshold was set as a score of 70%. On outcome 1 above, designing robot subsystems, 100% of students met the threshold. Outcome 2, autonomous behavior, was a weakness, as only 54% of students met the threshold. This provide a clear indication of an area needing more focus in the course, and more practice. This was also an area of weakness in team performance, as only a very basic straight line autonomous movement was achieved during competition. On Outcome 3, strategic planning, threshold was met by 70% of students, which is an acceptable level, but which has room for improvement.

Similarly, for Outcome 4, team management, the threshold was met by 70% of students, an acceptable level, but with room for improvement.

The final outcome, Outcome 5, professional responsibility, was assessed through the students' final reflective writing [6]. Each student was asked to reference at least 3 of their previous weekly reflective writings, to provide evidence of how they had grown as a mentor throughout the experience. Students each took away different lessons, but showed significant thought, and growth, 92% of students met the desired threshold.

As evidence, student reflections included comments such as these:

"We really do all have something to offer, if only just to show them that it is possible to grow up and go to college and do the same things they are interested in now."

"One kid in particular who sticks out in my mind… asked many questions about the robot and about [university] engineering and college life in general... It was a good feeling to be able to offer him advice about college, and the path of engineering. This experience, truly made me feel like a mentor."

"For me, if just one [high school] student is inspired to pursue college and some sort of STEM degree, it would be amazing. Getting to see their excitement in competing has been the most rewarding experience I have had as a mentor so far."

Improved youth robotics team competition performance demonstrates effectiveness of the university mentors. The team did not qualify for the end tournament in either of its competitions in the first year. During the second year, the team was as an alternate in the first competition. Then, they qualified to choose their alliance for the tournament at the second competition.

Evaluation

Robotics team mentoring is the main service-learning component of this course. All students are required to participate. Student learning is evaluated through class assignments, reporting on project deliverables, documentation, and other writing. Students keep a technical journal as a portfolio over the entire course. This weekly journal provides current project status, issues experienced, current week accomplishments, individual assessment for that week, the schedule for the next meeting and direction of where the project is moving. Student learning is enhanced through the service-learning methodologies by creating an enhanced sense of civic engagement through guided reflections in a weekly reflective journal [6].

Students are evaluated on their mastery of robot design skills after they have an opportunity to use those skills in a mentoring capacity, to measure objectively the effectiveness of the service opportunity in enhancing their learning.

Building Effective Partnerships

Through the course, we are forging an effective community partnership. We are guided by two umbrella goals, addressing the community and the university sides. We strive toward these goals by achieving outcomes directly tied to the transition of the robotics team to our community partner and university.

1. Increase the effectiveness and reach of K-12 STEM programming through the integration of the FIRST Robotics Competition Team resulting in more city area students pursuing STEM careers.

We have moved the team out of its original high school to our partner, a STEM Outreach non-profit, so that the team is community based, to recruit students from multiple schools to the team.

Our community partner is able to enhance its STEM outreach offerings by offering its students the opportunity to participate in the nationally recognized FIRST robotics program.

Our community partner is able to involve more college student mentors in its programs. The robotics team moved into new workspace with enhanced shop capabilities at the University

The robotics team members frequently visit the University campus, building a greater sense of their being part of the University community as well, and helping them see themselves as future college students

2. Increase the college students' understanding of socially responsible engineering, and the importance of mentoring the next generation of STEM students.

From the University side, outcomes include greater numbers of university students mentoring K-12 students, in credit-bearing service learning courses and extracurricular. The course has enrolled 28 students in two years. We extended our partnership by integrating our Web Development Service Learning course with the Robotics team, allowing an additional four students to serve as mentors with the youth.

We work closely with our community partner to define both qualitative and quantitative measures of success. We have begun to use measures of robotics team success, measuring how well the team achieved competition goals and whether the team placed at the competition.

We will also implement longitudinal tracking of youth direction, asking youth to respond to surveys about intended areas of study (STEM vs. non-STEM), and following up in future years to determine which students continue on that track.

Results

In the first pilot year, we participated with the team as volunteer mentors, not as an organized class. Six college students worked with youth from one high school FIRST Robotics Competition team. The mentoring has a demonstrable effect on youth attitudes toward STEM education and careers. This resulted in one of those youth enrolling in the university engineering program upon graduation.

The full course, with mentoring, was implemented in the second year. The course enrolled 13 students. Awarded an internal grant to strengthen the partnership with our community partner. Led to inclusion of a second service-learning course on Web Design working with the robotics team youth members to design a team website.

Now in the third year of the service-learning program, the team retained 85% of existing youth team members from the initial high school. Four additional new youth from three different schools also joined, expanding the reach of the robotics team in the community. The author was also awarded a grant to fund the work of the college students with the team. This second year of the course enrolled 15 students.

The impact of the course extends beyond the course participants as well. College students more easily volunteer their time as mentors to the robotics team, since they now meet on campus. This provides extracurricular learning to additional students. The course also utilizes a service-learning associate, who is a student that was previously in the robotics course that returns as a paid assistant to coordinate logistics as well as serve as a guide to the currently enrolled college students.

The course has also resulted in the university hosting a district competition, increasing STEM visibility to the 1200+ community attendees.

Future Work and Conclusions

We need to make the program grow organically. We opened up to additional high schools in the city, but need students to look forward to joining. The hope is also that students from other program sponsored by our community partner, especially those now in middle school, will join the high school robotics team in future years.

Moving the team from their home high school has created transportation issues, which requires greater funding in addition to that needed to build the robot. This challenge requires greater fundraising and grant writing. So far this year, we have been able to secure sufficient funding through granting organizations to provide for these needs. However, we need to establish consistent donors, to provide sustainability.

Another hope is the desire by other faculty as the University to find ways to participate in STEM outreach, and perhaps bring together further grants and STEM outreach opportunities for the group of students we are serving through our community partner.

Our work to date has been fruitful. We have met the milestones that we set for the course. We have strengthened our community partnership. We have increase college student involvement in STEM outreach. We have inspired some of our youth team members to go on to STEM careers. We see a bright future, where these outcomes will continue to grow.

References

[1] C. Cress, P. Collier, V. Reitenauer, et. al. *Learning Through Serving: A Student Guidebook for Service Learning Across the Disciplines*. Sterling, VA: Stylus, 2005.

[2] E. Coyle and L. Jamieson, “EPICS: Service-Learning by Design.” In *Projects that Matter: Concepts and Models for Service-Learning in Engineering.* E. Tsang ed. Washington, DC: AAHE, 2000.

[3] R.S. Renner and B.A. Juliano "Integrating Service Learning with Undergraduate Robotics Research" AAAI Spring Symposium. (2007) http://www.cs.hmc.edu/roboteducation/papers2007/c36_renner_chico.pdf

[4] Robotics Service Learning at UMD implements a similar type of mentoring relationship http://scholars.umd.edu/robotics

[5] M. Jawaharlal, C. Larriva, J. Nemiro. "School Robotics Initiative – An Outreach Initiative to Prepare Teachers and Inspire Students to Choose a Career in Engineering and Science" Proc. of 2007 ASEE Pacific Southwest annual conf. (2007). http://www.cpp.edu/~jmariappan/EGR200/SchoolRobotics-ASEEReno2007.pdf

[6] J. Moffatt and R. Decker, "Service-Learning Reflection for Engineering: A Faculty Guide." In *Projects that Matter: Concepts and Models for Service-Learning in Engineering*. E. Tsang ed. Washington, DC: AAHE, 2000.

Appendix A

Robots Final Project Rubric

Students are expected to show:

Creativity, Complexity, Critical Thinking, Analysis, Evaluation

Outcome	**Lacking** Only one idea was discussed, and at a superficial level. Clearly derivative or reused technology. No or extremely basic analysis. No evaluation of likely results.	**Developing** One or two possible ideas Some critical thinking shown. Limited creativity, but some application of best practices or adaptation of technology. Some analysis shown to validate ideas. Little evaluation of likely results based on analysis.	**Proficient** Two to three possible ideas. Beginning to think critically about those ideas. Some analysis of physical/math principles. Shows creative synthesis of other technologies to achieve a solution. Beginning to evaluate the likely results.	**Exemplary** Multiple ideas, clearly analyzed in detail and evaluated for likely success based on evidence, or best practice. Highly creative, yet well supported solutions presented.
Subsystem Breakdown (OC1a)	No clear representation of need for subsystems of robot, features not clearly articulated.	System features identified (such as manipulation, drive, controls, etc), but not clearly broken into modular components	Most features/tasks of robot broken into modular subsystems.	Clear modularity of design. Each subsystem operates independently.
Autonomous Control System Design and Algorithm (OC2a-c)	No distinction between open or closed loop control, very limited or no description of implementation algorithm	Open loop style control system described, partial control algorithm described	Closed loop style control system implemented with mostly descriptive algorithm.	Fully descriptive closed loop control algorithm, perhaps with multiple control loops, or with example coding
Drive train and mechanics selection (OC1b)	No attempt to consider drive train beyond kit of parts. No specification of needed torque, speed, etc. for motors.	Compares Kit of Parts style drivetrain with perhaps one other method. Some specifications for success defined.	Defines the needed specs and accurately compares the Kit of Parts drivetrain to another style. Defines most needed parameters, such as torque, speed, gear ratios, etc.	Fully descriptive of rationale for choice of drivetrain from 3 or more options. Clearly defines the needed specs that guide that choice.
Sensor selection and use (OC2c)	No sensors implemented	One sensor style is implemented in an open loop style system. No evaluation of alternative approaches.	At least two sensors are considered for implementation. Sensors are integrated in closed-loop feedback system.	Multiple sensor types are evaluated, and rationale for each is complete. Sensors are integrated in feedback control loop. Specific sensors, and necessary parameters are chosen.
Power and controls selection (OC1d)	No discussion of power beyond the need for a battery.	Power needs mentioned, the control board is discussed, but at a	Some analysis of likely power needs are calculated. The power distribution	Detailed power distribution system is defined, and sketched. There is a

		superficial level. No significant analysis.	system is designed, but may not be fully detailed.	clear attempt to plan for necessary power/current/voltage needs of the various subsystems.
Game Object Manipulation Design (OC1c)	Game elements are not adequately addressed	Some game elements are addressed, but not all. Little rationale as to why game elements are ignored is given. One possible design solution is proposed.	Most game elements are addressed, and if an element is not addressed, it is clearly stated why that decision was made. Two possible designs were considered (such as pneumatic vs. motor).	All game elements are addressed, with plausible and feasible features to address all aspects. Multiple possible design solutions were considered (like pneumatic vs. stepper motor vs. servo motor for moving a particular element), and analyzed for likely success (such as using a decision matrix)
Project Management Plan (OC4)	No project plan	Project plan is simple and only broken in main phases	Project plan begins to show a timeline and task breakdown	Fully detailed breakdown of tasks, and timeline, including what elements can be done in parallel and which must be done in series (like a Gantt chart)
Strategy Planning (OC3)	No strategic thinking presented	Little strategic thinking, but development of how the robot would perform individually is discussed.	Some strategic thinking about how the robot would participate in an alliance.	Clear strategy to address the game challenge as a whole, and to think toward building an alliance, including features that would be sought in another teammate.