Incorporating Service Learning in an Engineering Programming Course to Promote Teamwork

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Abstract

A key learning outcome required for accreditation of an engineering degree is that graduates have learned how to function effectively as a team. In a required first-year programming course for Mechanical Engineers, students worked towards that learning outcome through a service-learning project. The project consisted of development Arduino-based projects that could compete in the county and Kansas state fairs in robotics. Teams were expected to develop the project and then develop instructional materials such that a high school student could construct the project. These instructional materials were made available to participants in 4-H through a website. By creating a project that was public-facing and had impact beyond the classroom, students were encouraged to think about their team efforts beyond the impact individually to their grades. Future development of this project will focus on improving teamwork development and communication skills to improve the quality of the final products and the teamwork skills development within the class.

Keywords

Service learning, programming

Introduction

The Accreditation Board for Engineering (ABET) requires engineering programs document seven student outcomes on key program educational objectives. Of these seven outcomes, the 5th outcome is "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives." Teamwork has long been acknowledged as an important skillset valued by future employers. While this outcome is often evaluated in capstone projects in the senior year, fundamental skills can be developed starting the first year of an engineering program. In the first year, teamwork can not only develop the skills that will be eventually valued in the workplace, but also support students in developing social networks that will support student learning. For first generation students, who can have additional challenges in developing such networks, this is particularly valuable [1].

Teamwork itself is often not well defined. Perusich et al [2] defined this skillset as the ability to be interdependent in tasks, to share responsibility for outcomes, and to work together as an intact social entity. Successful teams can be described as having the attributes of: shared goals and values, commitment to team success, motivation for the team task, interpersonal skills, open and effective communication, constructive feedback, diverse team composition, leadership, accountability, interdependence, and adherence to team process and performance [3]. These skills can be further broken down into soliciting input, consensus building resolving conflict, and team leadership [4].

Teamwork often works against classroom characteristics where grades are assigned individually and the time for team interactions is limited [2]. Students can feel that group assessment is unfair. Prior to the capstone year, team projects can often be viewed as exercises without external value, just assignments required by instructors that quickly fade once the semester is completed. Service learning provides an opportunity to create teamwork projects that have external value. In this paper we will examine using a service-learning team project to promote teamwork skills.

Course

Introduction to Computational Methods in Mechanical Engineering, ME 208, is a required first-year course for mechanical engineering majors at the University of Kansas. The course covers programming skills in MATLAB and C++ on the Arduino platform. The requirements of the course include an active-learning lecture within class exercises, weekly individual laboratories, weekly individual homework assignments, three exams, and two team projects. The students have three class sections each week, a 50-minute lecture, a 2-hour lab, and a 50-minute discussion section. The discussion section is used to support team projects.

The learning outcomes for this course are that, at the conclusion of the course, students will be able to:

1. Understand logical processes and how they are used by computers and other engineering technology.
2. Break down engineering problems into logical steps and code those steps in computer languages.
3. Write programming code from scratch and problem solve errors until a goal is achieved.
4. Use the C++ programming language in the context of Arduino microcontrollers and the MATLAB programming package.
5. Apply programming methods to the solution of engineering problems including recording data and solving mathematical problems.
6. Work as a team to create novel devices.

The course contributes to the Accreditation Board for Engineering (ABET) Outcomes:

- An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
- An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

From these outcomes, an important component of this course is learning to function effectively as a team. This is the focus of the weekly discussion sections. In Fall 2023, a service-learning project was introduced as a major team project (one of two major projects). This project was continued in Spring 2024. 114 students completed the course in Fall 2023 and 85 students completed the course in Spring 2024. Each semester there were four discussion sections, and within each discussion section, teams of 4-6 students were created. Students spent half of the semester working on the service-learning project.

Community Partner

Service learning combines learning objectives with community service. At the University of Kansas this is accomplished through community partnerships. ME 208 has been designated as a service-learning course at the university. For this course, the community partner is Kansas State Research & Extension (KSRE), 4-H Program. The 4-H & Youth Development Program is a network of youth organizations supported by federal funding to develop citizenship, leadership, and life skills of children and young adults aged 5 to 18. One element of the 4-H programs is the opportunity to compete at county and state fairs in a variety of categories including livestock, foods, arts, and engineering & technology (STEM) fields. For this partnership, the focus was on the robotics and computer science competitions. A 4-H participant might spend the year learning skills in robotics such as computer programming. They would work with the guidance of parents and community leaders to develop a project that would abide by the rules for the competition. For the robotics competition at the 2024 Kansas State Fair [5], these include:

- "Each robot must be free-standing, without the need for additional supports in order to be moved or exhibited. Each exhibit must include a robot, information packets are not a sufficient exhibit."
- "Robots must have automated articulated structures (arms, wheels, grippers, etc.). Game consoles that display on a screen are not considered robots and should either be entered in the computer sciences system division or energy management project. Robots requiring no assembly, just programming, such as Ozobots, are considered computer system projects as the skill is focused on the programming not on the construction of the robot."
- "Robot dimensions should not exceed 2 feet high, by 2 feet wide, by 2 feet deep. Weight may not exceed 15 pounds. If displayed in a case (not required or encouraged for the state fair, but strongly encouraged for county fairs) the outside case dimensions may not be more than 26 inches in height, width, or depth."
- "Materials including but not limited to obstacles, spare batteries, and mats for testing the robot may be placed in a separate container, which is not included in the robots' dimensions, that container may not be larger than 576 cubic inches as measured along the outside of the container (Examples: 4" x 4" x 36" or 4" x 8" x 18" or 6" x 6" x 16"). The container, if used, and/or any large objects (such as mats or obstacles) should be labeled with the exhibitor's name(s) and county or district as they will be stored separately from the exhibit."
- "All electric components of the robot must be adequately covered or concealed with a protective enclosure. Paper is NOT considered an adequate enclosure or covering for electrical components."
- "Robots may be powered by an electrical, battery, water, air, or solar source only. Junk drawer robots may be powered by a non-traditional power source. Robots powered by fossil fuels/flammable liquids will be disqualified. Robots that include weaponry of any kind will be disqualified. Weaponry is defined as any instrument, possession, or creation, physical and/or electrical that is intended to inflict damage and/or harm to individuals, animal life, and/or property."

- "Remote controlled robots are allowed under certain conditions provided that the robot is not drivable. Robots programmed on phones/tablets need to have a specific program created, using motion controls to move the robot are not acceptable, for example "press forward on the screen to make the robot go forward." Robotic arms (hydraulic or electric) are allowed. A remote is allowed, provided more than a single action happens when a single button is pressed on the remote, for example "a motor spins for 3 seconds, at which point an actuator is triggered, then the motor spins for 3 more seconds." Remote controlled cars, boats, planes and/or action figures, etc. are not allowed."
- "Each robot must be in working condition. The judges will operate each robot to evaluate its workmanship and its ability to complete its intended task. In the event the robot uses a phone, tablet, or similar device for both programming AND control of the robot a video will be used to evaluate the working condition of the robot. It should follow the instructions provided for operation so that the judge can follow along with the provided instructions. For county fairs, where consultation judging is used the video requirement should be waived in favor of actual operation of the robot."

The computer science competition rules allow for "chip systems" that can include Arduino. These rules do not require an articulated structure but require more extensive documentation of the coding process in an engineer's journal.

When the participant has a project completed, they can enter the project into their county's fair, which typically takes place in late summer. The participant is judged based on a set of criteria that include not only the quality of the project but also the quality of documentation and presentation of the work [6], [7], [8], [9]. Participants compete within their age category and can receive a ribbon (Purple, Blue, Red, or White) based on their performance using the Danish ribbon system of judging [10]. Projects receiving a purple ribbon can then be entered in the state fair in the Fall.

In comparison to other robotics options for youth such as First Robotics, 4-H can be accomplished at home and doesn't require access to group programs that typically exist only in larger population centers. This opens opportunities for rural youth in particular to be exposed to engineering and technology (STEM) and encourages them to consider engineering careers.

Project

For the service-learning project in ME 208, teams were required to develop a project that could compete in the 4-H robotics competition using an Arduino microcontroller. They were then required to create instructional materials such that a high school aged student could recreate the project. For the course, all students purchased the Sparkfun Inventor's Kit which included a microcontroller and an array of electronic components including sensors and motors [11]. Teams also had access to additional sensors and motors that could be used.

The project took place over seven weeks with the following weekly deliverables:
Deliverable Week 1:

1. Completion of Safety Training (Individually)
2. Completion of Service Orientation and Reflection (Individually)
3. Investigation of Sensors and Motors

4. Individual Reflections on Team Collaboration

Deliverable Week 2:
1. Brainstorming Project 8-10 Ideas
2. Use Decision Matrix to Select Final Idea
3. Flow Chart Code
4. Individual Reflections on Team Collaboration

Deliverable Week 3:
1. Begin Coding and Wiring Diagram in Tinkercad
2. Begin Construction
3. Begin Testing
4. Individual Reflections on Team Collaboration

Deliverable Week 4:
1. Complete Initial Coding and Wiring Diagram in Tinkercad
2. Testing of Code
3. Initial Draft of Instructions
4. Individual Reflections on Team Collaboration

Deliverable Week 5:
1. Complete Physical Version of Project (Coding and Construction)
2. Complete Instructions.
3. Create Group Instructional Video
4. Create Project Poster
5. Individual Reflections on Team Collaboration

Week 6 – Poster and Live Demo Session with Working Prototypes

Week 7 – Final Submission
1. Written set of instructions. Teams are encouraged to submit instructions to instructables.com so they can be shared with 4-H participants.
2. Well-commented code.
3. A video with detailed instructions on how to make the project. Teams are encouraged to include their video on an instructables.com post.
4. An electronic version of the team's poster.

Each week, the team met with a GTA or the course instructor during their discussion class time to present the deliverable. Each team member was asked to be lead in presenting at least two deliverables over the course of the semester (two projects). All team members were required to be present (or have an excused absence) to receive credit for the deliverable.

For the instructions that were created, teams were asked to include:
1. a list of required supplies
2. construction instructions
3. commented code
4. images of the device, and
5. a video detailing the process of creating the project.

Promoting Teamwork

As teamwork is a fundamental learning outcome of these projects, several activities were included to promote effective teamwork. After teams are formed in the first few weeks of the course, their first activity was an ice breaker followed by writing a team contract and communication plan. In this activity, team members created a plan for communication, meeting outside the classroom, and completing activities.

For each deliverable, all members of the team were required to complete a reflection on what worked well for the team during the week and could have been better. Members were asked to think about how well their team communicated, how well work was documented so others could understand it, if everyone contributed as promised, and if everyone felt they were respected by their team members. Midsemester and at the end of the semester, CATME was used to perform peer evaluations of the team [12].

Service-learning projects allowed the teams to work toward a common goal. Because the projects are public-facing and oriented to the wider community, students may be more motivated to put detailed thought and effort into their work instead of taking an individualistic approach and completing tasks in solitude.

Student Learning Assessment

Grading for the project included 5 points for each weekly deliverable, 5 points for each time an individual led their deliverable presentation (up to 2 times), and 50 points for the final project presentation and report. Over the semester (and two projects), an additional 30 participation points based on feedback from the CATME peer evaluation and instructor observations. The final project and presentation grades were based on:

1. Instructions: Were the instructions to be provided to the community partner clear such that a high school student could recreate the system?
2. Code/Device/Commenting: Was the code well designed? Did it go beyond the basics and meet the rules of the 4-H robotics competition? Was the code properly commented? Was the construction of the device of good quality and meeting the rules of the 4-H robotics competition?
3. Video: Was the video useful for demonstrating the robotic system and how it might be constructed?
4. Poster: Did the poster clearly describe the function of the device and construction of the device?

Assessment of the Project

Systems created for this project included candy dispensers, a rowboat, a maze solver, a self-loading trebuchet, a dog feeder, small cars, an automated greenhouse, and a cardboard Wall-E robot. While many teams were able to complete quality projects, other teams ran into issues. One common issue for less successful teams is in putting tasks off and not anticipating the need to troubleshoot. This was particularly present in Spring 2024 when the project was in the second half of the semester when demands of other courses was high (in Fall 2023 it was in the first half of the semester). Another common issue was the commitment of team members. In first-year courses, it is not rare to have about approximately 10% of the students have issues with attendance and participation in the course. Teams that had several such students often struggled. To mitigate this issue, teams are not formed until a few weeks in the semester. This allows teams to miss those that drop the course before the no-penalty drop deadline. Teams in this course were also larger (4-6 students) in the hopes that a critical mass would remain.

Most of the final products of the groups would be able to be entered into a county fair robotics or computer science competition. The instructions that were developed varied in quality so future iterations of this course will spend more time on how to write clear instructions that have complete information and are written at a high school level. Because some groups still struggled with aspects of teamwork, in Fall 2024 a module will be added having the students discuss case studies on team dynamics prior to the project.

Creating a Resource

The final product of the service-learning project was the instructions for creating these projects. In Fall 2023, these were submitted with consent forms to be able to post them on a university hosted website. However, one team was interested in making their instructions more prominent and also posted them to the website instructables.com [13]. In Spring 2024, all teams were encouraged to post their instructions to instructables.com. This allowed the teams to opt-in to having their projects be public. All teams that posted publicly were linked to a common website: https://wilsonlab.ku.edu/mechatronics-resources-k-12-teachers-scouting-and-4h. From this website, our community partner and others can access these projects as well as other resources on Arduino programming. In addition to the projects created by the student teams in ME 208, the website hosts instructional videos, projects from other courses, and links to useful information. The goal of the website is to have a full collection of instructional resources for Arduino programming and mechatronics that could be used not only by 4-H participants but also by teachers, scouting programs, and others.

Community Partnership

In both semesters, extension professionals from KSRE, 4-H & Youth Development came to the class to meet with students. Early in the project, the 4-H & Youth Development Director presented on 4-H and how the projects would serve participants in the program. Extensions professionals and 4-H alumni returned to help judge the final projects during the poster and live demo presentations. The website became live in Summer 2024. This will be in place for the 2024-2025 4-H year. Dr. Wilson has joined the 4-H Engineering & Technology Project Partnership Team and is working with that group to further disseminate these materials beyond Douglas County.

Conclusions

In Fall 2023 and Spring 2024, a service-learning project was created in a first-year programming class. This team-based project had, as a primary learning outcome, the development of teamwork skills towards the ABET learning outcome on teamwork. The advantage of a service-learning project was that, as a public-facing project with an outcome that would have impact for others, teams could be motivated to look beyond individual within-course rewards such as grades. The service-learning projects also created resources that would service children in the county and state. Future iterations of this course will include additional team-work development including a module of case studies on teamwork and a module on writing clear instructional materials.

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Sara Wilson

Sara Wilson is an associate professor of mechanical engineering and a core faculty of the bioengineering department at the University of Kansas. Her research focuses on the neuromuscular control of human motion using engineering principles from control theory and dynamics. She is also active in teaching and developing educational tools for responsible conduct of research for graduate students in engineering.

Emma Grob-French

Emma Grob-French is a student at the University of Kansas seeking a master's degree in mechanical engineering. She has supported Dr. Wilson as a graduate teaching assistant for ME 208 in the Fall 2023, Spring 2024, and Fall 2024 semesters, primarily through weekly homework grading sessions, meeting with students weekly to review project progress, and hosting exam study sessions.

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Patsy Maddy is the Special Projects Administrator for the Kansas State University Research and Extension Office. She was previously active in the Twin Creeks Extension District serving as the 4-H Youth Development Agent. She received her BS in Kinesiology and Exercise Science from Kansas State University.

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Nancy Noyes is the 4-H Youth Development Program Assistant for Douglas County 4-H. She received her BS in Animal Physiology from Virginia Polytechnic Institute and State University and has worked as a livestock nutritionist and 4-H extension agent.