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Work in Progress: Leveraging the Diverse Backgrounds of Community College Students to Teach Team-based, Multidisciplinary Engineering

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Introduction

At the community college level, many students are considered non-traditional, in that they have taken time off from their educational goals to explore the workforce environment, or to serve our nation. Some are attracted by the cost efficiency and excellent student to teacher ratios, and yet others are coming back for a second career. Therefore, the experience level entering into a first year engineering course is typically very diverse, and this diversity can be harnessed to enrich the educational environment. The course that was developed and implemented in this work strived to harness the diverse backgrounds of the students in the classroom, introduce a multidisciplinary project to teach the fundamental principles of engineering, and to introduce a wide array of engineering disciplines within a single course.

The assumption entering into this project was that core engineering concepts can be grasped through practice, as opposed to traditional classroom lecture, to teach students the engineering design loop, intra- and intergroup collaboration and communication, design methodology, and critical thinking skills [1]. However, the idea of learning through practice in no way eliminates the traditional lecture to communicate topics necessary for practicing engineering, such as statics or basic circuit design. Therefore, the course that was developed incorporates two learning styles: active learning (learning by applying information) and reflective learning (learning by examining/manipulating information) [2]. At the same time, deeper learning is also achieved through peer-to-peer collaboration. To achieve this, students are paired based on experience and interest, which helps keep them engaged throughout the course [3]. In this way, students must become familiar with topics of less interest or familiarity, but also thrive by inevitably teaching others topics they are familiar with, which also helps keep them engaged due to the confidence they already have with the material they are assisting others with [3] and increases their own learning through teaching [4].

While the teaching approaches incorporated into the developed course are suitable for most engineering students, the diverse backgrounds of community college students greatly facilitate the learning process, because most of the students are already or quickly become very comfortable with a variety of material in this very broad course, enabling most students to contribute uniquely to the multidisciplinary project presented in the course.

This manuscript discusses the engineering concepts taught, the multidisciplinary project, and how they intertwine to create a deep learning environment. It then explains how diverse student backgrounds further improve the learning outcomes. The teaching methodology and results are reported, ending with a short discussion and future work.

Engineering Concepts

Critical to the course is focusing on subject matter that engages critical design concepts, and introduces as many analytical methods as possible, while not overwhelming students with more information than they can digest. Basic circuit analysis and introductory statics meets these criteria. Both subjects involve basic engineering design and problem solving methods that span the entire discipline of engineering. Beyond analytical skills, design development was implemented by teaching introductory SolidWorks CAD techniques along with Arduino programming. Both build a foundation for logical thinking and develop planning skills. Once the students complete the first half of the semester, they have a set of skills that enable them to work together to complete a multidisciplinary project, completely utilizing all of their learned skills.

Students are thus exposed to a wide range of engineering concepts within the course to both provide them the skills necessary to function within a multidisciplinary team environment as well as to provide an opportunity for them to gain further insight into their own interests and abilities so they can better choose which engineering discipline to pursue starting their sophomore year. Specifically, the engineering design loop (as given by Abarca et al. [5] in Figure 1), circuits, programming, statics, design, and manufacturing/prototyping concepts are built into the course.

DC circuits are introduced, and the fundamentals of circuit analysis are taught including Ohm's law, Joule's law, Kirchoff's laws, series circuits, parallel circuits, and mixed circuits. The theoretical concepts are reinforced through a series of Arduino based labs in which they additionally learn basic C programming, output signals, and input signals. In the first lab, students wire a standard servo to an Arduino Uno, and they are instructed in the basics of C programming to control the servo. For homework, they are required to add a continuous rotational servo to the circuit and modify their code to control both servos.

During the next lab, students wire a break beam sensor to the Arduino. The break beam sensor consists of both an output device (an IR LED) and an input device (IR sensor). The output device continues to reinforce the concept of simple circuits, while the input device teaches them the concept of reading electrical signals. For homework, students are required to use the input from the break beam sensor to control the action of a servo.

For the remainder of the circuits portion of the course, students use their Arduino to collect data from a thermistor, which requires wiring a voltage divider circuit. As part of this lab, they must also solder together the components for an LCD screen to read out the temperature. They use their thermistor to measure the temperature of a water bath at different tempeartures and compare their readings to a thermometer. They also collect resistance data from the thermistor as a function of temperature and fit their data to the Steinhart-Hart equation in Microsoft Excel. The circuits portion of the course is then concluded with a written exam that covers the circuit analysis concepts, Arduino wiring, and C programming taught.

Upon conclusion of the electrical portion of the course, vector mechanics is introduced. Concepts covered include Newton's First and Second Laws, static equilibrium, and torque. The lab component consists of teaching the fundamentals of sketching so students can convey design concepts and develop spatial ability in three dimensions. Students are then instructed how to create engineering drawings using computer aided design (CAD) software, SolidWorks. After learning how to create models and engineering drawings in CAD, students are given the opportunity to create a part of their choice with the restriction that it must fit within a three inch cube. This enables them to make one rapid iteration through the engineering design loop in which they conceptualize a preliminary design and sketch it, model it in a CAD program, and then prototype their design on a 3D printer, at which point they can see their physical product and assess the success of their design. This portion of the course is concluded in the same way as the electrical portion with a test of their understanding of statics, sketching, spatial ability, and CAD.

The skills developed—circuit analysis, wiring/soldering, programming, statics, sketching, CAD, prototyping, etc.— are then all utilized in an autonomous robot design project for the remainder of the course. The combination of lecturing, homework, lab, and the final project seeks to accommodate as many learning styles as possible. Due the the varied nature of these topics, students typically either prefer and/or excel in at least one of the aforementioned areas. While they are expected to learn everything and are tested accordingly, they may focus on areas of strength when working on the robotics project, which is executed over the remainder of the semester. As mentioned in the introduction, allowing students to focus on areas in which they are most confident helps keep them engaged for the duration of the project [3]. At the end of the semester, students are tested orally during presentations in which every student must present what they worked on and detail their contribution to the project. In this way, student contributions are assessed fairly on an individual basis. This prevents the common complaint of students who do little still getting a good grade because of their classmates' efforts and is made possible with small class sizes of six to fourteen students.

Course Project

During the project phase of the course, students are tasked with designing and prototyping an autonomous, line-following robot capable of picking up and storing 1/4 inch ball bearings in its path. They are free to extend the capabilities of the robot to pick up smaller or larger objects as they wish. Students are divided into two teams, an electrical engineering team and a mechanical engineering design team. Teams are assigned based on interests and abilities of students in order to maximize productivity within the project. Due to the diverse demographics of community college students, there is typically a wide range of abilities and skill sets represented in the classroom. While some students are traditional freshmen with no experience, other students may be changing majors or careers, and have significant experience in repairing and/or designing mechanical devices, while others are already experienced programmers or have electronics experience. This diversity results in very high-performance teams, wherein all students are stretched and learn how to function within a team comprised of different skill levels and backgrounds. Students with significant experience are able to tackle more challenging aspects of the project, while students with less experience are still able to contribute by working on tasks that require only the skills learned during the the first half of the course.

A Pre-Assessment survey (see Appendix) is administered at the beginning of the course to gauge the skill set each student possesses upon entry into the course, giving the instructor and student the ability to relate how each topic learned ties into and can be used for the project to be completed by the end of the semester. After the first half of the course is completed, the robot is introduced to the students, along with all the previous semesters' documentation, and groups are formed.

Project Evolution

Semester 1

The first semester that the project was introduced, students were provided with a prototype robot (Figure 2) developed by the authors, that represented one iteration of the design loop. The prototype included preliminary code to drive the robot, but it could not follow a line, could not pick up ball bearings, and had no place to store the ball bearings. Multiple design flaws were incorporated into the initial design to provide students a set of problems to easily identify and engineer new solutions to make the robot completely functional. For example, the front wheel base used micro-servo motors as a steering mechanism, with wheel mounts that required more than the maximum torque available.

During the first semester, the students rapidly identified the poorly designed front wheel system. They took advantage of the rear wheel mount system, replicated it for the front, and added a caterpillar track system for the motion of the robot (Figure 3). They justified this decision based on the agility and stability that track systems provide for a vehicle and the ability for tracks to maneuver rough terrain with ease. This design change required the mechanical engineering team to work with the electrical engineering team, because this fundamentally changed the steering controls of the robot. The changes were implemented, and a student with programming and electronics experience implemented a proportional integral derivative (PID) control algorithm to follow a line, using line-sensors that could detect a colored line on a predefined path. While PID is well-beyond the scope of most freshmen, the student with more controls experience was able to uniquely contribute this to the project and be adequately challenged during the course.

The students on the electrical engineering team also recognized that the kinematics required to maneuver a robotic arm with a claw to pick up a 1/4 inch diameter ball bearing were going to be quite complicated. Therefore, they worked with the mechanical team to redesign the arm to use a magnet to pick up the steel ball bearings (Figure 4), which would require considerably less precision than the claw. The magnet design however, was too heavy for the body of the robot, which caused them to connect the importance of statics in determining the stability of the robot.

Semester 2

The second semester the project was introduced, an older student with more than thirty years experience in various industries suggested abandoning the idea of an arm completely in favor of a rotating paddle that would sweep any bearings in the robots path into an Archimedes screw (Figure 5 and Figure 6) that would convey the bearings upwards to be deposited into the storage container developed during the previous semester. This completely eliminated the need for advanced kinematic controls and dramatically expanded the possible objects that the robot could collect.

Semester 3

Students in the third semester, after being briefed on the work of the previous two semesters, recognized the dramatic design change implemented during the previous semester, which motivated them to also brainstorm novel ideas of their own. The result was another dramatic simplification of both the collection system and the line following algorithm. The third semester mechanical design team abandoned the idea of the sweeper and Archimedes screw in favor of a single blade paddle that could be rotated to push anything in the robot's path it had the clearance to drive over up a ramp that was an integrated part of a collection bucket mounted underneath the robot (Figure 7 and Figure 8). The paddle was activated when objects were detected by a break beam sensor. The paddle was powered by a servo motor that was selected after a student made a torque calculation, as learned in the statics portion of the course, to properly size the motor for the task. This change further expanded the types of objects the robot could collect and eliminated fabrication difficulties with the Archimedes screw identified by the previous semester's team. Again, significant communication between the mechanical engineering team and the electrical engineering team was required. The electrical engineering team further simplified the line following algorithm to a three-sensor fuzzy logic concept, and was the first team to move past proof of concept tests and actually have the robot follow a line.

Learning Results

Several key learning results were observed. First, it was observed that communication within the engineering teams as well as between the teams dictated the success of the final product. For example, the students designing the bucket for storing the items to be collected had to communicate with the students designing the paddle to push the items into the bucket as well as the students designing the sensor mounts, because all items had to be integrated. Additionally, the electrical engineering team had to understand how the collection system was to operate so they could program the break beam sensor and servos accordingly. This was by design, as it is believed from the authors' experience that interdisciplinary collaboration experience is necessary for successful product development, and should be a fundamental skill taught in engineering education. Small class sizes of six to fourteen students allowed communication to be easily observed because there were only two engineering teams, and most of the work was completed in-class.

Skills diversity within the teams also had to be leveraged by the students to maximize the effectiveness of each individual. During all three semesters, students were permitted to choose which engineering team they wanted to be on based on their interests and skills. Within the teams, students had to decide who was responsible for what tasks. Due to the variation in skills, students naturally selected aspects of the project they felt they could handle, and students assisted each other.

During the third semester, an added dimension of student leadership evolved. This occurred during group formation. After the project was introduced, the instructor stepped back and told the class they needed to form groups and begin planning the project. After some discussion among the students, a combat veteran with five years military experience, including leading soldiers, stepped forward and documented every student's name and self-identified skills. The veteran then organized the students into the mechanical and electrical design teams needed and further subdivided those teams into design, fabrication, programming, and wiring subteams based on the skill sets and interests of every individual. Each subteam was also assigned a leader who reported to the veteran, who had assumed a project manager role, and he reported ultimately to the instructor. In addition to the class member with uncommon leadership abilities, there were students with a wide range of techical skills as well, which is not uncommon. These students were all able to maximize their effectiveness by working on aspects of the robot that utilized their skills and interests while forcing them to also learn from each other because of the required integration of the different systems needed for the robot to be functional.

Further, the students were able tie the fundamentals of statics to the collection system, among other areas, by calculating the maximum torque the servo operating the collection paddle would ever have to apply under normal operating conditions. The students also had to apply what they learned during the circuits portion of the course. As an example, they realized that the Arduino Mega microcontroller used to control the robot could not supply enough current to power all the servos. Therefore, they had to design a separate power supply to independently provide the servos the power they needed to operate while still being controlled by the Arduino.

As another example, the team responsible for the design of the wheel system and general robot design, used SolidWorks and additive manufacturing techniques (Stratasys Dimension 1200es), but were not responsible for determining the optimal location to mount the line following sensors. Thus, the programming team had to communicate the functionality of their product to the robot design and fabrication team to implement their product, and the fabrication team was required to communicate design constraints to the programming team. Even though the course is designed to build on itself by compiling documentation from student completed design loops, the success of each iteration is not only due to ideas from the previous semester, but from group cohesion that is developed because of the communication required to complete the work.

A Pre- and Post-assessment survey was developed for the third semester cohort and also demonstrated students' mastery of the engineering concepts taught. Identical online assessments consisting of fifteen, one-point questions related to engineering concepts, circuits, and statics were administered during the first class prior to any lecture and again on the last day of class. One student dropped the course, dropping the number of respondents from n=13 for the Pre-Assessment to n=12 for the Post-Assessment. Table 1 is a summary of the results of the assessments. The average score increased by 22% over the course of the semester raising from 59% to 81%. While the high score only increased by 1% over the semester, the low score increased by 35%. More importantly however, the standard deviation decreased from 3.19 to 1.69 indicating that the skills gap between incoming students decreased over the course of the semester.

Table 1 Assessment exam results administered at the beginning and end of the semester.

	Pre-Assessment (n=13)	Post-Assessment (n=12)
Average Score	59%	81%
High Score	97%	98%

Low Score	23%	58%
Standard Deviation	3.19	1.69

Summary and Future Work

A first-year engineering course has been developed that teaches the fundamentals of engineering design through an open-ended robotics project that requires communication within student engineering teams as well as between teams. The required integration of mechanical design, electrical controls, and programming to build an autonomous robot provides an ideal environment for students to learn how to function within the context of multi-disciplinary teams, and to leverage the skills diversity that is common in the community college classroom. Such a project requires a wide range of skills, and qualified students at any level ranging from freshmen with no engineering experience to non-traditional students with considerable technical experience can be challenged. In all cases, they must learn to communicate effectively within teams and between teams.

Further, the course has been created with the idea that the project will be passed on from one semester to the next, giving the students a sense of importance to their project, knowing that others will benefit from their progress and pick up where they left off. As can be seen from the development over three semesters, each subsequent class learned from the prior class and advanced the machine. Over a short three-semester period, the students were able to create a functional prototype of a high level autonomous robot that many sophomores in mechanical or electrical engineering would only begin to be exposed to. The progress over a short time span alone indicates progressive projects that do not simply reboot from one semester to the next are more rewarding and beneficial for student learning and development. Additionally, the students gain a real sense of what the design loop is, and how it can be utilized to create a great product. Students also learned how to leverage the skills diversity within their groups to maximize the effectiveness of each individual and function within very diverse teams.

Additional evaluation and self-efficacy exams need to be developed as metrics for student growth and development to accurately assess the efficacy of the course, and data will continue to be collected to develop a larger data set to assess the effectiveness of the course.

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Appendix: Pre- and Post-Assessment Survey Questions

1. Define engineering.
2. Define reverse engineering.
3. List as many fields of engineering as you can think of.
4. What is the engineering design loop?
5. Convert 5 MPa to Pa.
6. Define electric current.
    a. Flow rate of electric charge.
    b. Electric pressure due to the separation of charge.
    c. Energy per unit time converted to another form.
7. Define voltage.
    a. Flow rate of electric charge.
    b. Electric pressure due to the separation of charge.
    c. Energy per unit time converted to another form.
8. What is the resistance in Ohms of a light bulb in a simple circuit of 120 V and 0.5 A?
9. What is the power in Watts of a light bulb in a simple circuit of 120 V and 0.5 A?
10. Write the equivalent resistance of a circuit with two 10 Ω resistors connected in series. Give your answer in units of Ω.
11. Write the equivalent resistance of a circuit with two 10 Ω resistors connected in parallel. Give your answer in units of Ω.
12. A vector quantity possesses both _____ and _____.
13. A scalar quantity possesses _____ but not _____.
14. What is the force in N acting on a 1 kg mass accelerating 9.81 m/s?
15. A mass has three forces acting on it. One force is 10 N to the right. Another is 10 N to the left. The third is 50 N straight up. What is the magnitude of the net force on the object?

Figures

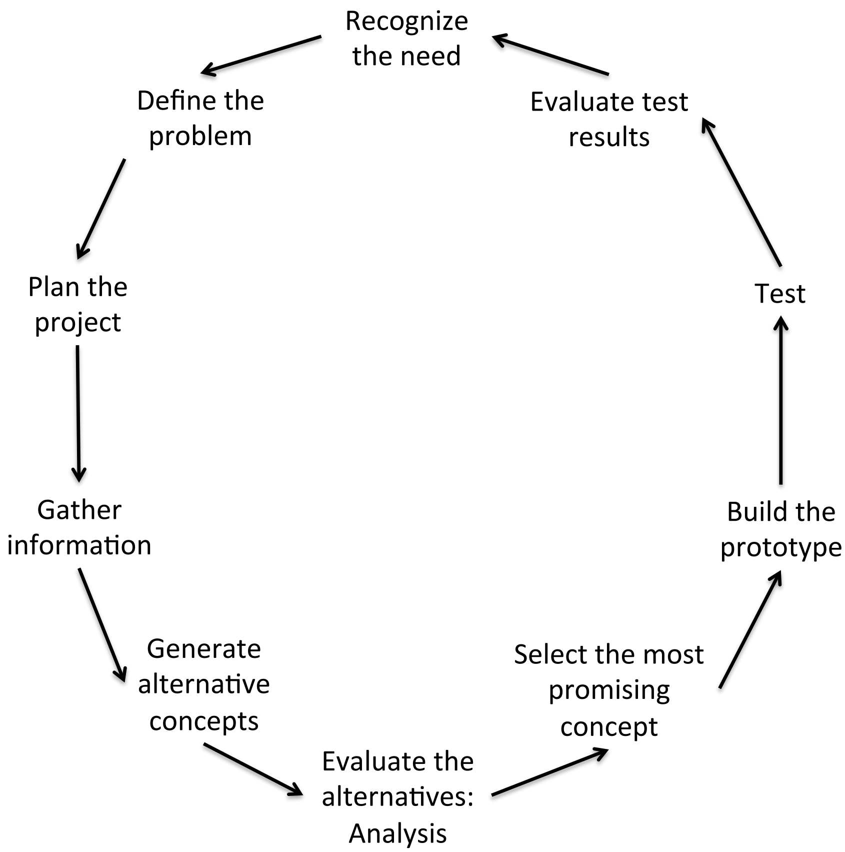

Figure 1 Steps in the engineering design loop as given by Abarca et al. [5]

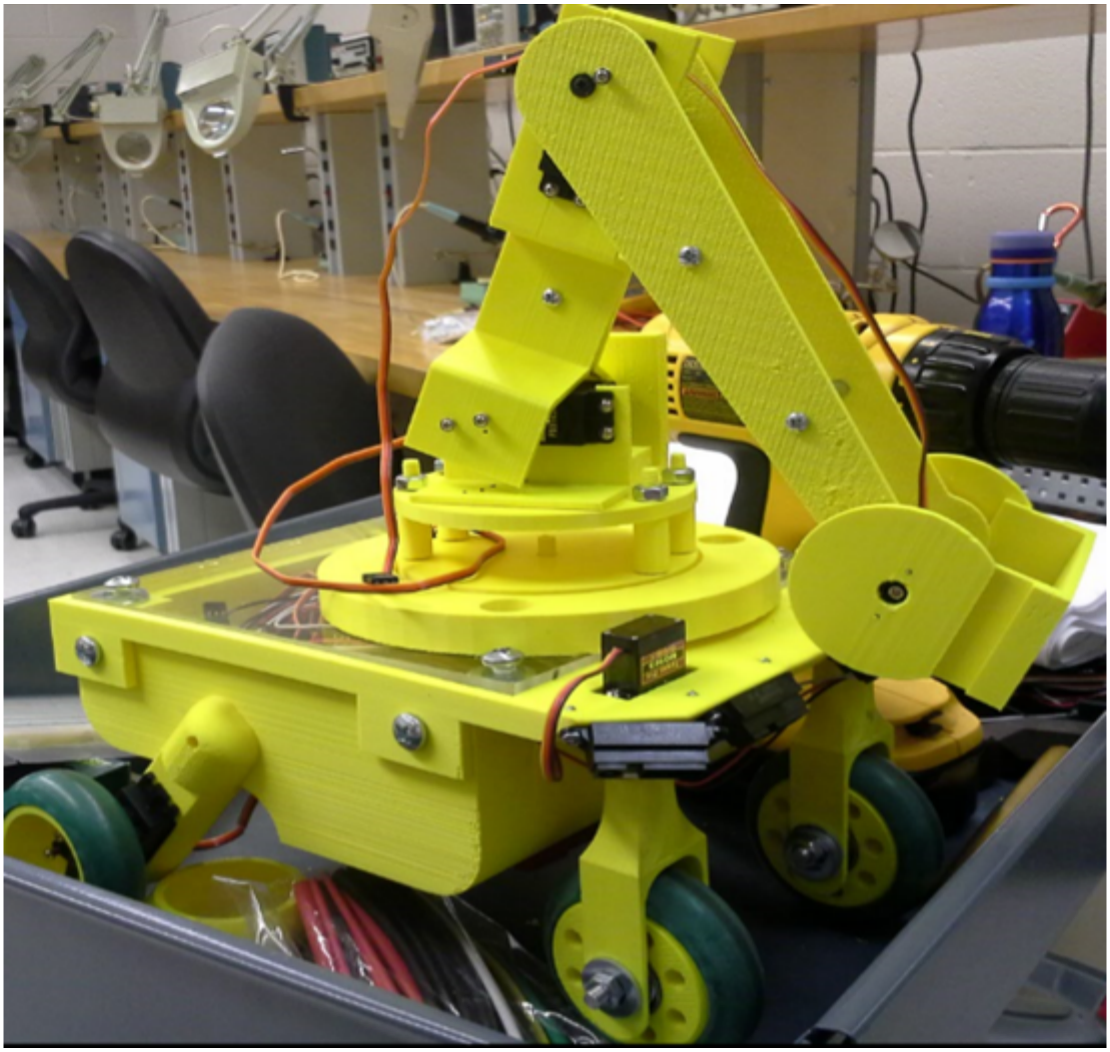

Figure 2 Original design that included fatal design flaws, by design, to help students easily detect what would not work. This was done because no student was required to have any previous engineering experience.

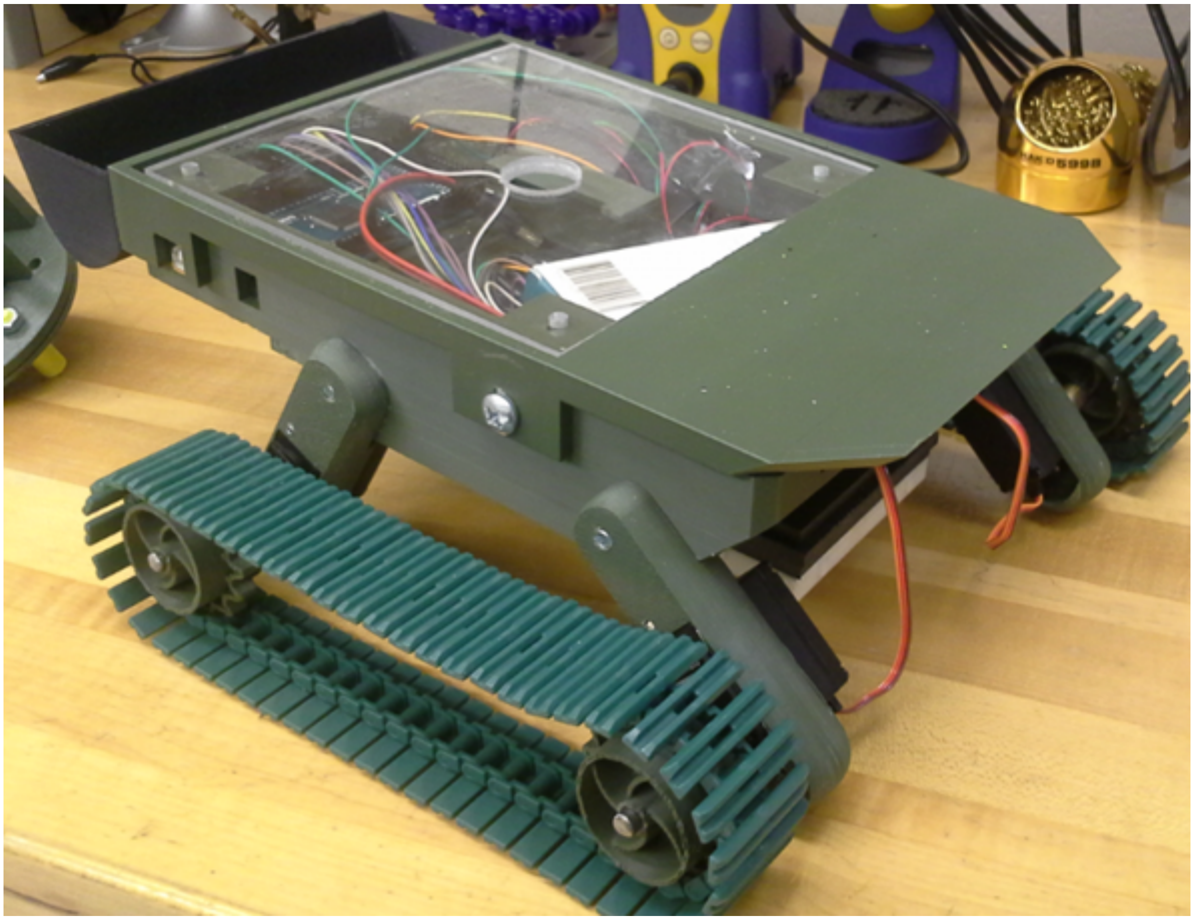

Figure 3 The final functional fabricated product the first semester produced—a robot with programmed line sensors. A large amount of time was put into programming and redesigning the robot and sensors.

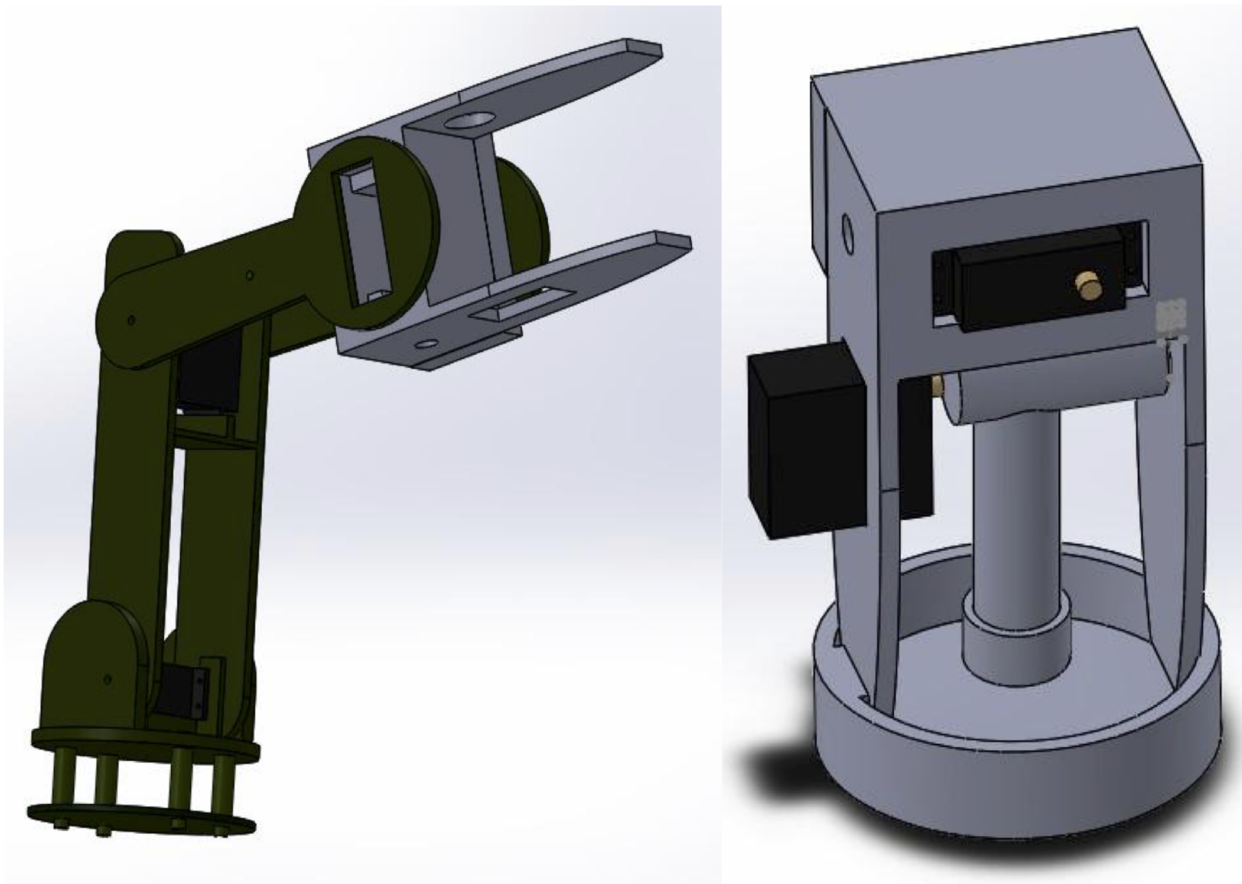

Figure 4 The left image is a student produced SolidWorks model of the robotic arm and mount for a magnetic “claw” to be used to pick up ball bearings. The right image is a student’s model of the magnetic “claw.” The arm and magentic claw were designed by two students and required substantial communication between the two of them.

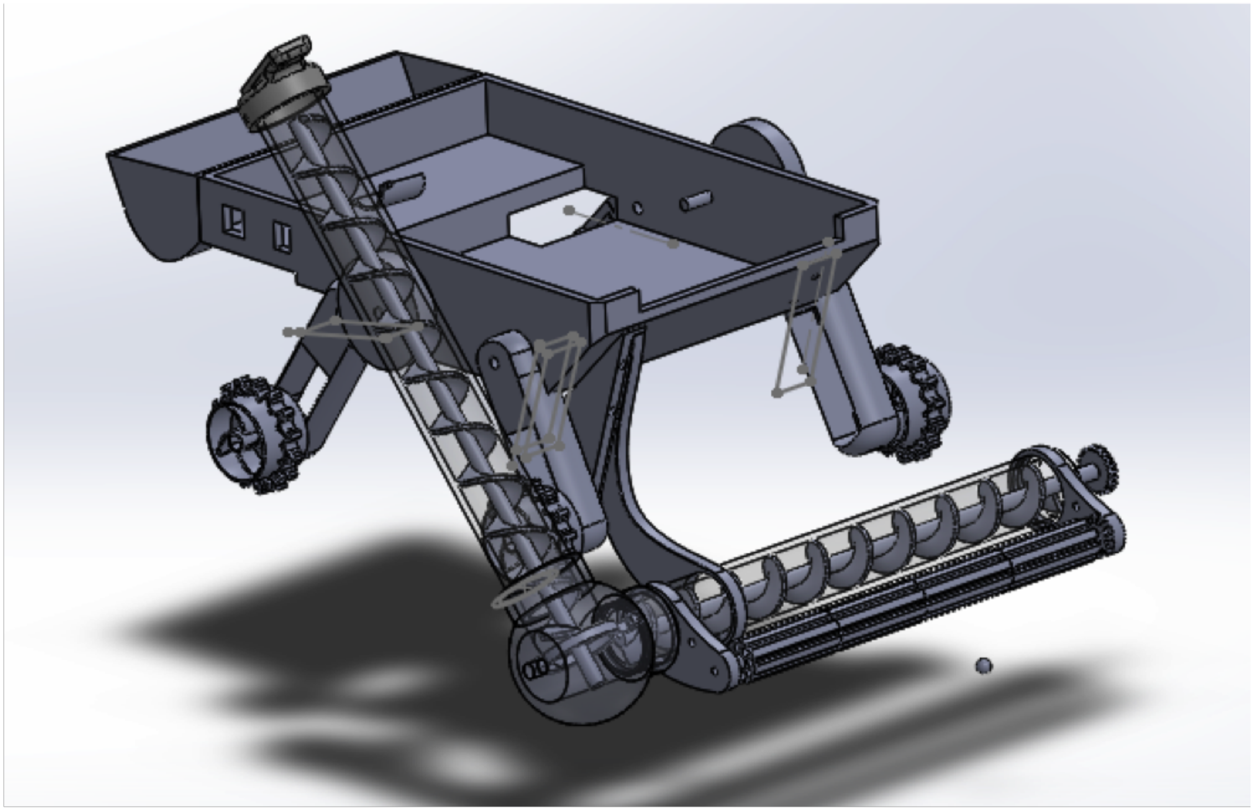

Figure 5 The second semesters design focused on the arm of the robot. The first semester's design of the robot body and drive system was not altered. However, after understanding the first semesters' difficulty redesigning the arm, they chose an alternative solution and selected an Archimedes screw and paddle design to pick up objects and deposit them into the bucket placed at the rear of the robot.

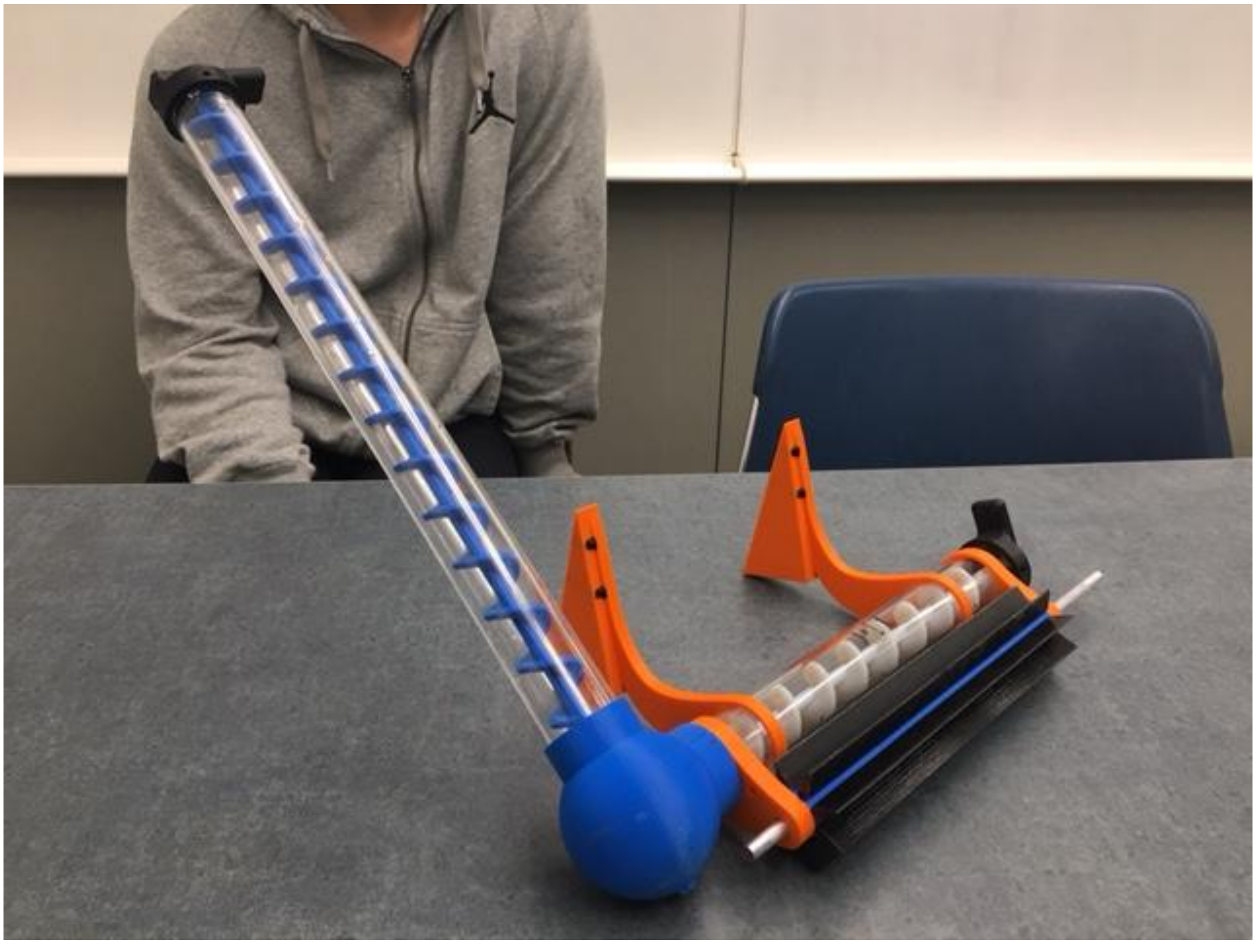

Figure 6 The final fabricated Archimedes screw and paddle design to pick up objects.

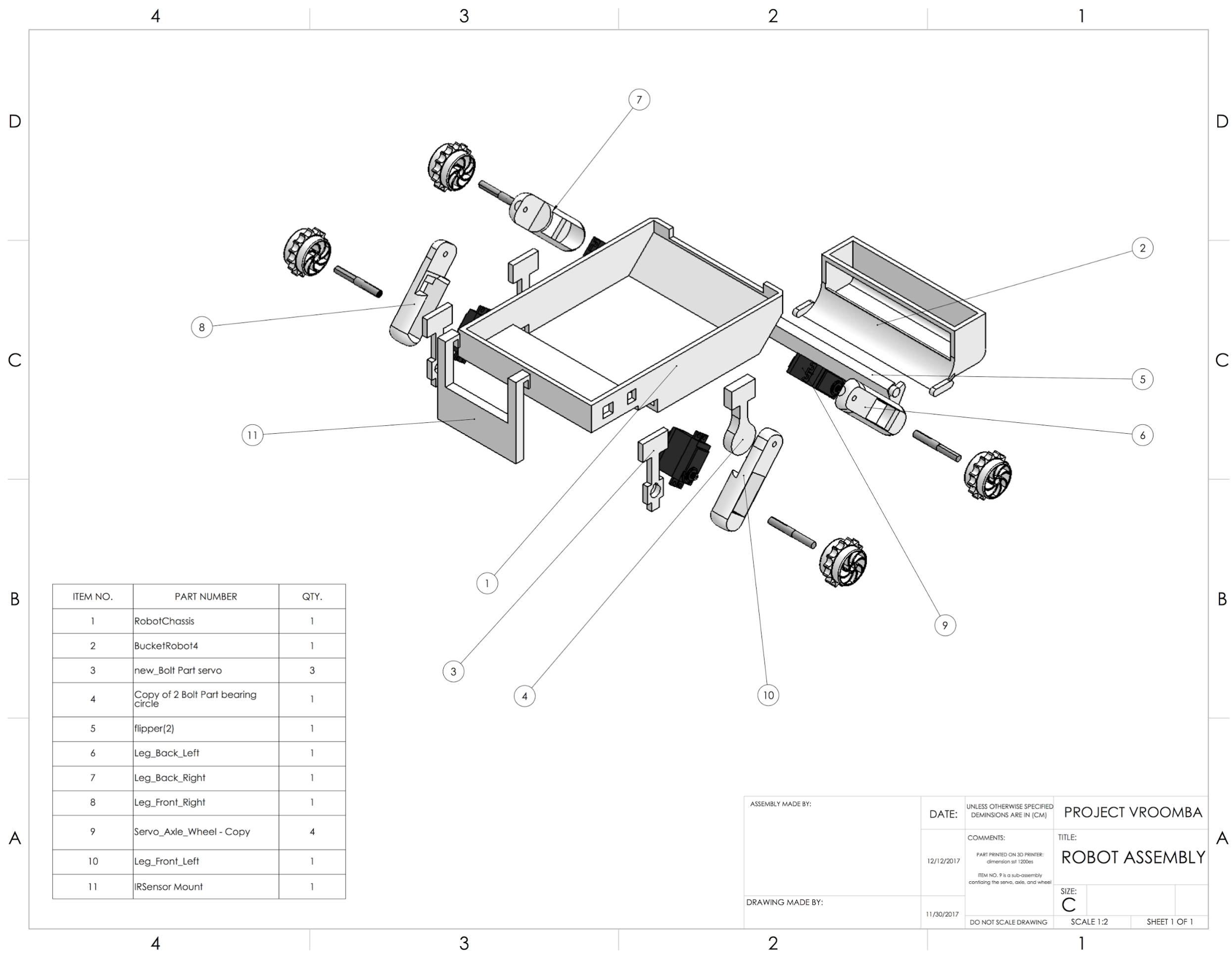

Figure 7 The third semester's final design drawing. As shown in Figure 1, the body and wheel system designed by the first semester was kept. However, the bucket and arm was completely changed from semesters 1 and 2. Semester 3, inspired by 2, created a bucket sweeper design, but placed the mechanism under the robot.

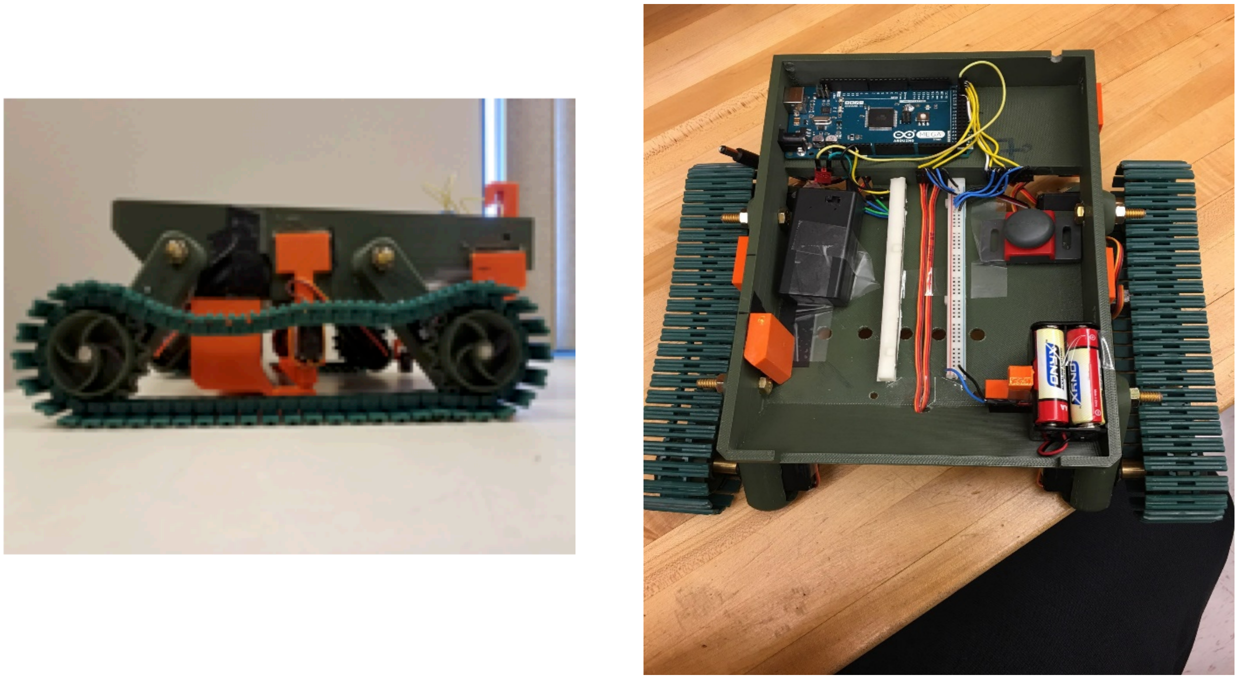

Figure 8 The final fabricated product from semester 3. During this semester the students were able to move past enabling individual systems to work, and implement system integration of all the components to provide a functional rover at the end of the semester. The students renamed their project, Vroomba.