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ADVANCING ROBOTICS AT THE HARRY FULTZ INSTITUTE

An Interactive Qualifying Project Report Submitted to the Faculty of
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Abstract

This project advanced the robotics club at the Harry Fultz Institute in Tirana, Albania by applying various teaching methods, including self-directed learning and group work. We worked alongside Professor Enxhi Jaupi and 6 teams of 5 high school students to understand, design, and construct robots to complete complex tasks. During this time, students were taught fundamental concepts of robotics, such as DC motors, computer-aided design (CAD), and programming. The biggest obstacle to project completion remained the long shipping time for parts. Two solutions proposed to address the long delay in part arrival are pre-selecting student projects or structuring the club around a final competition. The main future goal is to establish the school as the center of robotics in Albania.

Executive Summary

Motivation

In addition to teaching robotics itself, robotics education can function as an integrated approach to STEM subjects. A 2012 review of research on robotics as a teaching tool revealed that robotics has been proven to increase students' knowledge of mathematics, computer programming, and physics (Benitti, 2012). In addition, the review demonstrated that robotics education can improve other skills as well. Students showed improved thinking skills such as observation, estimation, and manipulation as well as improved science process skills such as evaluation of solutions, hypothesis generation, hypothesis testing, and control of variables. Students' also improved problem-solving approaches and social interactions. However, this review noted that there were cases in which robotics education did not achieve the desired learning outcomes as well. This indicates robotics is not the magic solution for improved STEM education, and that the results depend heavily on the implementation. That said, a successful robotics education program can have significant effects for student acquisition of knowledge as well as student development of cognitive abilities and social skills.

Foundation

The sponsor of this project is the Harry Fultz Institute, a technical high school and community college in Tirana, Albania. Last year, a student team from WPI was tasked with developing a robotics club in the school under the supervision of Professor Enxhi Jaupi, who specializes in electronics engineering. The club consisted of twenty-four students personally selected by Professor Jaupi, who were then divided them into six teams of four. The teams worked with the WPI students to create six unique robots for six separate, unconnected tasks.

Mission

Our project focuses on teaching students both technical and non-technical skills, researching the paths of expansion, and evaluating the effectiveness of various teaching methods.

Implementation

Lessons

With the goal of improving students' knowledge and skills, it was decided to implement a structured curriculum into the beginning of the club. Knowing many of the students had little to no experience with programming, robotics or group-work of any kind, students were introduced to robotics using Lego Mindstorms EV3s. Mindstorms is a Lego-based robotics platform geared toward beginners in manufacturing, wiring, and programming. The programming language of EV3s is a visual, block based code that is constructed by dragging blocks into processes to be executed. Construction and wiring are equally simple, requiring only to snap sensors, motors, and other components to one another.

After concluding the EV3 lessons and exercises, we moved on to more advanced robotics lessons that would be directly applicable to the students' projects. We chose to teach a full range of lessons, beginning with simpler concepts and gradually increasing complexity. The lesson topics included:

- 3D Printing
- 3D Modelling
- Mechanical Design Concepts
- Arduino C Programming
- Programming etiquette
- Brushed DC Motor Curves
- Stepper and DC motor drivers
- Pulse Width Modulation (PWM)
- Proportional control

These lessons stemmed from a hands-on approach to learning and experimentation used in order to enhance the students' understanding of robotics and engineering. From speaking with students who had graduated from the Robotics Club, it was discovered that the students' sense of autonomy is a very important aspect of their educational satisfaction. The key to successfully implementing this autonomy was to have a balance of self-directed learning and guided instruction. During lessons, students would be asked questions on how to proceed, and then be guided toward a valid solution. Once the lesson finished, the students were given an assignment that extrapolated on the information taught, ensuring that they had to learn information on their own to be successful. This encouraged students to explore the material hands-on, allowed them to delve into material outside of the lesson and aided them in better understand the concepts and processes to apply in the future.

Projects

Groups were given the task to research potential projects in order to choose the one that they would complete. It soon became apparent that many of the students' groups already had project ideas in mind. In particular, two groups wanted to make a combined project where one team would make a rover and the other group would make a drone that could carry the rover, with the intention for it to be used for dangerous situations like fire rescue. While this project was exciting, it was too ambitious for the limited time of our involvement and resources of the club. To encourage the students to maintain that ambition but recognize these constraints, we suggested that they try to make both projects this year, but wait until next year to combine them. The students accepted that their idea might be too ambitious and decided to focus on making their projects work individually. We talked to each group about their project and helped them work out the details in a similar fashion. The projects included:

- Autonomous Hex-copter Drone
- Autonomous Rover
- Balancing and Jumping Remote Controlled Robot
- 3-axis CNC Machine
- Robotic Hand
- Robotic Arm with Manipulator

The next phase, project planning and design, demonstrated the need for structure as well as communication. We asked the students to submit short project proposals to help them think through their project as well as keep us informed of their intentions. While three of the teams completed this task successfully, the remaining three did not submit a proposal for various reasons. In one case, the team was following an online guide which already outlined their project. Another group, building a rover, had a project that continually changed shape, and it was decided the additional work would have been a burden to an already stressed team. The last team, who intended to make a robotic hand, seemed to have some quarrels implying a potential lack of continuity among the team. Fortunately they have worked these issues out and are continuing their project as planned.

In our original model, project implementation was supposed to begin two weeks into the club once the parts arrived. Despite most of the parts being ordered in July, they did not arrive until the penultimate week of the project. As a result, we were only present for the physical construction of the robots using 3D printed parts, but not for the electrical wiring, programming, and testing phases. By the time we left, the projects were progressing well, but to make sure the projects are completed, we provided additional methods for the students to communicate with us including Facebook and email.

Result

The students clearly enjoyed the hands-on learning and our general approach to lessons. The emphasis on project examples supporting the lecture material made lessons engaging and interesting to the students. One student said that we "explained well the intersection between theory and practice." This seems to be a result of our lesson structure that consists of short lecture portions interspersed with hands-on activities. However, we believe the students might benefit even more from lessons that connect together to build a larger, more complex project that analogous to a complete robot. This includes the code that a robot might use, as well as CAD for the structure and a schematic for the electrical circuits. Leading them through the entire process in the beginning of the club would give them the ability and confidence to tackle such a challenge on their own, while making them aware of project feasibility and manufacturing limitations.

As expected, the lack of parts and shipping delays caused student interest and excitement to wane. Despite this, students still attended the club regularly, demonstrating impressive dedication and commitment to us and their teams. Once parts did arrive, the students were once more excited and enthusiastic, seemingly without skipping a beat.

Future

Through day to day communication with Professor Jaupi, he made evident his plans for the future of the club. Professor Jaupi's idea was to have the Harry Fultz Institute function as a hub for robotics education in Albania, continuing to run the club for the school but also running a second club for students from various schools in Tirana. In accordance, Professor Jaupi was interested in having a second WPI IQP team work with this other club. This is an interesting idea for the future of the club, however we determined it is too early to have this much rapid expansion. The club is still working through logistical problems such as work space and more importantly, acquisition of parts. On top of this, next year the club will be under new leadership because Professor Jaupi will likely be pursuing his PhD. We believe that this growth would be better suited further down the road.

This year's club consisted of 31 students, out of 80 applicants. Just as last year, the students were all hand selected by Professor Jaupi, being the brightest programming and electronics minds the school has to offer. This expansion of the club from last year and any future expansions must deal with workspace limitations. Professor Jaupi's lab is designed for twenty-four students to be working simultaneously, hence the twenty-four student limit of the first year's club. However, this year Professor Jaupi stated that there were simply too many great candidates to choose from that he could not narrow it down to twenty-four students. There is a larger workspace for the club available, however, the equipment from Professor Jaupi's lab would have to be transported back and forth nearly every day in order to use this area. While this year's growth does result in a very busy workspace, we believe this will be acceptable with thirty-one students. However, if the club continues to grow, other options such as a larger workspace or time slots will be necessary.

We worked with the Harry Fultz students to develop a plan for next year that would satisfy all of these requests for improvement. A change that would solve several of these problems is reducing the number of participants in the club back to 24 students. We understand that the number of students selected to participate was increased due to a large applicant pool, but this made it too difficult to ensure a quality learning experience. In this plan, there would be 8 groups of 3 students each, owing to experience in WPI classes showing 3 students to be ideal for robotics projects. Each of 4 WPI students would mentor 2 teams, acting as a liaison between the students and the professor. They would be responsible to know the detail of their group's projects as well as keeping the professor and other WPI students up to date. The WPI students and professor would separately collaborate in order to ensure diverse perspectives for all projects.

As we see it, the club's activities next year can have two different systems. One would involve continuing much like this past year with each group building a different robotic project. Continuation of the club's activities as they are would require some modifications to mitigate the difficulties we encountered, particularly the incredibly long delivery time of parts. Professor Jaupi ordered the parts in July and they did not arrive until December 10th. With this in mind, pre-selecting the projects would allow the parts to be ordered earlier, hopefully arriving long before the club so that they can be used for lessons. We also suggest that the orders be split up into smaller orders to decrease back-order delays if necessary. Additionally, we have documented and compiled our most important lessons and useful materials in our appendices, so that future teams can build from them.

The other potential plan for club activities is to implement a competitive game amongst the students. Students were intrigued by the idea of a tournament at the end between all the groups. One student said that this would be a good idea because "competition inspires innovation." Due to this, we decided that WPI's Savage Soccer, designed to be a low-cost, small scale robotics competition, would be a fitting program to use in the club. We believe it allows students to be directed in their robot building by having an already specified problem to solve, while still giving them the freedom to determine how to solve it. Further, we believe that Savage Soccer has the added bonus of the constructive motivation of collaborative competition. Further information about Savage Soccer can be found in **Appendix C**: Savage Soccer.

Lastly, as a supplement to club, we suggest separate, 1-2 week camps using the Lego Mindstorms EV3's. This camp would address some separate student concerns about the material, and student composition of the club: Students stated that they while they enjoyed the EV3's, they believed they were better suited for a lower-level introduction to robotics, separate from the club. Additionally, students were concerned that there was no way to know that they students committing to the 7 week projects were knowledgeable or dedicated enough. Lastly, students were disheartened by what they saw as a necessary limit to the number students that could participate in the 7 week projects. Addressing all of these concerns, the EV3 camps have many potential benefits:

- easily run by a professor with minimal training or practice
- executable without WPI student presence
- allow many times more students to participate in robotics
- function as a testing ground for student interest and ability
- have no recurring costs of operation
- allow the Harry Fultz Institute to bring in students from surrounding areas
- allow students and teachers experience with interactive lessons and hands-on exercises

Authorship

The members of this IQP team contributed equally to this report and this project. All members wrote a draft of individual sections, then modified the entire report, as needed. Members of the team worked together to make the sections a cohesive whole, with the result primarily edited by Clark and Lauren. Surveys and questions for interviews were developed by the entire team.

Lessons were divided as follows:
3D printing lessons were created and taught by Dean.
3D modeling and DC motor lessons were created and taught by Mead.
Programming Lessons and Example Code were created by Clark and Lauren and taught by Clark.

Acknowledgements

We would like to thank everyone who helped make this project a success. We could not have accomplished our goals without their help.

Our sponsor, the Harry Fultz Institute, has been extremely helpful throughout the course of the project, and their commitment to the robotics program has given us tremendous opportunities to assist the students.

In particular, we would like to thank Professor Enxhi Jaupi, who worked with us to run the robotics club. He was a vital partner in this endeavor, and he worked hard to help both us and the students, despite being very busy teaching other classes. His investment in the club and interest in robotics made working with him rewarding and fun. The project and the club would not have been the same without him.

We are also grateful to our students, who were motivated, communicative, and incredibly patient, given how many roadblocks they had to actually building their robots. We could not have asked for better students to work with.

We would also like to thank our advisors, Professor Robert Hersh and Professor Robert Dempski. Their feedback and guidance helped us organize all our ideas and take the project from concept to reality.

We also thank Professor Christopher for establishing this project center and for convincing us to come to Albania instead of anywhere else. Without him we would never have had this phenomenal opportunity.

Lastly, we would like to thank the WPI Robotics Engineering Department and the Robotics Resource Center for helping us prepare for the project. Their support has been paramount in our mission to spread the WPI model of robotics engineering to the Harry Fultz Institute.

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1 Introduction

STEM (Science Technology, Engineering, and Mathematics) has been on the forefront of enterprise and innovation in the recent years. Engineering development around the world is crucial to developing countries in order to provide greater opportunities for their citizens. As a developing country, Albania lacks opportunities which results in frustration among its citizens. The infrastructure for rapid development is absent due to decades of Communist rule limiting and isolating the lives of Albanians. In response, many emigrate in search of opportunity in other more developed nations.

Robotics, a growing industry (World Robotics 2015, 2015), has the potential to create opportunities for innovation and improvements to quality of life in all kinds of countries, including Albania. Fittingly, Albanian schools have been approaching issues in their country by creating technical programs to train its youth to engineer new and innovative solutions, creating the perfect foundation for robotics. The Harry Fultz Institute in Tirana, Albania is one school using this approach.

The sponsor of this project is the Harry Fultz Institute, which is a technical high school and community college. The Institute itself has four directions of study, including electronics, auto-mechanics, business, and general high school (Harry Fultz Institute, 2015). Last year, a student team from WPI was tasked with developing a robotics club with the school under the supervision of Professor Enxhi Jaupi. The club consisted of twenty-four students personally selected by Professor Jaupi, who were then divided into six teams of four. The student teams worked with the WPI students to create 6 unique robots from scratch.

The WPI team tasked with the development of the club last year faced many social, technical, and logistical challenges. To begin, the groups were organized based on personality, rather than diversity of skills, which left one team with little to no programming skills at all(Hunt, McQuaid, Sussman, & Tomko, 2014). The WPI team further noticed that while the students were eager to work with hands-on projects, they were disenchanted by conventional, classroom-based curriculum. Additionally, an interview with some of the former students uncovered hesitance regarding kit-based robots. Instead, they wanted to be able to explore their creativity and construct a robot of their own design rather than be limited by a set of instructions laid out for them. The most notable challenge faced by last year's team was ordering the parts earlier in the building process. The shipping of parts to the school took longer and cost much more than was acceptable, particularly given their limited resources.

It was decided in a discussion with Professor Jaupi that our project would focus on teaching students both technical and non-technical skills, researching the possibility of expansion, and evaluating the effectiveness of various teaching methods. In the next few years, Professor Jaupi plans on expanding the club to more students and schools in the future and he wants us to help prepare for this plan. We also intend to teach the students skills pertaining to robotics as well as the ability to plan, organize, and work as a team. Through all of our efforts, we discovered some unexpected challenges and we have documented these challenges for next year's group so they can prepare for them ahead of time. We have spent seven weeks continuing upon the work that the past year's group had done with a similar group structure, using last year's projects as inspiration as well as developing new projects. With our efforts, we hope to have left the students with an increased knowledge of robotics and a deeper interest in engineering.

2 Background

2.1 Background Introduction

This chapter will explain the value of robotics education, as well as describe teaching methods well-suited to robotics. It will also present information about the Harry Fultz Institute, feedback from the introduction of the robotics program last year, as well as a summary of the current state of the program.

2.2 Why Robotics Education is Valuable

STEM (Science, Technology, Engineering, Mathematics) education is on the rise. As the world economy moves towards computers and technology, the demand for STEM educated workers is increasing (Carnevale, Smith, & Melton, 2015). In addition, STEM education gives us all an understanding about the world around us, of both the natural systems that govern the universe and the technology that we use every day. Robotics education is increasingly being used as an integrative approach to STEM subjects and as a gateway for students into the growing industry of industrial and service robots.

2.2.1 Robotics as a Growing Industry

Robotics is a rapidly developing industry comprised of two sectors: industrial robots and service robots. The International Organization for Standardization (ISO) defines an industrial robot as “An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications” (Industrial Robots, 2015). Service robots are defined as “a robot that performs useful tasks for humans or equipment excluding industrial automation application” (Service Robots, 2015). The industrial robot market is more established than the service robot market, but both are growing. In 2014, 229,261 industrial robots were sold, which is an increase of 29% from the year before (World Robotics 2015, 2015). Figure 2.1 shows the annual supply of industrial robots from 2002 to 2014. Similarly, the sales of service robots grew 28% in 2014, selling over 4.7 million robots (World Robotics 2015, 2015). These double digit increases in sales indicate that robotics is a growing industry, and the acceleration in growth suggests that these markets will continue to expand over time. The world will need skilled engineers to produce these robots and robotics education is a gateway for students into this growing industry.

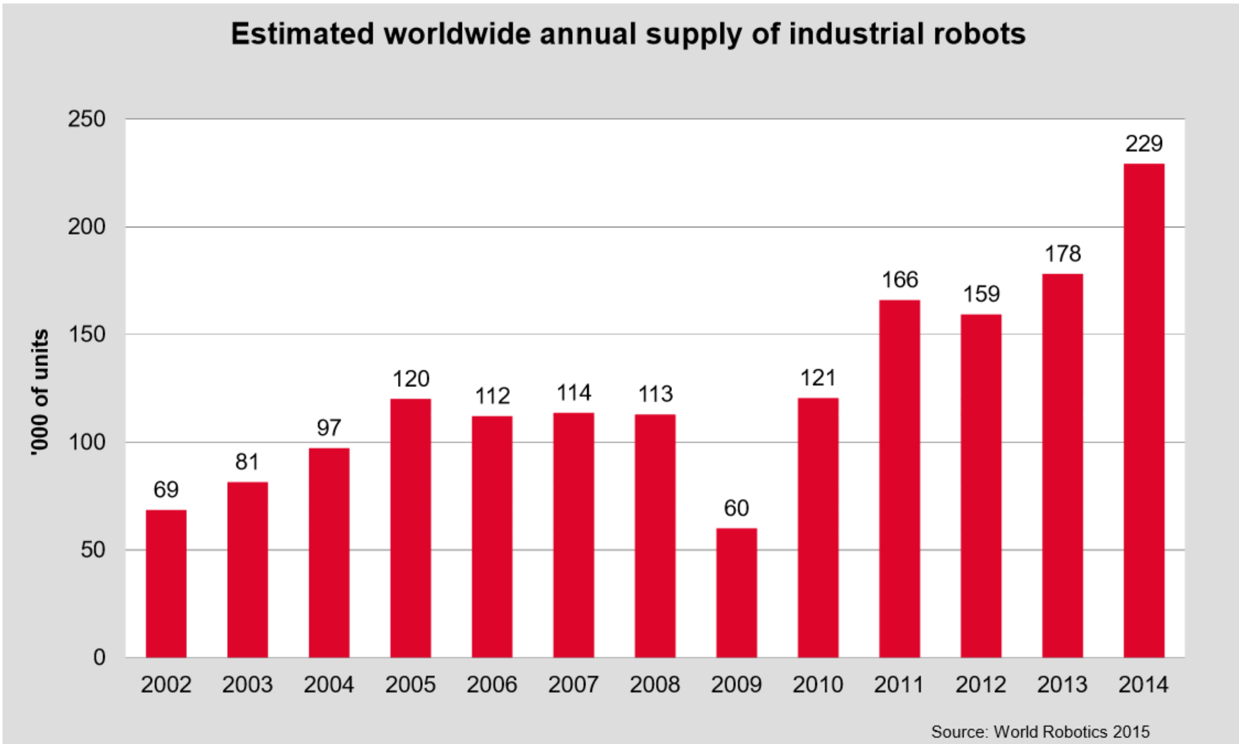

FIGURE 2.1: ESTIMATED WORLDWIDE ANNUAL SUPPLY OF INDUSTRIAL ROBOTS (WORLD ROBOTICS 2015, 2015).

2.2.2 Robotics as a Teaching Tool for STEM

In addition to teaching robotics itself, robotics education can function as an integrated approach to STEM subjects. A 2012 review of research on robotics as a teaching tool revealed that robotics has been proven to increase students' knowledge of mathematics, computer programming, and physics. In addition, the review demonstrated that robotics education can improve other skills as well. Students showed improved thinking skills such as observation, estimation, and manipulation as well as improved science process skills such as evaluation of solutions, hypothesis generation, hypothesis testing, and control of variables. Robotics education also improved students' problem-solving approaches and social interactions (Benitti, 2012). However, this review also noted that there were cases in which robotics education did not achieve the desired results, which indicates that robotics is not a magical solution for improved

STEM education. The results depend on the quality of the implementation. That said, a successful robotics education program can have significant effects on student acquisition of knowledge as well as student development of cognitive abilities and social skills.

FIRST Robotics, which is an acronym meaning For Inspiration and Recognition of Science and Technology, is a large scale example of using robotics for educational purposes and demonstrates the power of this type of education. FIRST is an international organization that coordinates robotics competitions around the world at various skill levels. A 2007 study concluded that students who had participated in FIRST and attended this study were 50% more likely to seek out a career in the science and technology field. The study determined overall that in all seven categories, including but not limited to attitude to scientific inquiry, enjoyment of science lessons, and leisure interest in science, students in FIRST showed significantly more positive attitudes toward science. One limitation to the study is that they had a limited pool of applicants, most of whom were already involved in science one way or another (Welch & Huffman, 2011). Nonetheless, FIRST demonstrates that robotics education can be a powerful tool for STEM education and shows that it can be done successfully on a large scale.

2.3 Teaching Methods Well-Suited to Robotics

Certain teaching methods are well-suited to robotics b ecause of the physical nature of robotics and the open ended problems typically addressed. Three teaching methods that pair well with robotics are project-based learning, group work, and self-directed learning. Each of these methods carries its own benefits and challenges.

The first of these methods, project-based learning, is well-suited to robotics since robotics education typically involves projects where students produce a robot demonstrating a particular concept. Project-based learning differs from traditional education in that students use the knowledge they gain in class to complete a project that demonstrates their understanding, rather than demonstrating that understanding through written assessments such as tests or essays. The goal of project-based learning is to give students a chance to work hands-on, allowing them to creatively solve a problem and synthesize the information they have learned. Research on project-based learning has shown that it can improve academic achievement in traditional subject matter areas. In addition, it can improve the quality of learning, giving students a chance to use higher-level cognitive skills and apply their knowledge in novel, problem-solving ways (Thomas, 2000). For STEM education, project-based learning allows students to integrate the various disciplines in STEM and exercise the type of problem-solving that is used in STEM careers.

The second of these teaching methods, group work, is often employed in robotics education because robots have different components and tasks that teams can complete simultaneously. Also, robot design benefits from multiple perspectives and opinions, so teams are ideal. This group work experience in robotics is valuable because it trains students how to work cooperatively with others, which they will need when entering the workforce. When such group work is successfully implemented, it can help students complete more complicated projects, improve interpersonal skills, challenge and widen their perspectives, and prepare students for the real world (Gatfield, 1999). Furthermore, a 1996 survey of both industry and academia found that teamwork and communication were the two skills deemed most valuable for mechanical engineering graduates (Bahner, 1996). A follow up survey determined that most new graduates are not prepared in these areas. Thus, experience with teamwork can give students a leg up when they enter the workforce. On the other hand, a negative experience with teamwork can sour students on the idea itself and bring negative attitudes towards future teams (Adams & Laksumanage, 2003). Successful teamwork requires careful planning and involvement from instructors, but the benefits for students are huge if it is done well.

The final teaching method is self-directed learning. Self-directed learning is a teaching method in which the students drive their own education, choosing what they want to learn and deciding how to learn it. Self-directed learning pairs well with robotics since it allows students to design and implement robots themselves. Like projects done in groups, this mirrors the work students will do after they graduate from school. When self-directed learning is done properly, it can help students synthesize knowledge, produce creative solutions, and “learn how to learn” (Beach, 1968). However, students may have difficulty with self-directed learning. There are potential issues regarding finding the right question, managing time, or directing their investigations (Thomas, 2000). In order to maximize the benefits of this teaching style, educators should provide students the freedom to choose tasks, investigate ideas, and pursue solutions. Conversely, they need to be aware of the challenges to student autonomy and be prepared to intervene if these issues interfere with learning.

2.4 About the Harry Fultz Institute

Our project, the robotics club, is sponsored and hosted by Professor Enxhi Jaupi at the Harry Fultz Institute. Through the school's website, our talks with Professor Jaupi, and our time at the school, we found the following information.

The Harry Fultz Institute was established in 1921 by the American Red Cross Youth Organization as the first vocational school in Albania. Located in the heart of Tirana, the school's purpose is to educate and enable the youth of Albania to solve problems in their communities. Harry T Fultz, the Director of the school for the first 11 years, pursued this through his philosophy of "Learning by doing." From its meager beginning with only 32 students, the Fultz School has grown immensely and now maintains around 900 students in the high school alone (Harry Fultz Institute, 2015).

FIGURE 2.2: THE HARRY FULTZ INSTITUTE CAMPUS (HARRY FULTZ INSTITUTE, 2015)

The Harry Fultz Institute is a vocational school composed of a private high school as well as a community college. It offers a variety of curricula to teach students skills that include welding and fixing cars to programming mobile phones and making circuit boards. Aiding its focus on practical skills and knowledge, the school possesses 13 labs, 10 practice rooms, and 5 demo classes in which students can practice real-world scenarios.

2.5 Last Year's Formation of the Robotics Club

Last year, a robotics club was formed at the Harry Fultz Institute with the help of a WPI student team (Hunt, McQuaid, Sussman, & Tomko, 2014). The club consisted of 24 students divided amongst 6 groups. The WPI team spent the first week talking to the students and getting them to feel more comfortable communicating because they were shy. Next, they picked a student leader from each group and taught them first, relying on them to teach the rest of the students in the coming weeks. Lessons were pulled from www.opensourcehardwaregroup.com and also contained a code debugging challenge. Although the leaders achieved better understanding through teaching, the process ended up taking twice as long as teaching all the students at once. The goal of the student leaders was to reduce the teaching strain on Professor Jaupi. We do not think this is necessary because we will be doing most of the teaching, but we will keep the student leader structure solely for organizational purposes.

After the week spent learning about writing code, the student leaders chose projects for their group based on advice from the WPI team. Some discussed it with the other members of their group, while some did not. These projects were required to use at least one sensor, an Arduino and to be as inexpensive as possible to fit within the group budget of $50. Projects this year are more complex than last year and have a budget of $165. In the third week, students did a short presentation that included drawings or schematics for their robot. Once designs were fully conceptualized, each team was given time to find parts. These parts were costly, yet their prices were dwarfed by shipping expenses from Canada to Albania. The distance also greatly delayed the arrival of the parts. During this delay, students worked out the details of their projects and calculated any mathematics necessary. This allowed projects to be engineered rather that built, which was important because limited time required that the projects not need large amounts of fine tuning. The enthusiasm of the students waned by the time parts arrived and the lack of remaining time proved challenging for the students. An additional challenge faced by students was an imbalance of skills in the groups, where some groups were lacking a person with any previous programming knowledge. This resulted in some groups having to simplify their projects. Before the WPI students left, students developed reports and presentations to be shown to faculty and parents.

Our team conducted interviews with three of the club's previous students. They confirmed our research with stories of frustration at both shipping times and the lack of part availability. They also indicated that their final projects should be as personally designed and constructed as possible. Specifically, when we suggested the use of Lego robotics kits, they were wary of using any type of kit to build robots. This may have been a miscommunication regarding the nature of the kits in question, but the students went on to talk of how their other classes did not afford them any creative license. Due to the slight sensitivity around the issue, we must ensure we grant as much creative opportunity as would be productive to the students.

In addition to feedback on parts and kits, the students told us something concerning the women of the Harry Fultz Institute; they tend not to be vocal or involved and that there are very few of them. This is concerning and we decided to pay attention to this possibility amongst our students. Concannon and Barrow suggest that this may be because “women exhibit lower engineering career outcome expectations” and they “also seem to be low in coping- self efficacy, or the belief that they are unable to successfully cope with sudden change” (Concannon & Barrow, 2009, pp. 164-165). The way society presents engineers, in particular female engineers, discourages women from wanting to become engineers (164). In talking to Professor Jaupi, our project sponsor, he said that gender balance was not a problem at all, even though there are less girls because they are very smart and work hard. As a middle ground, we talked to Elizabeth Tomko from last year’s research team, who suggested an alternative explanation for the conflicting information we were receiving. She believes the girls, who are in fact very smart, were suffering from an imbalanced project team and the lack of skilled programmers in their group was preventing them from developing their project as quickly as some other groups. While this is not the challenge we originally thought we would be facing, we will be paying special attention regardless.

2.6 The Current State of the Club

This year's club consisted of thirty-one students chosen from the eighty that had applied. Just as last year, the students were all hand selected by Professor Jaupi as being the brightest programming and electronics minds the school has to offer. This expansion of the club and any future expansions must deal with workspace limitations. Professor Jaupi's lab is designed for twenty-four students to be working simultaneously, hence the twenty-four student limit of the first year's club. However, this year Professor Jaupi stated that there were simply too many great candidates to choose from that he could not narrow it down to twenty-four students. There is however a larger workspace for the club available. To use this workspace, the equipment from Professor Jaupi's lab would have to be transported back and forth nearly every day. While this year's growth does result in a very busy workspace, we believe this will be workable with thirty-one students. However, a larger workspace will need to be found if the club continues to grow.

The thirty-one students are split up into five groups of five and one group of six. One student in each group was designated as the leader by Professor Jaupi. The group leader will serve as the student that we interact with in terms of distribution of various assignments or materials to the club. Each group had at least two programmers and two electronics specialists to ensure that all of the teams would have sufficient knowledge to construct their robotic project. Unlike last year's concentration of females in one group, this year was much more distributed. Four of the groups had one female, one of the groups had none, and the remaining group had two females, one of which was the group's leader. Another notable change from the first year of the club was the number of 3rd and 4th year students participating. The first year's club consisted of twenty-one 4th year students and three 3rd year students, the latter of which all returned to the club this year. The striking number of 4th year students was not present this year, as a majority of the participants are currently in their 3rd year at the school. 3rd and 4th year students were evenly distributed amongst the groups excluding one purely 3rd year group of which was planned by Professor Jaupi as an experimental group. It was stated by Professor Jaupi that no students earlier than the 3rd year were considered for the club because they would not have the required knowledge from classroom education to actively participate in the club's activities.

Each group of students designed and developed a project of their own choosing. We have assisted each group throughout their engineering of the project. Professor Jaupi's goal is to have the students present their projects at the end. These presentations will be for parents, friends and school officials.

Resources and supplies were a limitation to the club's projects due to the budget. However, 15,000 euro was spent on acquiring new materials and resources in preparation for this year. This includes, but is not limited to motors, sensors, drivers, and a 3D printer. These funds were acquired by Professor Jaupi from the Harry Fultz Institute. The $300 total fund last year was low because the club's creation occurred after the Institute had already distributed its finances to the school's various activities and $300 was the most that could be put together. This year, however, the club had its groundwork and was had already proved that it could be successful. This allowed for a significantly larger fund for this year's operations. Professor Jaupi predicts that the school will not only match this year's funds, but also increase them in the coming years. There has also been talk with two different companies who are both interested in sponsoring the club.

Professor Jaupi was the driving force behind the creation of the robotics club and will be leaving it in this upcoming year to explore opportunities for a PhD. A friend of Professor Jaupi's from the University Polytechnic of Tirana will be taking over the club's activities. Even though Professor Jaupi will not be directly involved, he still has very large plans for the future of the club. His long term goal for the club is for it to become the robotics center of Tirana, eventually expanding it to all of Albania, then even inviting international participants. The first step planned to be taken is to add another robotics club to the school that would consist of students who are not from the Harry Fultz Institute, but instead from various high schools around the city of Tirana. To assist with the development of both of these clubs, Professor Jaupi was hoping to add another WPI team to work with this group, while still continuing the one with the Harry Fultz students.

3 Methodology

3.1 Methodology Introduction

The goal of this project was to help the Harry Fultz Institute advance their robotics club by refining the club organization, applying proven STEM education methods, and expanding student knowledge and skills. Our objectives with this project were as follows:

- Assess the ability of the robotics club to teach students technical and soft skills through the use of hands-on, project-based learning.
- Examine the effect that our involvement has on the students' learning and their confidence in their abilities.
- Explore the expansion of the robotics program in the Harry Fultz Institute and provide recommendations for the future of the program.

This chapter describes our approach to these objectives.

3.2 Curriculum for Technical Skills

With the goal of improving students' knowledge and skills, a curriculum was created for the beginning of the club. Unfortunately, many of the students had little to no experience with programming, robotics or group-work of any kind, as the previous IQP team discovered. For this reason, students were introduced to robotics using Lego Mindstorm's EV3s before they were moved on to more complex systems. Lego Mindstorms is a Lego-based robotics platform geared toward beginners in manufacturing, wiring, or programming. The programming language of EV3s is a visual, block based code that is constructed by dragging blocks into processes to be executed. This makes the flow of the code very obvious and simple. However, despite being tailored for beginners, the EV3 platform is powerful and expandable.

To begin the process, time was allotted to become acquainted with the students and their ambitions. Using an intentionally informal setting, each group was asked to explain their motivation in joining the club as well as any projects they had in mind. The students were split into five groups of five and one group of six. Each group was assembled to have an even spread of skills, abilities, and personalities throughout. Once acquainted with the students, the technical lessons, activities, and workshops began. The objective was to understand the effective and ineffective points of our methods.

The technical lessons began with robot construction. The students constructed the basic robot as described in the kit instructions and **Appendix D**: Lego MindStorms EV3. This activity was used to give insight into who the inherent leaders of each group were and how the group functioned as a whole. At the same time as the robot construction, flash drives were passed around with the Lego Mindstorms software for students to install.

The day following the construction, the students were given a brief overview and demonstration of the Lego MindStorms software. This included a walkthrough of basic block functions, such as movement, program flow, and sensor blocks. There was then a demonstration given on how to write basic code to drive forward, to turn, and how to use loop blocks. This was done by creating the program in front of students using a projector, uploading the code to the robot, and running the program to observe its actions.

Once the beginning demonstration concluded, student teams were given a simple task, followed by progressively more difficult tasks to complete using their EV3s and the Mindstorms software. These lessons introduced many facets of robotics programming including program flow, functions, sensors, and sensor feedback loops utilizing proportional control algorithms. The lesson plan can be explored in detail in **Appendix E**: EV3 Lesson Plans. This lesson plan was continued until it was determined that the students were ready to move on and start their projects, with the understanding that they would be free to use the Lego kits if they so chose. The EV3 curriculum spanned a total of 3 days from construction to proportional line and wall following. Finally, an anonymous google survey was administered, which can be seen in **Appendix F**: EV3 Evaluation Survey**.** It contains questions pertaining to group work as well as the EV3 curriculum. The results of the survey are in **Appendix G**: EV3 Survey Responses.

After the students were done with the initial instruction, they began the project selection process. For a few days, the students researched potential projects. They began with many ideas, but had to filter out those that would be too difficult or require particularly specialized parts. During this phase, the students were guided to ensure that they did not commit to projects beyond their abilities and more importantly their time constraints. New projects or variations on what the students were considering were suggested to ensure they were within the aforementioned limitations. The students presented their ideas to the class, and were assisted in choosing a project that interested them and would be educationally beneficial. To help students organize their thoughts and requirements for a project, they were given an example of a project proposal to follow. This example is in **Appendix H**: Example Project Proposal**.**

In constructing our curriculum, hands on learning and experimentation were used in order to enhance the students' understanding of robotics and engineering. From speaking with students who have now graduated from the Harry Fultz Institute and in particular, graduates of the robotics club, it was discovered that the students' sense of autonomy is a very important aspect of their satisfaction in their education. The key to successfully implementing this autonomy was to have a balance of self-directed learning and guided instruction.

To balance the need for both instruction and autonomy, we structured our lessons in two parts. The first part of the lessons consisted of a more standard classroom style setting during which the developed material for the lessons was taught. Once the lesson plan had been run through, the students were given an assignment that extrapolated on the information taught. This allowed the students to casually experiment with the information that was just formally taught. This guided learning encouraged the students to explore the material hands-on and allowed them to delve into material outside of the lesson and better understand the concepts and processes.

Subsequently, in the project setting, the sense of autonomy was fostered more than in the guided learning. The students had increased opportunity to develop their own ideas, while they were still able to request guidance as necessary. The students in these six project groups internally decided their goals and methods of development regarding their robot, with some guidance as described in the next section.

3.3 Monitoring and Improvement of Soft Skills

Alongside education of technical skills, there was a need to ensure that the students were engaged and that they learned non-technical, or soft skills. Such soft skills included project management, communication, team interaction, and conflict resolution, many of which fall under the more well-known category of teamwork. Also, as the group projects progressed, steps were taken to keep students engaged in the material and the club in general.

Throughout the course of the club, various anonymous online surveys were distributed through email to be taken on students' own time. Online surveys meant that responses were obtained without the pressure of the other students and our group being there. This was done to both obtain more honest answers and to avoid taking up valuable interactive club time. A full compilation of these administered surveys can be found in the appendices. The first survey was administered after the EV3 Lego Kit section of our lesson plans had been completed. The second survey was given after the other technical lessons were complete. These surveys focused on the students' enjoyment and opinions of the material introduced, personal view on how their group worked, as well as their judgment of the teaching methods and execution. To clarify some feedback from the surveys, we also met with each group before the end of the project for a series of discussions which also informed us about students' ideas for the future and how they felt they improved after our efforts.

Along with this direct feedback, observation and communication with the groups were crucial and constant sources of information on the students' application and understanding of technical and soft skills. The use of observation and casual communication allowed the students to continue to work while their progress, or lack of it, was still able to be monitored. Through observation of the students' work, the problems they faced became clear. By staying attentive, these difficulties could be addressed to ensure efficiency as well as to maximize education.

Although efforts were made to prevent students from being hindered in their projects by unknown knowledge, learning through self-direction is an important and powerful tool. Thus, our overall monitoring and interaction with the club took a holistic approach. The students were helped with anything that we felt was unreasonable or uneconomical for them to learn on their own. By being ready to intervene only if deemed necessary, the students were allowed to retain a strong sense of autonomy and self-directed learning in their projects. Situations where assistance was needed were treated on a case by case basis due to their varying nature and unpredictability.

When there was an imbalance or disruption amongst a team, meetings were then held with solely that team to avoid any uncomfortable nature that may arise from meeting in front of their other peers. By asking questions regarding their team and using prior experience with teamwork, suggestions were then made to implement methods of solving the group's problems.

3.4 Expansion, Documentation, and Recommendations

One objective for the project was to explore the expansion of the robotics program, and to provide materials and recommendations for the future. Upon arrival, it was discovered that Professor Jaupi had already begun planning for future expansion of the club to include more schools and students. This preliminary plan was evaluated, challenges were identified, and recommendations were provided for ways of successfully managing the proposed expansion.

One of the main challenges the robotics club will face is a transition to a new professor. Professor Jaupi will likely be pursuing a PhD next year, which means that he will be not be able to lead the robotics program. A new professor will have to pick up where Professor Jaupi left off, and doing so while simultaneously managing more students and schools would be difficult. This transition is therefore an obstacle to expansion. This has been taken this into consideration while planning for the future of the club by providing longer term recommendations spanning the next few years.

To ensure a smooth transition between professors, the process of education and development this year has been documented in detail. Table 3.1 below shows the data that used to produce this documentation, the purpose of the data, and where the data can be found.

TABLE 3.1: SUMMARY OF DATA COLLECTED FOR DOCUMENTATION

Data Category	Description	Purpose of Data	Location of Data
Daily Journal	Notes on daily activities and observations of students.	To record the full schedule of what was done each day and to record observations of student interactions.	**Findings**
Lesson Plans	Detailed plans on what was taught to students and how it was taught.	To provide the next professor and IQP group with lessons that they can follow or modify as desired.	**Appendix E**: EV3 Lesson Plans **Appendix I**: Technical Lesson Plans
Improvised Solution Notes	Notes on how we addressed problems that came up over the course of the club	To provide the next group with solutions to these specific problems, as well as to give examples of how to improvise ways to deal with issues.	**Appendix L**: Improvised Solutions to Club Problems
Student Surveys	Surveys that asked for feedback on the club, the results of their group work, and the successes and challenges each group faced.	To understand students' opinions on the club and to provide recommendations regarding lessons and organization to better accommodate the students.	Results: **Findings, Appendix G**: EV3 Survey Responses, **Appendix J**: Interim Survey Survey Questions: **Appendix F**: EV3 Evaluation Survey, **Appendix J**: Interim Survey
Student Discussions	Group discussions with students to discuss their opinions on the club and their self-reported improvements due to the club.	To clarify survey responses and to receive deeper analysis of robotics club outcomes, including potential changes in attitude, self-efficacy, and autonomy.	Responses: **Findings** Discussion questions: **Appendix K**: Student Discussion Questions

4 Findings

4.1 Introduction with EV3

To introduce students to robotics and to get the groups working as teams, the club began with interactive lessons using the Lego Mindstorms EV3 robotics kits. These lessons also served to make the students feel more comfortable with asking us questions and talking to us in general. In addition, students that had little programming knowledge became less intimidated by it. We were worried that each group's programmer would take over, but several encouraged others to write code and learn instead, partly because they thought programming was below their level. The EV3s were good as an introduction because students could immediately see whether their code had worked and the mechanical parts were easy for them to assemble.

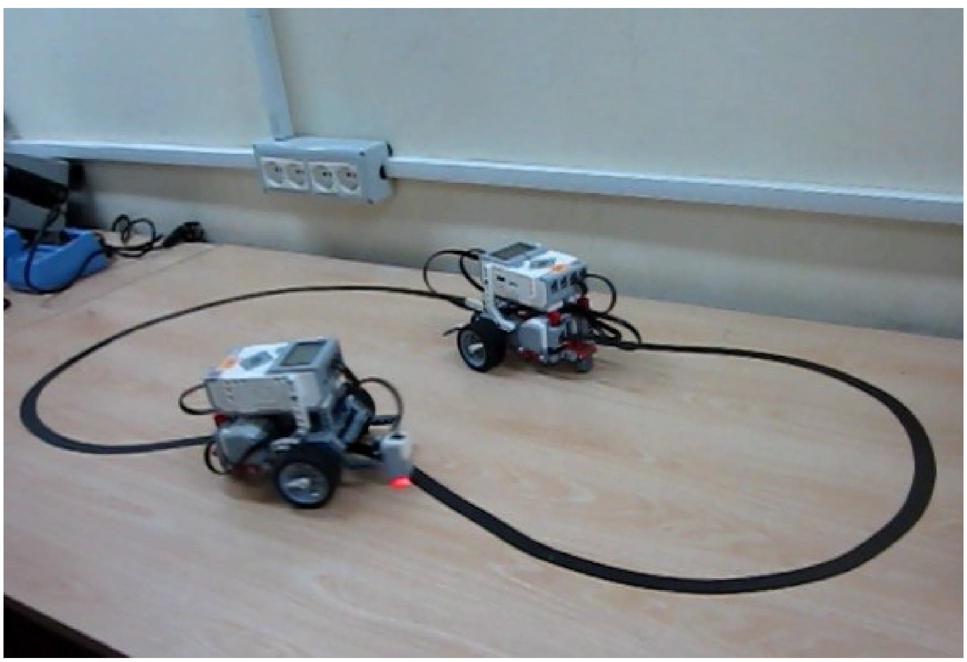

FIGURE 4.1: LEGO EV3 LINE FOLLOWING ROBOTS IN ACTION

The students completed a number of activities using the EV3s, including the one seen above where it uses a color sensor to follow a line. When the students were completing an activity on proportional control, we noticed that they were uncertain about what that meant and that it was making it difficult for them to finish the project. To fix this, we presented a more in-depth lesson specifically on proportional control. In order to find out more feedback from the students, we gave them an online survey about the EV3 lessons that is located in **Appendix F**: EV3 Evaluation Survey with responses in **Appendix G**: EV3 Survey Responses. They said that they liked how the EV3s allowed people to program without previous programming knowledge. One of the students mentioned that they thought the EV3s were a "great tool for beginners" and fun to work with. Another student said, “I am not a programmer and I don't like programming very much but I definitely liked Lego EV3,” which suggests success in one of our goals with the EV3 lessons: to make programming less intimidating to students. The survey responses showed that the EV3s functioned as an introduction as we anticipated. Students said that the EV3s were limited and they would not choose to use them for larger or more complex projects, but they were a good way “to get in the robotics world.”

4.2 Lessons

Over the course of the project, we developed a system for creating lessons. This resulted in an adaptable plan to help the students learn. The process that we used can be seen in Figure 4.2 below.

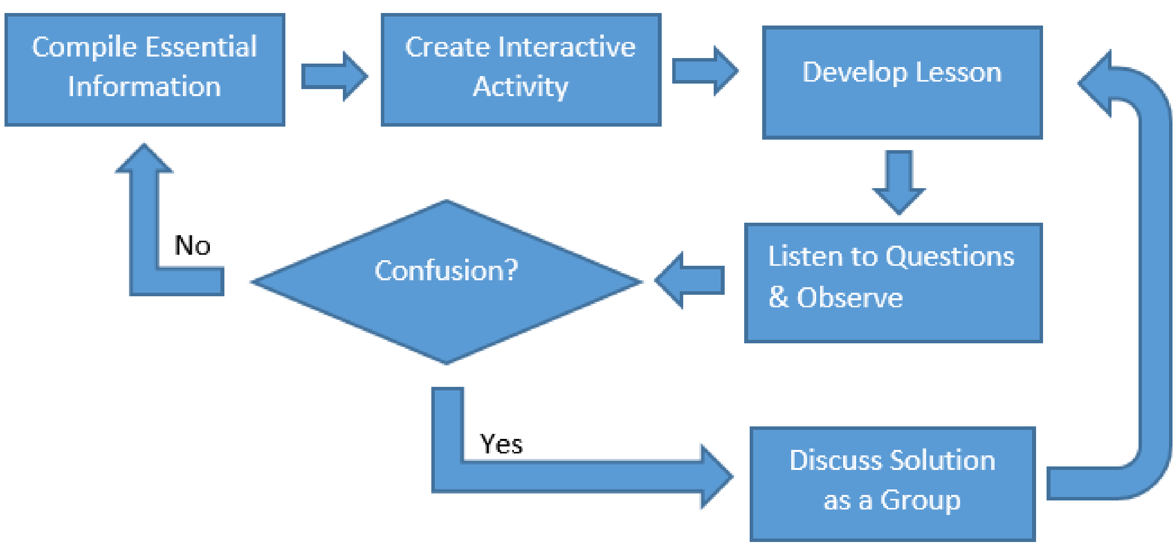

FIGURE 4.2: FLOWCHART OF THE PROCESS FOR DEVELOPING LESSONS

Feedback on these lessons was generally favorable. One student said that, "The explanation was very clear and easy to understand, even for the ones who had not much knowledge about things we learned." After reading student feedback on our second survey, we realized that we needed to talk slower and provide more examples for abstract concepts. Student also requested more math and physics in lessons to have a more solid understanding for independent project work.

4.2.1 Programming

When teaching programming lessons, we mistakenly tried to show the students many different things at once. The students became confused and overwhelmed by the breadth of the information. Professor Jaupi suggested that programming lessons should be broken down into smaller bits and then combined into a larger program later on. We took this into consideration for the lessons and started the next lesson from the ground up, writing all the code with the students. After the lessons were finished, most of the students improved in their programming abilities. Some students, however, did not improve significantly for a number of reasons. These include:

1. They were intimidated by the code writing process
2. There was limited time to learn
3. They felt that their group's designated programmer would handle it
4. They did not have a chance to practice on their own and they felt underprepared.

This list is comprised of responses from a survey given to the students as well as our own theories based on personal experience.

In addition to teaching the mechanics of programming, we also attempted to instill the value of programming etiquette. This included methods of making code easier for other people to read, including comments and good variable names. The students were receptive to this lesson and one student specifically indicated on their in-class survey that it was helpful. Students also mentioned that they liked the programming lessons in general, but requested more detailed lessons about Arduino and using the built in functions.

4.2.2 3D printing

FIGURE 4.3: THE 3D PRINTER IN THE ROBOTICS LAB

Upon the arrival of the 3D printer, both the students and Professor Jaupi were ecstatic. They all wanted to print their own models, play with printed objects, and just watch it print in general. This was partly because it was new to them, but it also allowed them to manufacture custom parts and parts that would take months to arrive in Albania because of customs delays. The next step was to guide this enthusiasm into their education on 3D printing. Initially, the students were intimidated by the apparent complexity of 3D printing. While the machine itself may have very precise and complicated movements, this does not correlate with the difficulty of its operation. This led to Professor Jaupi predicting a much longer and more complicated lesson on the topic than was needed.

The lessons covered two main sections, the first section was specifically about the 3D printer at the school and how students could print their designs. This section primarily included a walkthrough of an example print and settings that could be modified to change certain properties of the item produced. The secondary section of the lessons consisted of broader information regarding 3D printing, including different methods of printing, post processing prints, how to attach two prints together, and 3D modeling etiquette with regards to successful 3D prints.

The class, including Professor Jaupi, had a wide range of prior knowledge or experience with 3D printing. We conducted a survey asking about students' prior knowledge with 3D printing where the students rated their experience on a scale of 1 to 5, with 1 being no experience, and 5 being a large amount of experience. Figure 4.4 shows that there was an almost uniform distribution of ratings from 1 to 4, with only 1 student giving a 5. All the information taught in the 3D printing lessons had to take this into account by introducing everything at a very basic level. The survey also measured the students' interest in the lesson. Figure 4.5 shows more survey results and plots the students' helpfulness ratings on the Y axis against the students' enjoyment ratings on the X axis. The chart shows that the vast majority of the students enjoyed the lessons and thought they were helpful. This aligns with our goal to guide the students' natural fascination with 3D printing into a more concrete knowledge of its processes.

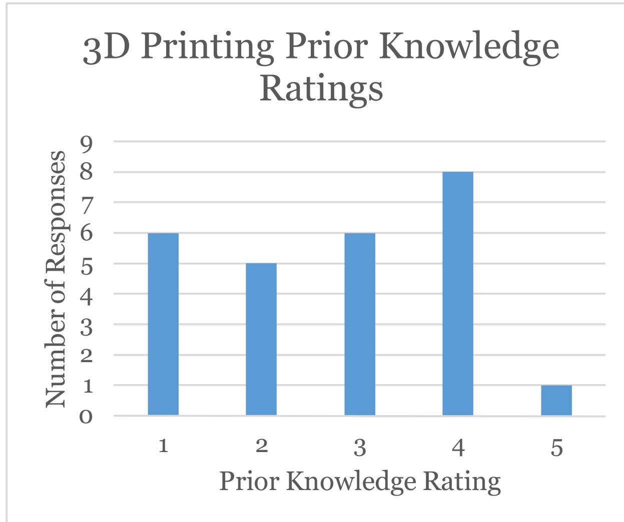

FIGURE 4.4: CHART OF RESPONSES FROM INTERIM SURVEY REGARDING THE STUDENTS' REPORTED PRIOR KNOWLEDGE OF 3D PRINTING

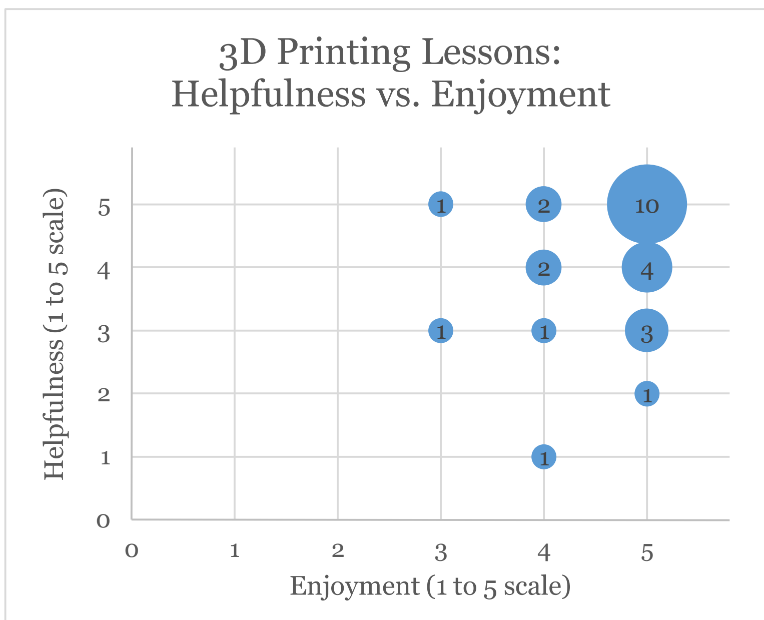

FIGURE 4.5: CHART OF INTERIM SURVEY RESPONSES, COMPARING HELPFULNESS AND ENJOYMENT RATINGS

4.2.3 Computer Aided Design (CAD)

The students were equally intrigued and intimidated by 3D modeling using CAD. Though there are many kinds of software, they all allow the user to create a 3-dimensional drawing that the printer can use to print. While they thought that it was a very powerful and useful tool, most lacked proficiency in any given software. It seemed about half of the students had been taught AutoCad, to varying degrees of success. Due to the balancing of the team, only one group had no experience with 3D modeling. Unfortunately, few students seemed to have access to any professional modeling software at home and did not seem very comfortable modeling on their own. Furthermore, only a few students had a laptop to bring to class, which limited the possibility of working on models during the club hours. Some groups would borrow a computer from a member of our team. Students enjoyed the introduction to SketchUp, which most of them are familiar with and already had on their computers. However, they were not as excited as with the demonstration of SolidWorks, which is a professional software that allows users to run simulations on their parts and has a better user interface than SketchUp. The students were greatly impressed and excited by the functionality of professional modeling software and were very receptive towards design techniques as well as using simulations for design validation.

4.2.4 Motors

We decided to present a lesson on DC motors because of issues that students had in their preliminary project work. They were trying to create an electrical schematic for their robot, but were unsure how the motors fit in. Further questions revealed that students were also unclear on how a DC motor works. Since DC motors are very common in robotics, we decided to create a lesson to make this concept clearer because we want the students to be self-sufficient when building their own projects. During and after our lesson on DC motors, it became clear that the students struggled much more with this lesson than others. Talking with Professor Jaupi revealed three issues: First, not all of the students had a basic knowledge of mechanical or electrical physics. Relating to the first issue, many students either did not know some terminology, or in some cases, only knew it in Albanian. The last issue, which was anticipated, was that the lesson was almost entirely theoretical and designed for college students. The combination of these issues proved difficult for the students, yet they persevered through the lesson regardless. Many seemed quite surprised at the intricacy of DC motors and how to use them. In the end, students reported that they found the lesson helpful and informative despite its complex nature. One student wrote in a survey, “the explanation of DC motors and how they work was very efficient even though I had some difficulties at the beginning.” In addition, figure 4.6 shows that almost all students rated the lesson above a 3 out of 5 for helpfulness regardless of their prior knowledge of DC motors. Based on this data, along with our observations, it seems the students may not have understood every aspect of the lesson, but were certainly more able to understand and analyze systems involving motors upon its completion.

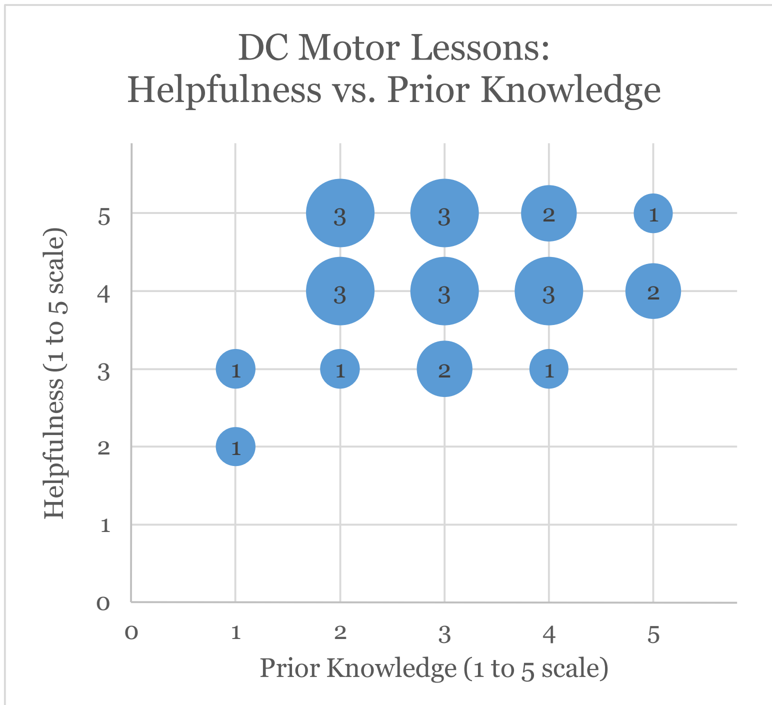

FIGURE 4.6: CHART SHOWING STUDENTS' RATINGS OF DC MOTOR LESSON'S HELPFULNESS COMPARED TO THEIR PRIOR KNOWLEDGE

4.3 Project Selection

During the project selection phase, students researched potential projects in order to choose the one that they would work on. We discovered that many of the students’ groups already had clear project ideas in mind. In particular, two groups wanted to make a combined project where one team would make a rover and the other group would make a drone that could carry the rover, with the intention for it to be used for dangerous situations like fire rescue. While this project was exciting, it was too ambitious for the limited time and resources given, and the knowledge required to implement it would have been much more than the students could have learned in the club. To encourage the students to maintain that ambition but recognize these constraints, we suggested that they try to make both projects this year and then attempt to combine them next year. The students accepted that their idea might be too ambitious and decided to focus on making their projects work individually. We then talked to each group about their project and helped them work out the details. They seemed to recover their enthusiasm after this.

Another example of our attempts to keep project scope manageable was with the group that wanted to make their own self-balancing two-wheeled vehicle, similar to the Segway. With this project, to make such a vehicle that a person could ride, the school would need more powerful motors and large wheels, which would be difficult to procure. At first, they wanted to make a smaller version that could be remote controlled, but eventually, they decided to make a jumping, two-wheeled robot instead. In this case, the project change made the project both more feasible, and also more fun, since the students were more excited to see a robot drive fast and jump.

While these groups had clear ideas in mind, other groups had less of an idea of the direction they wanted to go in for project selection. In order to help them find ideas, these students were given some example project ideas and pointed to popular sites for do-it-yourself projects such as Instructables and Thingiverse. As a result, some of these groups chose project ideas directly from these sites.

4.4 Project Planning and Design

The project planning and design phase demonstrated the need for structure as well as communication. We asked the students to submit short project proposals to help them think through their project as well as keep us informed of their intentions. While three of the teams completed this task successfully, the remaining three did not submit a proposal for various reasons. In one case, the team was following an online guide which already outlined their project. Another group, building a rover, had a project that continually changed shape as different issues and ideas arose. The team had many ideas from wheels to tracks to even legs. Similarly, they struggled to decide whether they wanted a camera or to use sensors to autonomously find the fire. As such, the additional work would have been a burden to an already stressed team. The last team, who intended to make a robotic hand, seemed to have some quarrels implying a potential lack of continuity among the team. It appears that they have worked those out amongst themselves and are continuing their project as planned.

Once teams had decided on their projects, we attempted to monitor the teams by talking with them regularly and working with them to develop their designs. This proved difficult for two main reasons. First, students did not know what design around due to the club's lack of parts and the students' lack of experience robotics. Second, students did not have a strong, structured method of communication with us outside of the club. The combination of these made it difficult for students to progress in their designs and limited our perspective of it as well.

4.5 Project Implementation

In our original plan, project implementation was supposed to begin two weeks into the club once the parts arrived. Despite most of the parts being ordered in July, they did not arrive until the penultimate week of the project. As a result, we were only present for the physical construction of the robots using 3D printed parts, but not for the electrical construction, programming, and testing phases. By the time we left, the projects were progressing well with the groups assembling, programming, and wiring their robots, but to make sure the projects are completed, we provided additional methods for the students to communicate with us including our emails and through our Facebook accounts. We also set up a Facebook group allowing the current, past, and future club students communicate with each other as well as any WPI students who are willing to help from afar.

5 Conclusions

We had varying success with our approaches to student learning. We can confirm that using self-directed research helped students learn. As one student said, they "read random stuff and learned in the process." This shows that the WPI team does not need to pass on the entirety of their knowledge; instead the students have enough motivation to do comprehensive research on their own. We originally wanted to pass along the group skills that we have acquired. We were more successful with our goal of using self-directed learning than our goal of making the students more comfortable with group work.

Students became more comfortable with group work as the term progressed. They did not necessarily become better at it, however. One student said, “We don’t think we progressed in group collaboration, but I could do more things on my own.” We decided to have the students learn about group work by simply being in a group because we did not want to run out of time to teach the necessary robotics skills. This turned out to be unnecessary because there was a block of time where we were waiting for parts that we expected to have already arrived. If this is a skill that the next team wants to focus on, then some lesson time should be set aside to teach students about working effectively as a group.

The students really enjoyed the hands-on learning and our general approach to lessons. The emphasis on projects that support the lecture material made lessons more engaging and interesting. One of the students said that we "explained well the intersection between theory and practice." This seems to be a result of our lesson structure that consists of short lecture portions interspersed with hands-on activities. The students would benefit from lessons that connect together to build a larger, more complex project that is directly related to a complete robot. This includes the code that a robot might use, as well as CAD for the structure and a schematic for the electrical circuits. Leading them through the entire process in the beginning of the club would give them the ability and confidence to do it on their own, as well as make them aware of project feasibility and manufacturing limitations.

The students' English is good, but the language barrier is still present. Professor Jaupi sometimes translated our lectures into Albanian for the students. It was difficult for us to tell how effective these translated lectures were because of the language barrier, but we suspected that some information was being lost. In the end, students reported that our lessons were very understandable and often did not need translation.

The students are very ambitious and while we attempted to manage it, there were still some problems with project scope. We believe that we managed to find a way to make the projects more reasonable without dampening student enthusiasm. Student enthusiasm waned, however, because of the delay in parts. The greatest impediment to the club is receiving parts. If we had known the parts would take so long to get here, we would have structured our classes differently, instead of trying to teach so much at once. We did an overview of all robotics related topics when we could have focused more in-depth.

During the course of our project, we paid special attention to the female students because it was mentioned in last year's report. We were relieved to note that there did not seem to be a gender divide in the groups. There were fewer females because the gender ratio in the school is not balanced, but they did not appear to be as shy or quiet as we were led to expect. In fact, the number of female students that reached out to us through methods like email and Facebook was approximately equal to the number of male students. The gender balance did not turn out to be a problem in this respect, but we discovered more nuance during our interview with the students at the end of our project. Some students believed that accepting all of the girls who applied led to a decrease in standards of work because only the best male applicants were selected for the club. We explained that there is a balance that has to be found between accepting all female students and finding the ones that may not have had much privilege when it comes to engineering, but are committed to learning.

6 Future Plans and Recommendations

Through day to day communication with Professor Jaupi, he made evident his plans for the future of the club. Professor Jaupi's idea was to have the Harry Fultz Institute function as a hub for robotics education in Tirana, continuing to run the club at the school but also running a second club for students from various schools in the area. In accordance, Professor Jaupi was interested in having a second WPI IQP team work with this other club. This is an interesting idea for the future of the club, however it is too early to have this much rapid expansion. The club is still working through logistical problems such as work space and more importantly, acquisition of parts. On top of this, next year the club will be under new leadership. We believe that this growth would be better suited further down the road.

We suggest that next year be used as a transition year. The new head of the club will have a lot to do simply getting settled in and learning all of the logistics behind the club that it may be too much to handle to try to make great changes. Therefore, we suggest that the club remain very similar to this past year, with various changes to improve the inner workings, productivity, and learning.

During a conversation with students that participated in the club last year, we asked them for a comparison of the two years. They said that they had more space to work, which is probably a result of there being 32 students this year rather than 24. In addition, they said that the club lacked structure and that the organization "was a bit messy." This may be largely attributed to the fact that we are also students and do not have much practice teaching. It may partially be that we did not have much to build on from last year's project and we were trying to cover significantly more information. Lastly, the uncertainty regarding when parts would arrive made concrete planning difficult.

We worked with the Harry Fultz students to develop a plan for next year that would satisfy all of these requests for improvement. A change that would solve several of these problems is reducing the number of participants in the club back to 24 students. We understand that the number of students selected to participate was increased due to a large applicant pool, but this made it difficult to ensure a quality learning experience. In this plan, there would be 8 groups of 3 students each due to experience in WPI classes showing 3 students to be ideal for robotics projects. Each WPI student would mentor 2 teams, acting as a liaison between the students and the professor. They would be responsible for knowing the detail of their group's projects as well as keeping the professor and other WPI students up to date. The students and professor would discuss every group in order to ensure diverse perspectives.

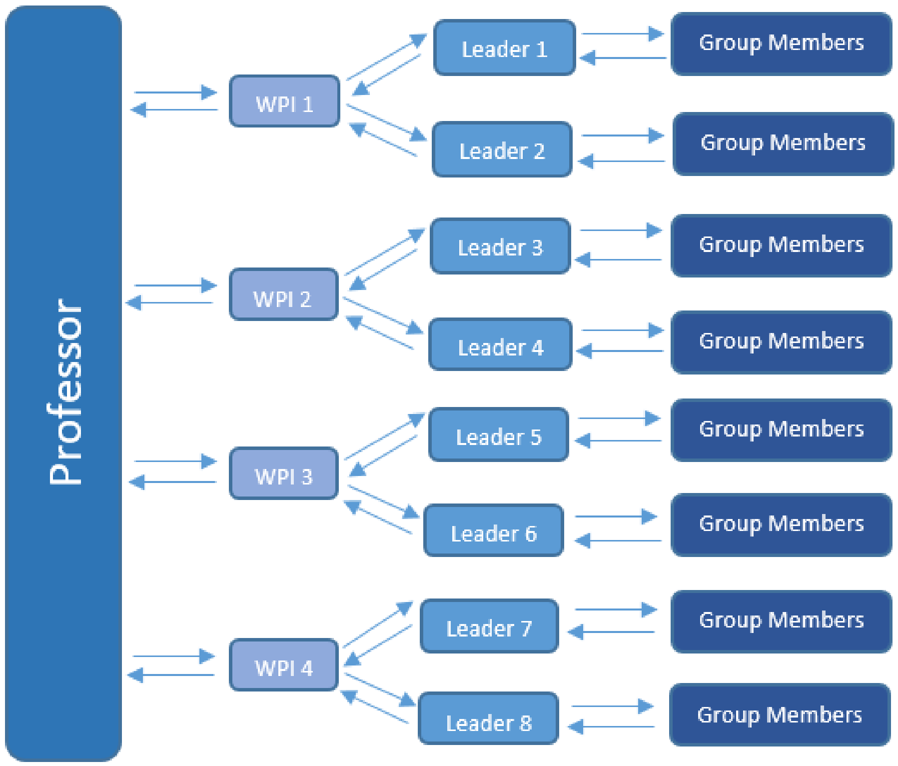

FIGURE 6.1: CHART DEPICTING A POTENTIAL SYSTEM FOR ADVISING STUDENTS

As we see it, the club's activities next year can have two different systems. One would involve continuing much like this past year with each group building a different robotics project. The continuation of the club's activities as they are this year would consist of some modifications to improve the difficulties we encountered. The biggest problem faced was the incredibly long delivery time of parts. Professor Jaupi ordered the parts in July and they did not arrive until December 10th. Pre-selecting the projects would allow the parts to be ordered even earlier. We also suggest that the orders be split up into smaller orders to decrease delays.

The other potential plan for club activities is to implement a competition amongst the students. Students said that they like the idea of a competition at the end between all the student groups. One student said that this would be a good idea because "competition inspires innovation." Due to this, we decided that Savage Soccer, which was designed to be a low-cost, small scale robotics competition, would be a good program to use in the club. This would allow students to be directed in their robot building by having an already specified problem to solve, while still giving them the freedom to determine how to solve it. Further information about Savage Soccer can be found in **Appendix C**: Savage Soccer.

In addition to these organizational recommendations, we have some general suggestions to ensure smooth operation of the club next year. Our first recommendation, which we will start implementing this year, is a Facebook group for the club. We believe this will help encourage communication and provide continuity to subsequent project teams, since prior WPI and Harry Fultz students could remain in the group to provide help to future participants. If other WPI students want to help, we could also invite them to join the group and answer questions. We think this support network would be beneficial to the Harry Fultz students.

We also recommend documenting and recording anything that would be helpful for subsequent years, as we have attempted to do so this project. Continuity and longevity is important with this robotics club, so any materials that can be reused will be helpful for the future. In addition, any information about the workings of the club or how lessons were developed and evaluated would assist future teams in running the robotics club.

Our final recommendation pertains to the use of Lego EV3 kits. We brought the kits with the intention of using them as an introduction to robotics and, if they were useful, sell them to the Harry Fultz Institute. Despite the usefulness of the kits this year, the school was not able to buy them for legal reasons. Therefore, we suggest that either WPI students bring the kits again next year or that Harry Fultz Institute buy kits through their own means.

Furthermore, we suggest creating a short course using the EV3s that lasts 1 to 2 weeks to get students comfortable with robotics before participating in the club.Students stated that they while they enjoyed the EV3's, they believed they were better suited for a lower-level introduction to robotics, separate from the club. They were disheartened by what they saw as a necessary limit to the number students that could participate in the 7 week projects and this would allow more students to be included. Students were also concerned that there was no way to know that the students committing to the 7 week projects were knowledgeable or dedicated enough and the course would allow students to learn skills that help them in being a productive member of a team. This would help with selecting students for the full robotics club. Other benefits of an introductory EV3 course are that it would be easily run by a professor with minimal training or practice, executable without WPI student presence and have no recurring costs of operation.

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8 Appendices

Appendix A: Project Schedule

Table 8.1: Calendar of Project Activities

	Monday	Tuesday	Wednesday	Thursday	Friday
Week 1 Oct. 27 – 30		Introduction, talked to students about project ideas and why they joined the club	*Worked on lesson plans, completed EV3 build for our demos	Students built the EV3s. It took longer than planned; about 1 1/2 hours	Taught code. Projected onto screen and explained block functions. Students drew square and followed lines
Week 2 Nov. 2 – 6	Clarifying lecture on proportional control. Students rewrote line follower and wrote wall follower	Showed students potential projects and talked to them about ideas. Explained surveys	*Planned lessons, made student alias, decided how to change background chapter	*Divided up background chapter and began making edits.	Discussed things that may be difficult with students. Met with Jaupi and advisors
Week 3 Nov. 9 – 13	Students presented physical models and plans for their projects	Showed the students how to interface with a 3D printer and explained some terms	3D printer arrived, finished revising background section	Put printer together and ensured we could get it to function	Showed students the range of things that can be printed and the printers limitations
Week 4 Nov. 16 –20	documented what they have and have not done, including CAD and electrical schematics	Student PowerPoint presentations including all finished materials	Revised Intro and Methods due	Show students SketchUp and SolidWorks, explain common CAD practices	Begin teaching Arduino, good practice, basic programming knowledge. Started explaining motors
Week 5 Nov. 23 –27	3D printer lesson/simplified motor lesson led by Professor Jaupi	Arduino Lesson controlling LED with potentiometer	Thanksgiving	Thanksgiving	Thanksgiving
Week 6 Nov. 30 – Dec. 4	Holiday- No Robotics (wrote outline for preliminary findings	Gave survey on lesson feedback	Preliminary Findings, Conclusion, Recommend -ations due	Tested 3D Printed Propeller, *Exploded Propeller*	Students tried doing LED project on their own
Week 7 Dec. 7 – 11	Scheduled meetings with students, tried to fix 3D printer	3D printed a new propeller mold, interviewed students	Worked on report draft, 3D printed parts for student projects	Work on Abstract, Executive Summary and Presentation	Abstract and Executive Summary Due
Week 8 Dec. 14 – 18	Presentation Rehearsals	Final Presentations	Final Draft Due	Submit report online	Farewell Gathering

Figure 8.2 is a Gantt-style chart depicting our proposed project schedule

Task	Duration	Start	End	26-Oct	2-Nov	9-Nov	16-Nov	23-Nov	30-Nov	7-Dec	14-Dec	19-Dec
Preparatory Research	3 Days	26-Oct	28-Oct									
Technical Training	2 Days	29-Oct	30-Oct									
Team Training	2 Days	2-Nov	3-Nov									
Project Selection	6 Days	4-Nov	9-Nov									
Student Work on Projects	24 Days	10-Nov	3-Dec									
Student Presentations	1 Day	4-Dec	4-Dec									
Club Assessment	6 Days	7-Dec	12-Dec									
Final Documentation Preparation	7 Days	12-Dec	18-Dec									

TABLE 8.2: PROPOSED PROJECT SCHEDULE GANTT CHART

Figure 8.3 is a Gantt-style chart depicting our actual project schedule

Task	Duration	Start	End	26-Oct	2-Nov	9-Nov	16-Nov	23-Nov	30-Nov	7-Dec	14-Dec	19-Dec
Initial Preparation	2 Days	27-Oct	28-Oct									
Lego EV3 Introduction	3 Days	29-Oct	2-Nov									
Project Selection	4 Days	3-Nov	6-Nov									
Project Preparation	26 Days	9-Nov	4-Dec									
Project Implementation	Indefinite	4-Dec	N/A									
Club Assessment	3 Days	7-Dec	9-Dec									
Final Documentation Preparation	10 Days	9-Dec	17-Dec									

TABLE 8.3: ACTUAL PROJECT SCHEDULE GANTT CHART

Appendix B: Learning Outcomes

Arduino Programming

Learning Outcome Statement

Students will be able to read, understand, write, and test the Arduino C programming language.

Description

Recently, Arduino programmable microcontrollers for robotics projects have become ubiquitous. As a powerful, low cost option, being able to program such devices is extremely advantageous. Computer programming acts as a vehicle to allow students to understand the thought process of robots and computers. Programming skills are highly valued due to society's dependence on computers and other programmable devices. The ability to program also hones students' minds to be able to think in the same way as a computer in order to gain perspective on the world.

Project Presentation

Learning Outcome Statement

Students will improve and develop their presentation design and delivery skills in order to be able to effectively communicate their projects and ideas.

Description

Presentations are an extremely important tool for garnering interest about projects, communicating information and findings, and organizing previous work into concise and coherent compositions. These skills will be refined and tested by having students create and deliver presentations about their projects as they develop.

Group Project Organization

Learning Outcome Statement

Students will be able to work in teams with at least 4 other members and coordinate the framework of a group project.

Description

Students must gain experience working with others toward a common goal as individuals cannot complete large, multi-faceted projects as effectively. Student must learn how to progress when there are disagreements, divide work, and remain on schedule while retaining a positive environment.

3D modeling

Learning Outcome Statement

Students will be able to accurately model their projects using a 3D modeling software of their choosing.

Description

3D modeling is a fundamental tool used in industry because it allows the most in-depth planning of a project possible without any material or parts cost. The ability to 3D model allows students to see where their design will and will not work while allowing them to make changes and fix mistakes without any construction or purchasing of components. In addition, 3D models are an excellent way to communicate complex ideas.

3D printing

Learning Outcome Statement

Students will be able to design parts optimized for 3D printing in order to reliably and effectively 3D print components with minimal waste.

Description

Because shipping parts to Albania is problematic, students need to be able to 3D print well because it may be the only reasonable way to acquire the necessary parts. Similarly, the limited ability to buy more material for the printer necessitates fewer failed prints and designing to use as little material as necessary.

Appendix C: Savage Soccer

"Savage Soccer is a robotics program that can be used and adapted by schools and groups to help their students learn more about engineering, design, and robotics through fun competition. Savage Soccer began as a team-building activity for the WPI/Mass Academy *FIRST* Robotics team in 1995 and has since grown to be a national competition with events at several sites throughout the country.

One of the goals of Savage Soccer is to keep events affordable for both participating teams and those running the event. Anyone with a VEX kit can compete and event registration fees range from free to $50 per team.

Each year, WPI students work to develop a new game for the Savage Soccer competitors and organize a large tournament on campus. Several other venues around the country use that or previous s game to run a tournament in their local area. The event uses the same basic field structure year-to-year with new challenges and game pieces that can be created inexpensively" (Savage Soccer: Welcome, n.d.).

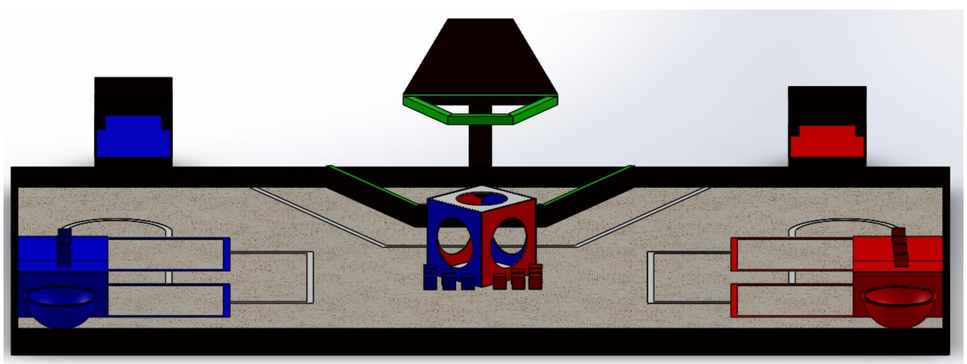

FIGURE 8.1: SAVAGE SOCCER 2015: FOAM FRENZY (SAVAGE SOCCER: WELCOME, N.D.).

Appendix D: Lego MindStorms EV3

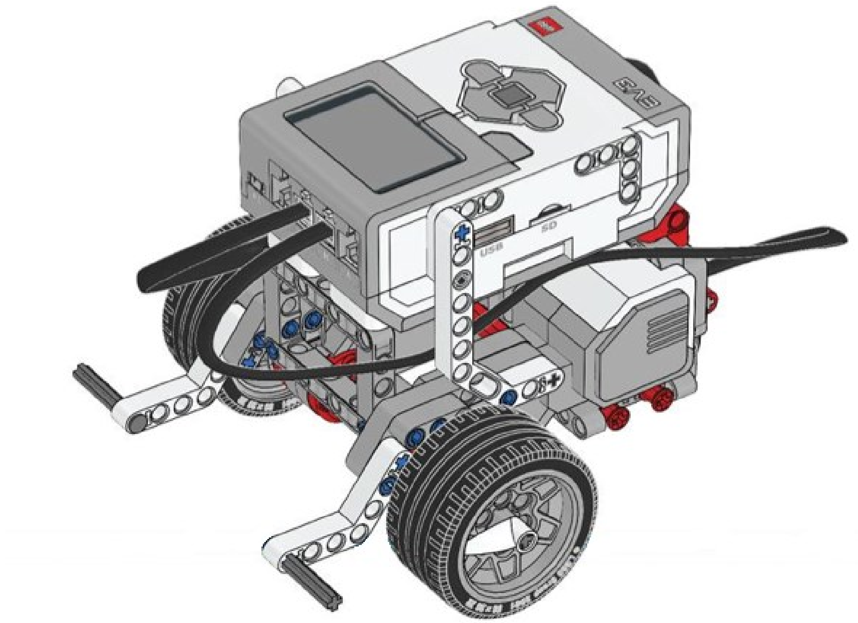

FIGURE 8.2: LEGO EV3 BASE ROBOT WITHOUT SENSORS (EV3 BASIC ROBOT [IMAGE], N.D.)

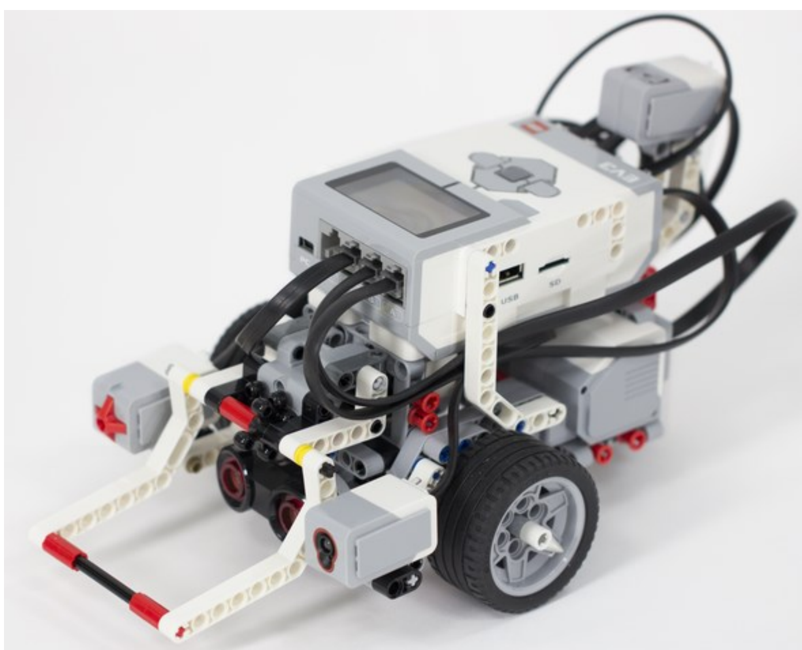

FIGURE 8.3: LEGO EV3 BASIC ROBOT WITH SENSORS ATTACHED (UNTITLED PHOTOGRAPH OF LEGO EV3 ROBOT [IMAGE], N.D.)

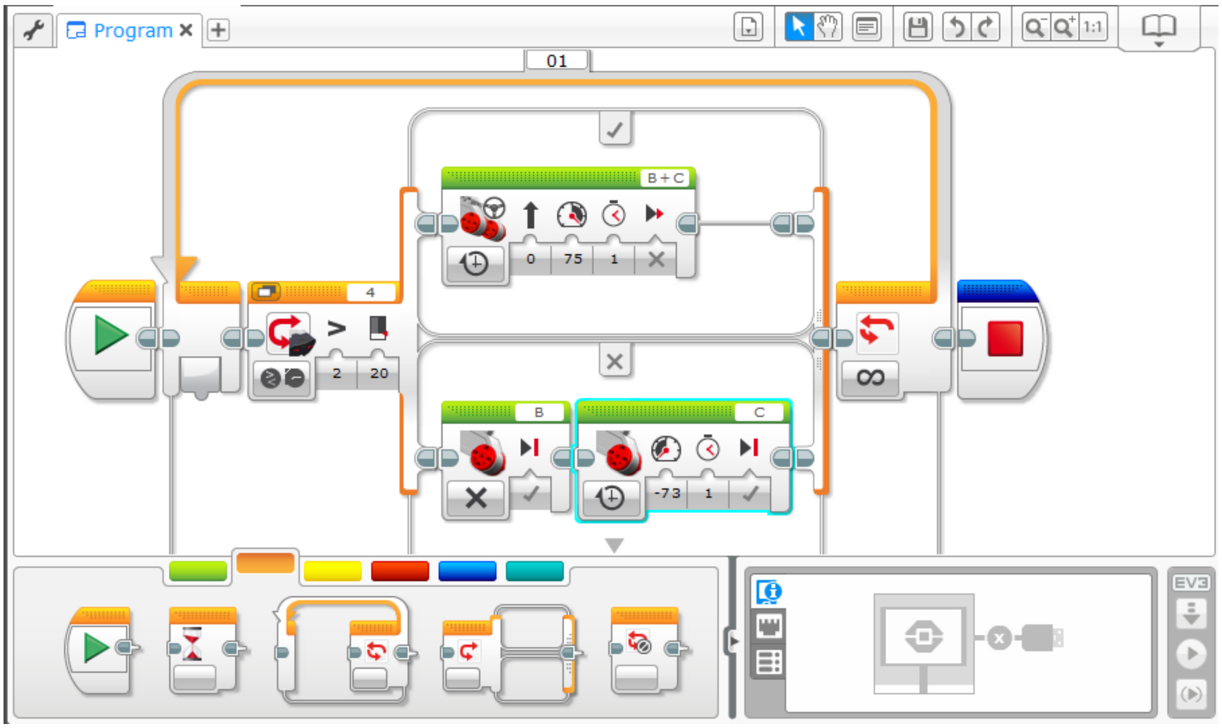

FIGURE 8.4: LEGO MINDSTORMS PROGRAMMING USER INTERFACE (UNTITLED SCREENSHOT OF LEGO MINDSTORMS SOFTWARE [IMAGE], N.D.)

Appendix E: EV3 Lesson Plans

Programming Lesson Plan Using Lego Mindstorms EV3:
Each consecutive task is presented to each team as the previous is completed. At decided points, teams can be told to skip the higher-difficulty tasks so that progress can be controlled. Lectures to entire class or select teams may be desired at points (such as to explain proportional control conceptually).

1. **Basic Commands**
    a. Drive forward for 1 second
    b. Drive forward for 270 degrees of wheel rotation
    c. Turn 90 degrees
2. **Program-Flow**
    a. Draw a 12" square
    b. Draw a 12" Circle
3. **Sensor Incorporation**
    a. Follow a line (electrical tape) using:
        i. One color sensor
        ii. One light sensor using proportional control
        iii. Two light sensors using averaged proportional control (Now make it faster)
        iv. One or two sensors while saying any color seen
        v. Any previous configuration, follow the line backward
    b. Use the ultrasonic sensor to:
        i. Stop exactly 12 inches from a wall
        ii. Use proportional control to stay exactly 12 inches from the a hand
        iii. Follow along a wall while staying 12 inches away
4. **Advanced Projects**
    a. Make a robot that:
        i. Navigates a color maze (requires color maze)
        ii. Follow a line while playing notes corresponding to colors seen
        iii. Remotely controls another robot
        iv. Mirrors the movements of another
        v. Can be taught to follow a path by pushing it along that path
        vi. Actively pursues any target within a two foot radius
        vii. Determine the maximum RPM of the motors
        viii. Determine the maximum number of times code can loop each second

Appendix F: EV3 Evaluation Survey

Lego Project Evaluation

We will not know who submitted which response. Only the WPI Team and Professor Jaupi will see responses.

What is the name of your group leader?*
This is so we know which responses are from the same group. If you are the group leader, put your own name.

What did you like about working with the Lego EV3s?

What didn't you like about working with the Lego EV3s?

Was there enough work to keep everyone busy?

What about your group worked well?

What about your group didn't work as well?

Would you have preferred more explanation or more experimentation?

Would you want to use the EV3s on your own after we (The WPI Students) leave?

Appendix G: EV3 Survey Responses

What did you like about working with the Lego EV3s?

- Lego EV3 was very practical and interesting.
- The first thing I liked was the programming part, because it was not needed to write every instruction, just drag and drop blocks.
- The second thing was building the robot, entertaining but a little bit complicated.
- The third thing was the interface between any user and the robot kit. Even if any user doesn't know any programming language it is relatively easy to control the robot.
- I liked Lego EV3 very much. I was entertained and I learned very useful things. It was not very difficult. I am not a programmer and I don't like programming very much but I definitely liked Lego EV3.
- It was an easy and beautiful project. I worked with my group. I learned a lot from him and from the American staff.
- They were entertaining and fun and a cool way "to get in the robotics world".
- When we used Lego EV3 we understand the concept of what we were doing. So we learn how to do something for less than one hour which would be very difficult with Arduino.
- Simplicity in programming.
- It was really helpful trying to figure out how to perform different tasks. A great learning tool for beginners.
- I liked a lot of things about the Lego EV3s. My favorite was the EV3 controller, it was so powerful and so easy to use at the same time. Furthermore, using the Legos you could build a lot of stuff at a small amount of time.
- The combination of engineering and software problems and solutions help us develop problem-solving skills.
- EV3 with Lego like for fun but not to work

What didn't you like about working with the Lego EV3s?

- The programming part had also some difficulties, because when I wanted the robot to do many tasks at the same time more programming blocks were needed and also many formulas to write.
- I liked all of it except the weight. For some projects it can't be used because it's very heavy.
- Nothing. Everything was well thought.
- I didn't like the limitation of Lego EV3.
- The interface could be better, not something to worry much about though.
- Nothing, the Lego EV3 was awesome and really taught us much about how to implement the robot's logic to perform different tasks.
- I didn't like the motors, they were sloppy and not so good for building powerful and heavy robots. Another thing that I didn't like was the programming language, even though you could code with GUI this kind of programming wasn't sufficient for decent project.
- Nothing
- It is a module which does not have a lot of work is very simple electronic

Was there enough work to keep everyone busy?

- Work is never enough but since we worked with the robot for around two weeks and there are 5 or 6 members per group the work was finished earlier than within two weeks.
- So in the last days many of us (the group members) were experimenting with multitasking of the robot.
- Yes, there was enough work to keep everyone busy.
- Yes. Everyone worked a little bit
- Yes. Although at first it seemed like something easy, actually it wasn't that easy
- Yes, it was. Me with one other guy were working on "programming" part and others were busy with construction part.
- Yes, there is enough work for each member of the group to do.

- Yes, everyone tried himself how to operate the Lego EV3 robot to follow the line or perform other duties. Well, based on the project start date, that was about two weeks ago, I think the work rate was satisfactorily.
- In fact, there wasn't enough but our team decided that everyone will do something with Lego EV3 even it will be a small work.
- Yes

What about your group worked well?

- Since we finished the building of robot in the first week, our group was coordinated and we collaborated with each other.
- Building the first robot with Lego EV3 that follows the black line and stops when it has an obstacle was a very good experience for our group. We were all working, we learned new things, everything went perfect and we had a good time.
- WE WERE THE BEST! Because according to me we completed the whole Lego project with all the elements. (in comparison with others)
- Following the path, color detecting.
- Our communication and simplicity was the main reason for the good work.
- The group is working really well, things at the moment are flowing and we understand our duties.
- There weren't any misunderstandings, everyone compromised with each other and worked together like a team.
- We managed to find a good group spirit and we are all focused making our goals happen.
- Our team was the fastest one about the engineering problems
- We have worked well

What about your group didn't work as well?

- At first was difficult to coordinate but only at the beginning. Now we all have our tasks.
- It's not our case.
- Taking strong turns.
- When you use something for the first time you need time to take control.

- Except the first day everything was all right.
- Nothing so far
- I can't think of anything.
- We had some difficulties sharing the work equally to all our groups members.

Would you have preferred more explanation or more experimentation?

- Even though the explanation and experimentation were made it was a bit hard for me to understand everything because sometimes the class got messy, and I couldn't hear.
- No, everything was clear.
- No, there were enough.
- Everything was great. I wouldn't complain about anything. The students have been not only helpful, but also friendly and communicative.
- Yeah, more experimentation means more knowledge, and I am a big fun of learning more :D
- Some explanation in programming here and there, maybe later when the robot coding will begin.
- Maybe some more experimentation would give us a clearer idea of what we would like our robot to do.
- I think that it will be best if we had some C language learning classes.
- No the WPI team was there in every single minute when we wanted help or needed explanations.
- were enough

Would you want to use the EV3s on your own after we (The WPI Students) leave?

- Why not, EV3 was generally easy to use and you can do a lot interesting and beautiful of things with it.
- I don't know. Maybe if we decide to do another project on our own after the Robotics Club finishes, EV3 could help us a lot and we may use it.
- Maybe.

- Yes, I would because I find it as an entertaining way to learn more about programming, building stuff and robotics.
- Actually I do. It was fun to use it so far so why not? :D
- Maybe.
- Yea if i am given the chance because it boosts you analytical and logical abilities and keeps you busy trying to figure out how to carry out different tasks.
- Yes, I think that it will a good resource for our school and a good modeling reference point to design our first prototype models.
- Yes .... it was fun.
- I say no

Appendix H: Example Project Proposal

Team Name: Dajti

Project Description: A robot that follows a line and turns right if it sees green tape and left if it sees blue tape. If it sees an obstacle in front of it, it stops and waits for the obstacle to be removed, then continues. If the robot sees red tape, it has reached the end of the course and plays victory music while driving in a 20 cm circle and waving a flag.

Purpose: This robot will be a concept proof for cars that can park themselves in parking garages. The garage would have lines laid out and a central computer would control where the car drives by changing the color of the line. The use of a flag and speaker will be examples of how the system can be expanded. A speaker might be used to say that an obstacle has been detected or that the car has successfully parked. The servo might be used to open the doors or the trunk of the car once parked.

Sensors Required:

- 1 x Ultrasonic Rangefinder (To detect any obstacles in front of the robot)
- 2 x Color/Line Sensor (To detect and follow both sides of the line)
- 2 x Motor Encoders (To know how far each wheel has turned for the circle)
- 1 x robot microcontroller (robot control)
- 1 x Speaker and Audio Driver (to play victory music and announce actions)

Actuators Required:

- 2 x Motors (To drive the robot around)
- 1 x Servomotor (To wave the flag)

Building Materials:

- Two wheels and a caster, or 3-4 wheels
- Robot Chassis (3d Printed)

Priorities/Mile-Stones:

1. Have a robot that moves effectively
2. Line Follow using both sensors
3. Detect and stop for obstacles
4. Detect and follow turns based on color
5. Use the speaker to announce completion
6. Wave the flag on completion

Biggest Obstacle: How to save audio files and play them through a speaker and audio driver. Memory might limit how many things the robot can say.

Estimated Schedule:

Week 1: Figure out which sensors and motors to use, design chassis, create Bill of Materials

Week 2: Order any necessary parts and build the chassis. Split up into two teams, one team builds the drive base of the robot. The other tests and codes the line sensors.

Week 3: Two teams again, one tests and codes the motors and encoders for driving in straight lines and perfect circles. The other team tests and codes the object detection sensors.

Week 4: Finish priorities 1 through 4 and begin work on 5 and 6. Split into two teams to work on speaker and servo code.

Week 5: Continue working on speaker code.

Week 6: Finish project, refine code for speed and accuracy. Document project.

Appendix I: Technical Lesson Plans

Programming Lesson Plan

Datatypes:

- boolean
  - true
  - false
- int
  - integers
  - ex. -1, 2, 0, 3615
- Other stuff you might use, but probably won't
  - char
  - byte
  - unsigned int
  - String

Example of Variable declaration and Initialization:

int **number** = 7;

datatype of variable   name of variable   assignment operator

value initialized to variable   semicolon to end statement

Example of a Function:

```
 int myMultiplyFunction(int num1, int num2){
return  num1 * num2;
}
Void loop(){
int num1 = 4;
int num2 = 6;
int answer;
answer = myMultiplyFunction(num1, num2); // answer equals 24
}
```

Data type of input (parameters)

Parameter names   Data type of output

Function name   Curly braces around function

*The data type "void" is used if nothing is returned

Setup Example:

```
void setup(){
   Serial.begin(9600);
  pinMode(ledPin, OUTPUT);
  pinMode(sensorPin, INPUT);
 }
//required at the beginning of every Arduino program
```

Reading and Writing to Pins:

1. Analog pins vs. Digital pins:
   Digital pins can only be set to 0 or 1, while analog pins can be a range of values
2. **DigitalRead** says if pin is HIGH or LOW and stores it
   example: value = digitalRead(inputPin);
3. **DigitalWrite** sets pin to either HIGH or LOW
   example: digitalWrite(ledPin, HIGH);
4. **AnalogRead** stores a value between 0 and 1023

example: value = analogRead(analogPin);

5. **AnalogWrite** sets pin to value between 0 and 255
   example: analogWrite(ledPin, value);

Good Programming Practices:

We taught students about programming techniques that make it easier for others to read the code that they write.

- Good code is easy to read, understand, modify and debug.
- Good code is important because it allows other people to change things and makes debugging easier.
- Other things to do is use descriptive variable names, add comments to code, split large tasks into smaller functions, and to save (and modify a copy) of code that works.

Example Code Given to Students:

We went through this code with the students, but they got a bit lost because it is a long program. For the lesson after, we focused on writing smaller sections of code with them. The code is on the following 2 pages.

```
#define lightSensorPin 5
#define leftMotorPin 10
#define rightMotorPin 11

// Set up communication with Arduino
void setup() {
  Serial.begin(9600);
  pinMode(lightSensorPin, INPUT);
  pinMode(leftMotorPin, OUTPUT);
  pinMode(rightMotorPin, OUTPUT);
}

// Line following using two cases
void loop() {
  if(isOutsideLine()){
    // Turn left
    drive(50, -20);
  }
  else{
    // Turn Right
    drive(50, 20);
  }
}

// Returns whether the robot is outside the line
boolean isOutsideLine(){
  const int lightSensorThreshold = 512;
  int lightSensorValue = analogRead(lightSensorPin);
  return lightSensorValue > lightSensorThreshold;
}
```

```
/*
 * Sets the robot to drive at the given speed in the given direction.
 *
 * Parameters:
 * speed: 0 to 255, determines how fast the robot drives
 * direction: -255 to 255, determines how much the robot turns.
 *     Negative values turn left, positive values turn right.
 */
void drive(int speed, int direction){
  // Initialize new motor values to speed.
  int leftMotorValue = speed;
  int rightMotorValue = speed;

  // If direction less than 0, we are turning left, so slow down left motor.
  if(direction < 0){
    leftMotorValue = (speed, 0, 255, 0, abs(direction));
  }
  // If direction greater than 0, we are turning right, so slow down right motor.
  else if(direction > 0){
    rightMotorValue = (speed, 0, 255, 0, abs(direction));
  }

  // Write new values to motors.
  // In reality, writing to motors is more complicated, but I'm simplifying it
  // for this lesson.
  analogWrite(leftMotorPin, leftMotorValue);
  analogWrite(rightMotorPin, rightMotorValue);
}
```

Direct Current (DC) Brushed Motors

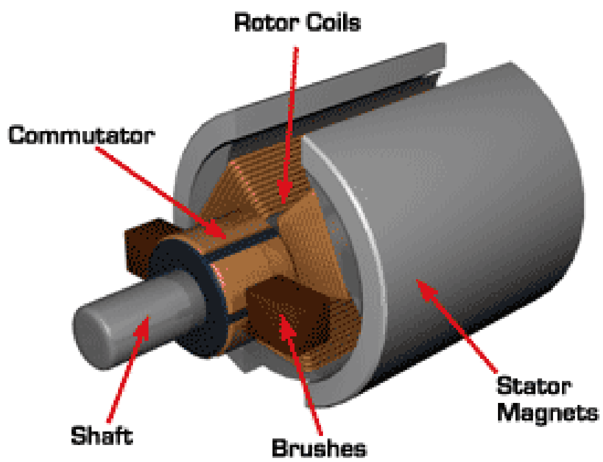

FIGURE 8.5: DC MOTOR ILLUSTRATION
(UNTITLED ILLUSTRATION OF DC MOTOR [IMAGE], N.D.)

We are building robots, and robots need to move. This means we need to use actuators. The most common actuators we use on robots are motors.

There are many types of motors, however the most common kind used on robots is known as a brushed Direct Current motor (see above).

These motors work by using electromagnets to attract different coils of the rotor (spinning part) to magnets on the stator (stationary part). The brushes complete different circuits with different coils depending on how far the motor has rotated.
In the end, the purpose of motors is to convert electrical power from our batteries into mechanical power to move the robot.

To decide which motors to use for our robots, we need to understand how motors work in different terms.

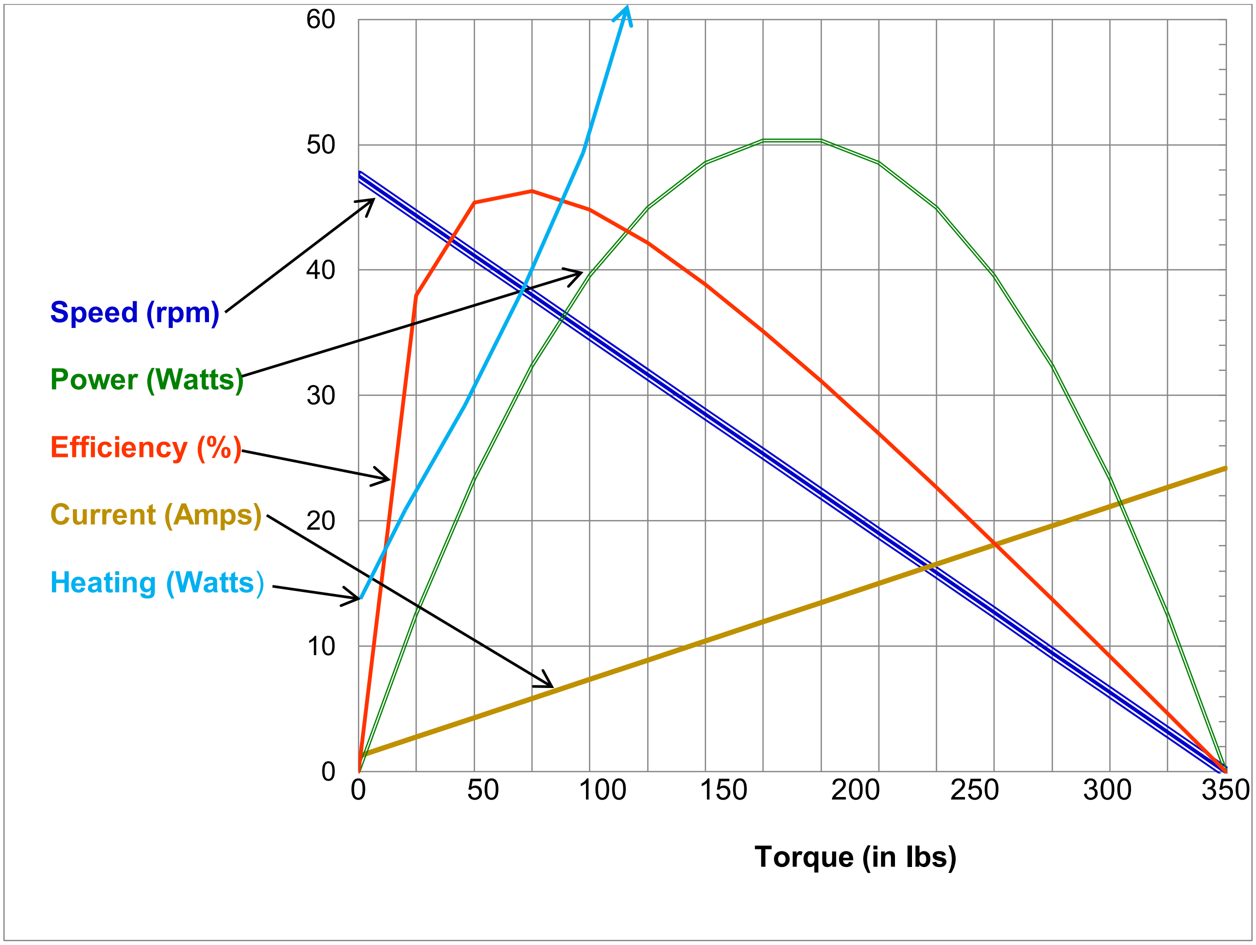

FIGURE 8.6: GRAPH OF VARIOUS DC MOTOR PARAMETERS VS. TORQUE ADAPTED FROM KEN STAFFORD (2010)

This graph is known as a motor performance curve. Each motor has a unique graph associated with it, but all DC motor graphs look similar, but with different numbers. Using the graph, we can determine exactly how a motor will run in a given situation.

As we can see, there are six different, yet related parameters when it comes to motors: Torque, Speed, Power, Efficiency, Current, and Heating.

Torque is a measure of how hard a motor will push in trying to move something. Everything else in the graph is based upon it because the torque a motor must put out is something we can measure and control. A motor will only push as hard as necessary to move a load. Stall Torque is the maximum a motor will output, and occurs when the motor cannot push the load on it and it stops completely.

Speed is how fast the motor is turning, usually measured in Revolutions per Minute (RPM). It is exactly opposite of torque. The harder a motor has to push, the slower it will spin. No-load speed is the fastest the motor will spin, and occurs when there is no load on the motor.

Power is the rate that a motor can do work, such as lifting an object. It is usually measured in Watts (W). Motors are most powerful at exactly half of their stall torque, which is also half of their no-load speed. It is important to realize that the same power output can be achieved at two different points on the graph. One will have more torque with less speed, while the other has the opposite.

Efficiency is how much mechanical power is put out compared to how much electrical energy is put in. The most efficient anything can be is 100%, meaning that no power is lost to heat, noise, or other losses. The more efficiently your motor is running, the longer your batteries will last. Typically, motors will be most efficient at about 25% of their stall torque, or 75% of their no-load speed. For this reason, it is always better to operate on the left side of the curve.

Current is how much electricity the motor is drawing to supply the necessary torque, usually measured in Amps (A). More torque is directly related to more current. The motor will only draw as much current as necessary. Because of this, current-sensing resistors are often used to estimate how much torque a motor is outputting.

Heating is how much electrical power is not turning into mechanical power, and instead turns into heat. It is usually measured in Watts (W). Heating is a concern because motors can get hot enough to melt themselves or what they are attached to. As the torque required of the motor increases, so does the heating. If they are stalled, most DC brushed motors will burn out (smoke) in only a few seconds.

With all of this in mind, how should we choose what motors to use? There are plenty of criteria to use, however this some general guidelines organized by importance:

1. **Power Requirement**
2. **Weight of Motor & Transmission**
3. **Physical Size of Motor & Transmission**
4. **Efficiency**
5. **Availability**

   (adapted from Ken Stafford 2010)

If you do not know how much power we need, and instead only know how much torque we will need, it is generally a good idea to pick a motor and gearbox that has a stall torque 5 times greater than what we expect is necessary.

Mechanical Design Principles and 3D Modelling

Going to go over some design principles:
Going to use the OctoCopter group as an example for today
We use 3D modeling to think through the details of our design, not just to illustrate it.
To begin, we start with what we know and work from there.
We have eight propellers, each six inches in diameter, which we want to evenly space and not collide with each other.
So we can make a general, but dimensionally accurate, sketch:

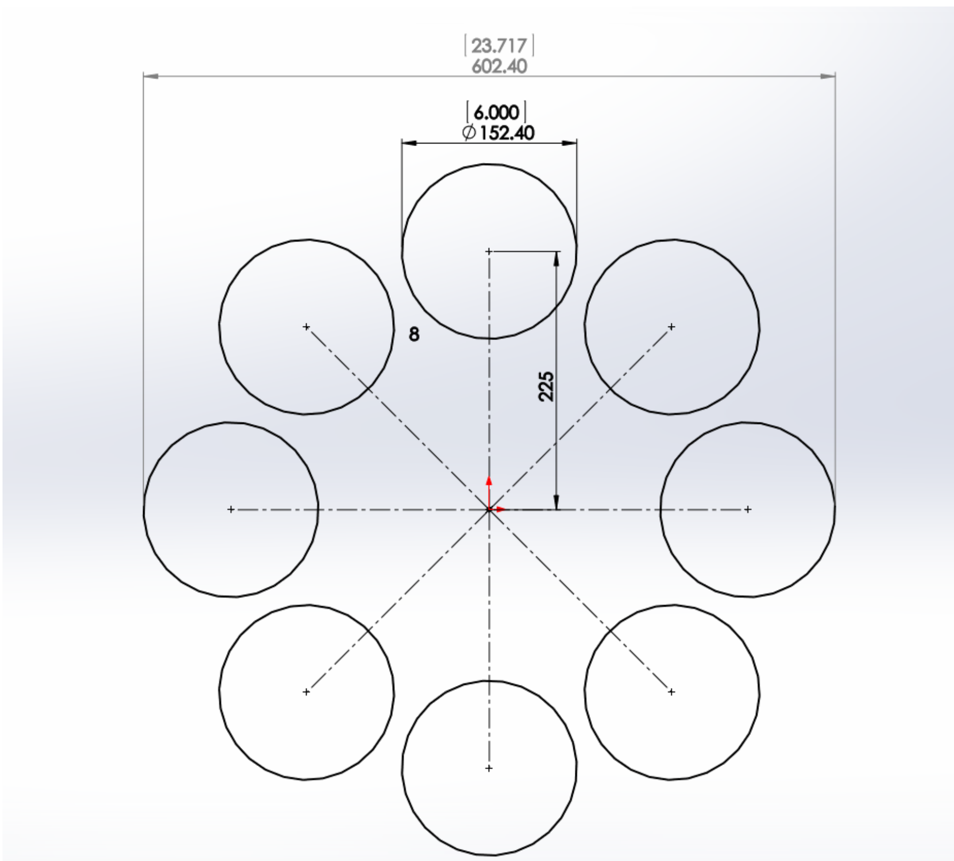

FIGURE 8.7: SKETCH OF CAD OCTOCOPTER MODEL FOR LESSON

There are many ways we could choose to connect all of the motors and their electronics, but we decided to model one central hub with eight arms.

However, this poses an issue: (ask students) Answer: Our octocopter frame is going to be 3D printed, yet it is nearly twice as large as our build platform. This means we will have to print it in multiple pieces and attach them together somehow.

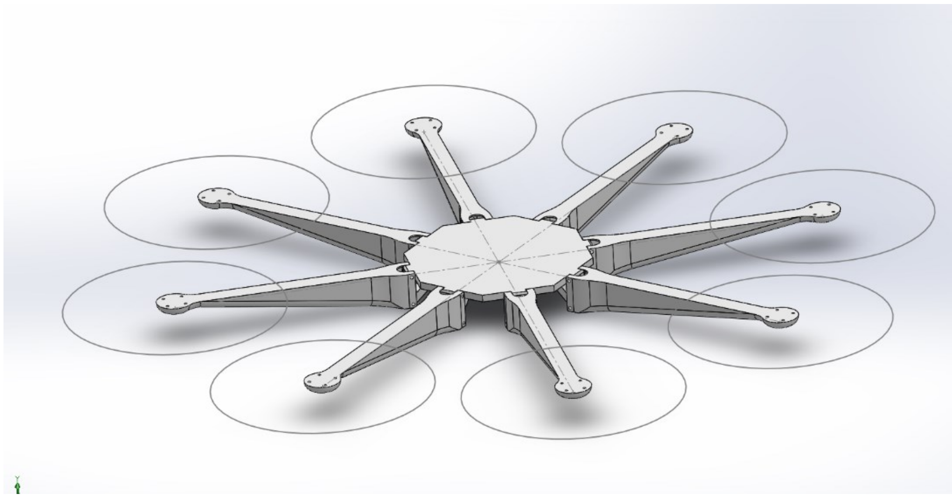

FIGURE 8.8: CAD OCTOCOPTER ASSEMBLY FOR LESSON

What are different methods to attach two things together? (Ask students, probe for answers with examples)

- Glue things together (superglue, hot glue)
- Melt things together (welding, dissolving ABS with acetone)
- Fasteners (nuts, bolts, screws, pins, rivets, clips)
- Friction, press, interference, and shrink fits (flash drive in a computer, snap fasteners, bearings)

Since we would like to be able to replace arms if they break, we decided to use some type of fastener. Most other methods are usually permanent.

Now that we have a general design, we can analyze the design of the arms we have.

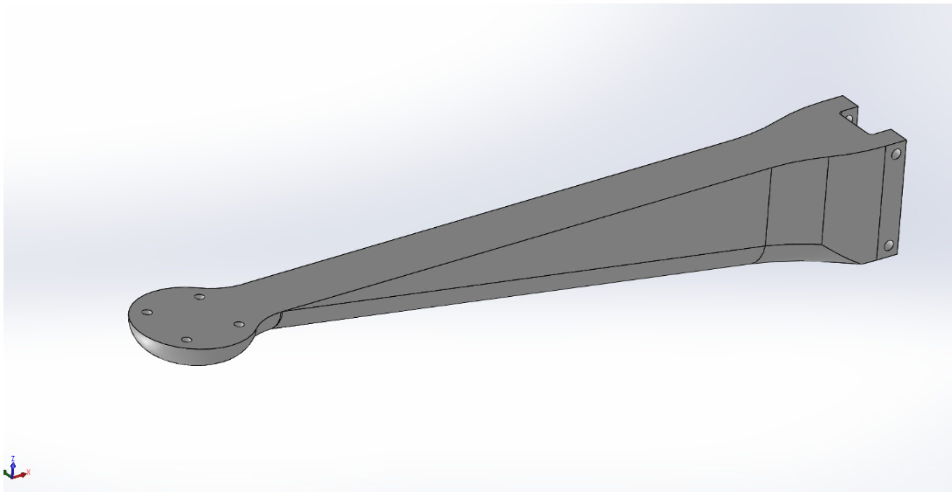

FIGURE 8.9: CAD MODEL OF OCTOCOPTER PART FOR LESSON

We want our arms to:

- Weight as little as possible because we want to increase our flight time
- Use as little material as possible because we have a very limited supply
- Easily withstand normal forces during flight

This last point brings up an interesting consideration: what happens when the drone crashes? We have some options for this as well.
We could make the arms very strong:

- Arms would not break, so nothing would need to be reprinted
- Could transfer the force and break something else instead, like the electronics in the middle of the drone
- Would make the arm heavier, if we also strengthened the middle, the whole drone would become much heavier
- Would use more material
- As the drone gets heavier, it has more momentum at the same speed, so we have yet more force to deal with

We could make the arms strong enough to fly, but weak enough to break with a bad crash:

- Arms would be lightweight and use little material
- Breaking would absorb a large amount of energy, like a crumple zone in a car
- Arms would break, saving other parts
- Arms would have to be replaceable and would have to be reprinted every time

We could connect the arms with a shear-pin made out of filament

- The arms would only need to be slightly stronger
- Crashing would break the shear pins, which are easily replaceable
- Need to calculate the force and stress involved to make shear pin correctly

We decided that a shear pin might be the best approach, now we can move on to evaluating the actual design.

We know that the arm will be attached by the four holes at the end and we know that our selected motors and propellers can supply, at most, 600 grams equivalent of force, or 5.88 Newtons. Using this data, we can use SolidWorks Simulation software to run a statics analysis of the arm.

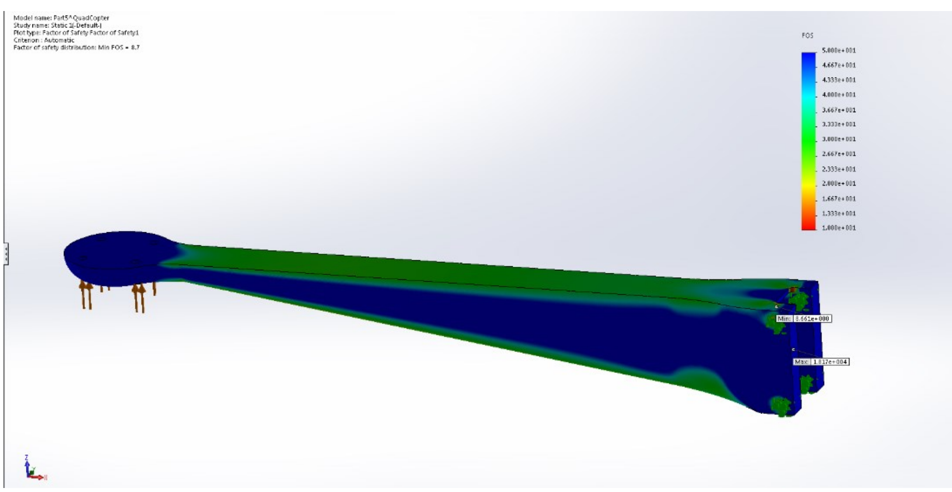

FIGURE 8.10: STATICS ANALYSIS OF CAD PART FOR LESSON

This simulation shows that the minimum Factor of Safety is 8.7. Factor of Safety is how many times the expected force would be required to break the material. Therefore anything under 1.0 will always break under the expected load. However we can see that most of the stress is evenly distributed, although it is concentrated at points, which we will get to soon enough.

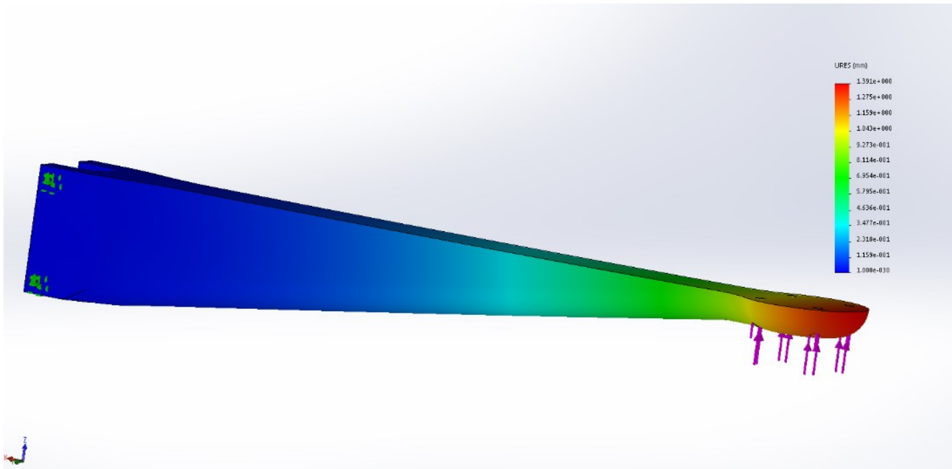

FIGURE 8.11: FURTHER ANALYSIS OF CAD PART FOR LESSON

The deformation simulation shows that the arm will deflect upward 1.39 mm, which will barely be noticeable.

Now that we know the arm should definitely work, we can look at the simulation in more detail.

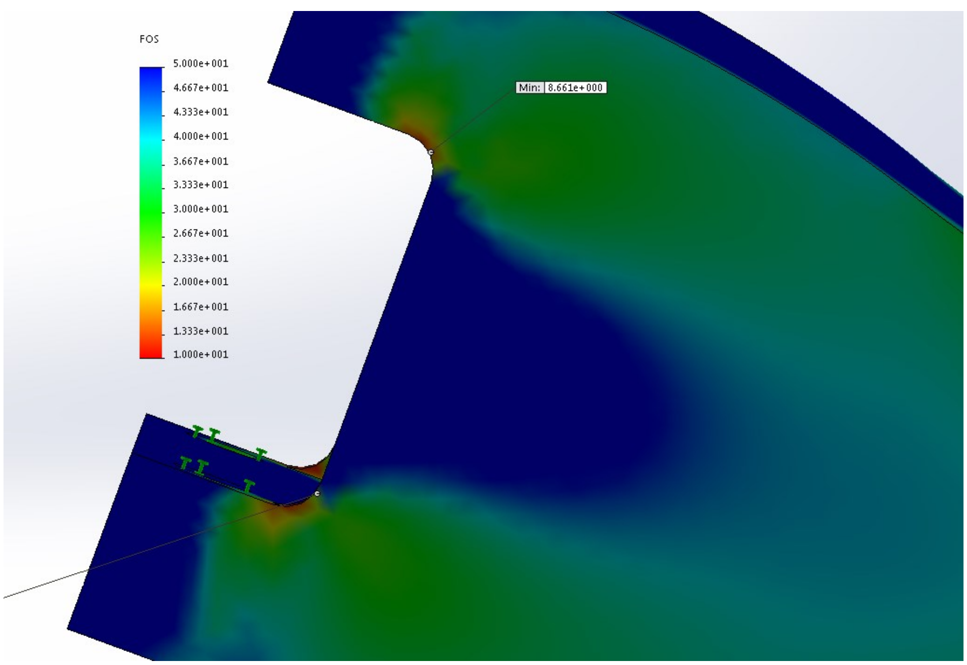

FIGURE 8.12: ANALYSIS OF JOINT IN CAD PART FOR LESSON

Here we can see that the stress is concentrated in the sharp corners on top and bottom of the arm.

Stress concentrations can be very dangerous because they can lead to cracks that will continue to tear through the material, even though it would not have broken before the crack.

So how do we rid ourselves of this stress concentration? (ask students for ideas)

Make the corners more rounded!

- Rounded or beveled corners called fillets and are intended to reduce stress concentrations.
- But we can't round these corners more because that is where the two pieces join together!

Make the material thicker there!

- Stress is defined as force distributed over an area, so if the material is thicker, there will be more area to handle the same force. This would reduce the stress, increasing the Factor of Safety.
- But this requires more material and it doesn't seem like we need any more material.

Solution: If we look at the plot, there is a large blue area between the stress concentrations, it doesn't seem to be doing any work, so what happens if we make rounded corners, but by removing the blue section?

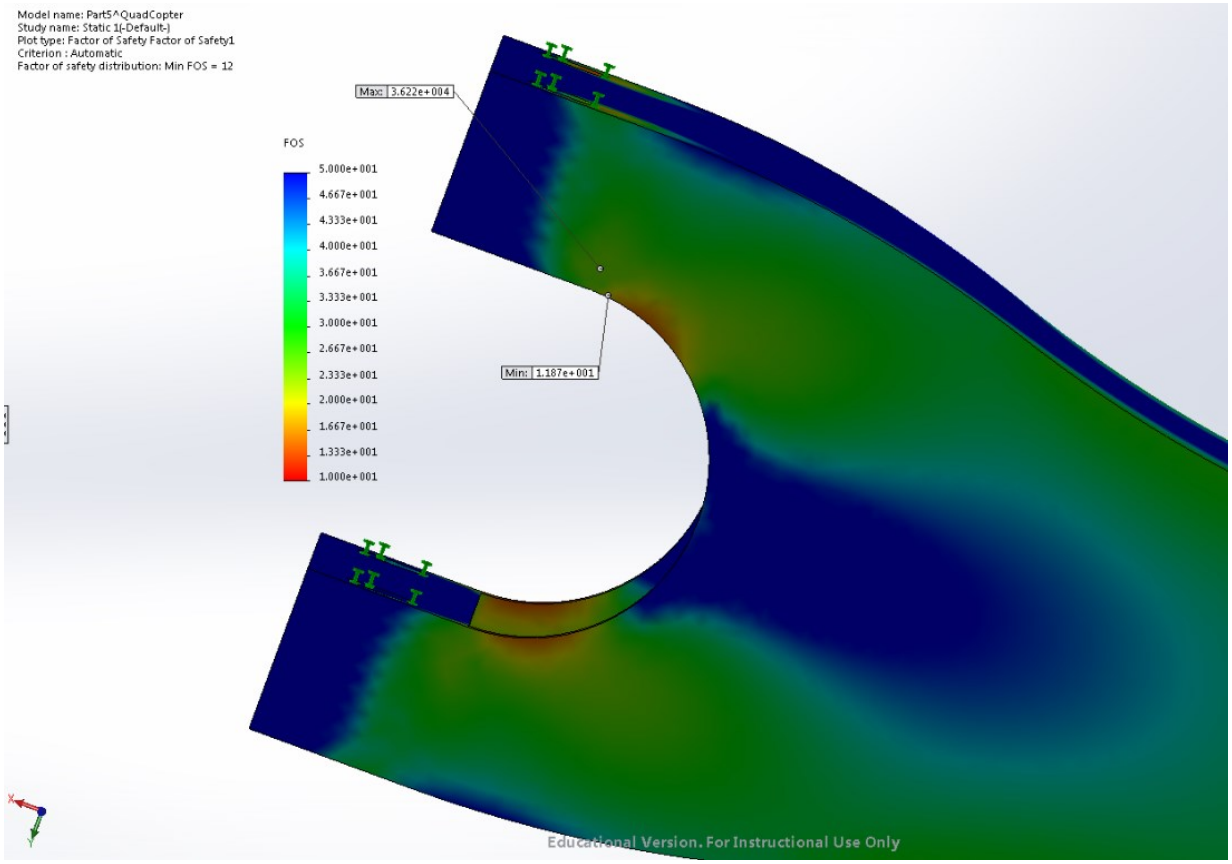

FIGURE 8.13: ANALYSIS OF JOINT IN CAD PART FOR LESSON AFTER MODIFICATION

Now we have decreased stress and increased our factor of safety to nearly 12, all while removing material and making the part lighter.

3D Printing Lesson Plan

For all purposes the printer at the Harry Fultz Institute (Creator Flashforge Pro) should be treated as a "MakerBot Replicator Dual". The Software used accordingly is the "MakerBot Desktop" software.

- Stereolithography is another type of 3D printing that involves a liquid resin which is solidified layer by layer with a laser beam.
- DLP or Digital Light Processing is a very similar method of 3D printing which uses focused light rather than a laser to achieve a similar result.
- Laser Sintering is a more industrial method 3D printing and is praised in the fact that is can print in metal. A fine metal powder is spread across a building platform at which point a high powered laser calculatedly melts the metal. More metal powder is then spread across the previously melted layer and the process is repeated.
- The most common household 3D printing method is Fused Deposition Modeling, of FDM. This is the style of printer that the Harry Fultz Institute has. It involves a heated extruder that calculatedly places down plastic layer by layer to create the final object.

Methods of adhesion of parts-

- ABS Slurry- This method consists of ABS plastic (scraps are welcome) and acetone. The acetone melts the plastic into a thin slime like substance. When placed on the desired parts and allowed to dry the pieces will be adhered. This is mainly only used with ABS plastic not PLA
- Super Glue- This works with all materials. It may not be resistant to higher temperatures.
- Friction welding- A method that should be used only on top of another form of adhesion. It involves placing a section of filament into a drill head and using the friction from the rotation to heat up the end and use it as a weld.
- By printing in according holes into your projects you can use nuts and bolts to attach pieces of your project.

Strength of the prints- Prints will nearly always break with the grain or orthogonal to the Z axis of printing.

To finish a print, (for mostly aesthetic reasons), you can use an acetone vapor bath. This uses the fumes from evaporating acetone to slightly melt the surface of a print and give it a smoother shinier finish. One problem with this is that the strength of a piece that has been under this procedure is unpredictable.

Links for reference:

- http://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/processes/
- http://my3dmatter.com/influence-infill-layer-height-pattern/

Appendix J: Interim Survey

Survey Questions

Programming	3D Modeling
How much did you like the programming lessons? **1 ____ 2 ____ 3____ 4____ 5____**	**How much did you like the 3D modeling lessons?** **1 ____ 2 ____ 3____ 4____ 5____**
How helpful were the programming lessons? **1 ____ 2 ____ 3____ 4____ 5____**	**How helpful were the 3D modeling lessons?** **1 ____ 2 ____ 3____ 4____ 5____**
How much programming did you already know? **1 ____ 2 ____ 3____ 4____ 5____**	**How much 3D modeling did you already know?** **1 ____ 2 ____ 3____ 4____ 5____**
3D Printing	**DC Motors**
How much did you like the 3D Printing lessons? **1 ____ 2 ____ 3____ 4____ 5____**	**How much did you like the DC Motor lessons?** **1 ____ 2 ____ 3____ 4____ 5____**
How helpful were the 3D Printing lessons? **1 ____ 2 ____ 3____ 4____ 5____**	**How helpful were the DC Motor lessons?** **1 ____ 2 ____ 3____ 4____ 5____**
How much about 3D printing did you already know? **1 ____ 2 ____ 3____ 4____ 5____**	**How much about DC motors did you already know?** **1 ____ 2 ____ 3____ 4____ 5____**

General

What did you particularly like about the lessons?

What did you particularly dislike about the lessons?

What would you change for next year?

Survey Response Chart Explanation

For these charts, each survey response contributes to the size of a bubble on the chart. Responses are grouped by student, comparing their answers to the second question ("Helpfulness") in the table with their answers to the first ("Enjoyment") and third ("Prior Knowledge") questions. The first group of charts shows helpfulness vs. enjoyment, and the second group of charts shows helpfulness vs. prior knowledge.

Helpfulness vs. Enjoyment Charts

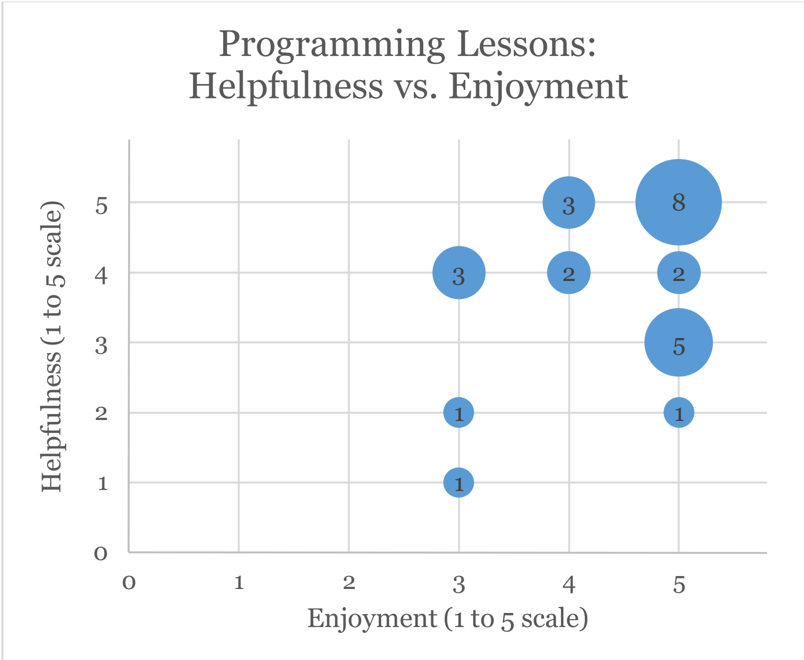

FIGURE 8.14: CHART OF SURVEY RESPONSES FOR PROGRAMMING LESSONS SHOWING HELPFULNESS VS. ENJOYMENT

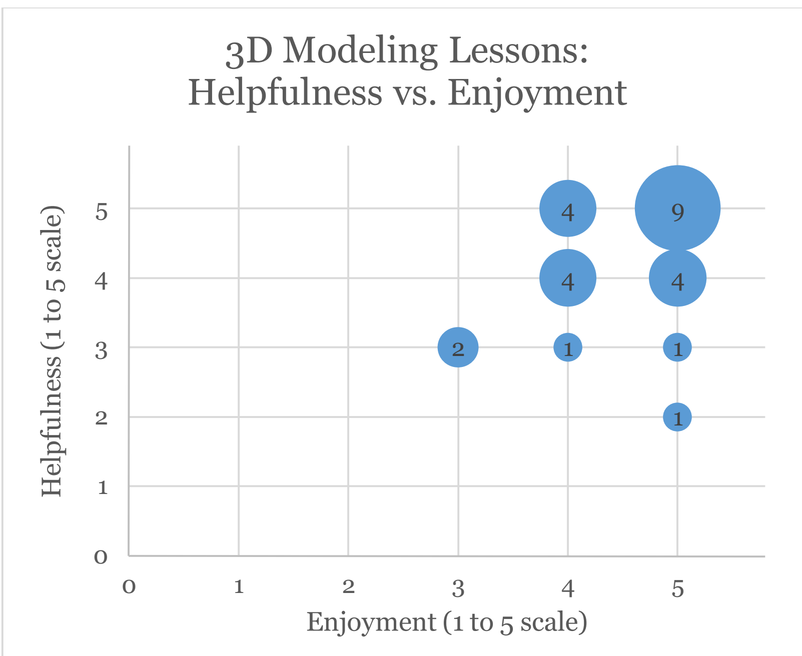

FIGURE 8.15: CHART OF SURVEY RESPONSES FOR 3D MODELING LESSONS SHOWING HELPFULNESS VS. ENJOYMENT

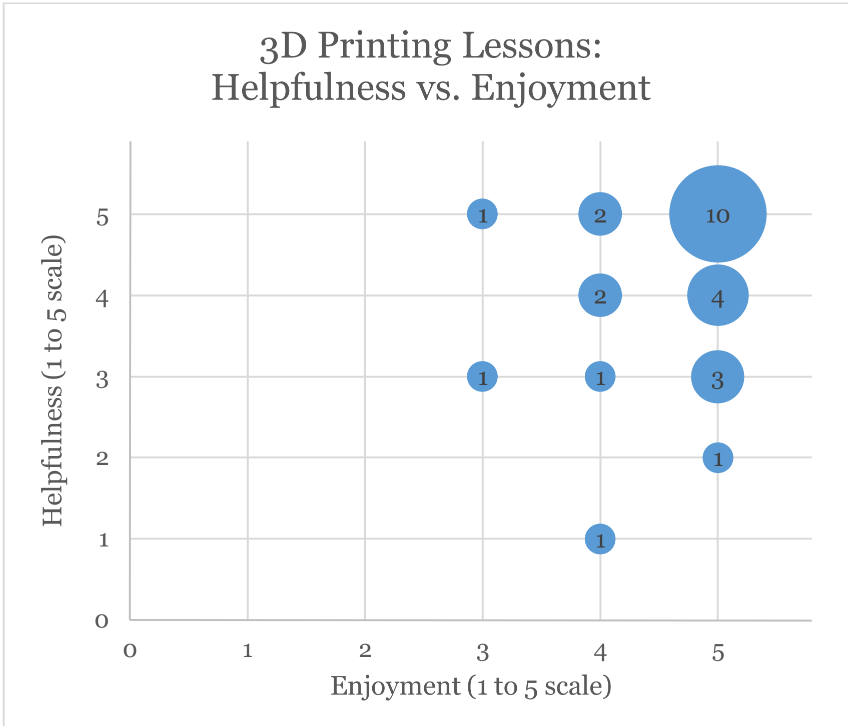

FIGURE 8.16: CHART OF SURVEY RESPONSES FOR 3D PRINTING LESSONS SHOWING HELPFULNESS VS. ENJOYMENT

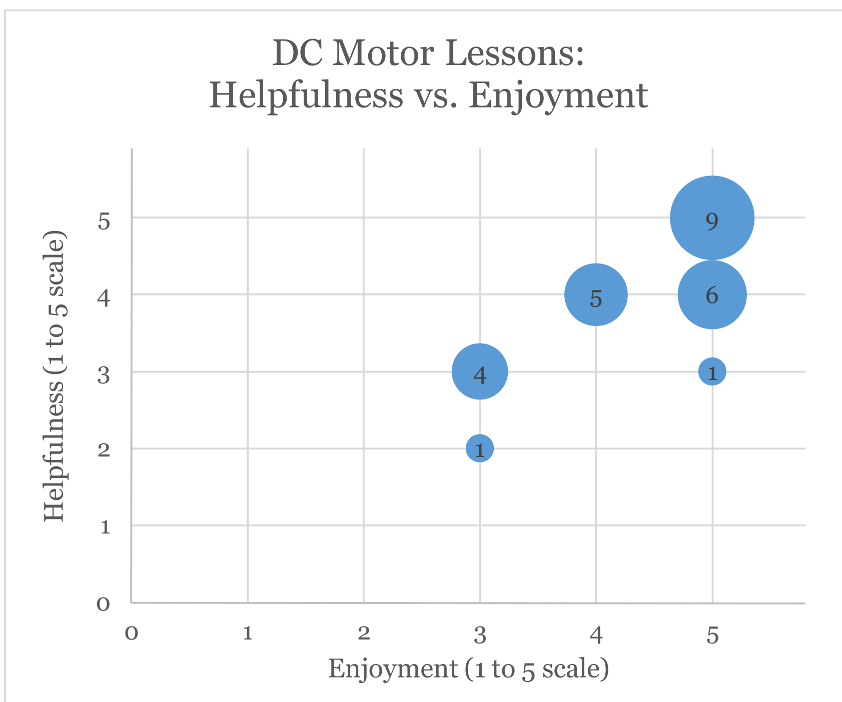

FIGURE 8.17: CHART OF SURVEY RESPONSES FOR DC MOTOR LESSONS SHOWING HELPFULNESS VS. ENJOYMENT

Helpfulness vs. Prior Knowledge Charts

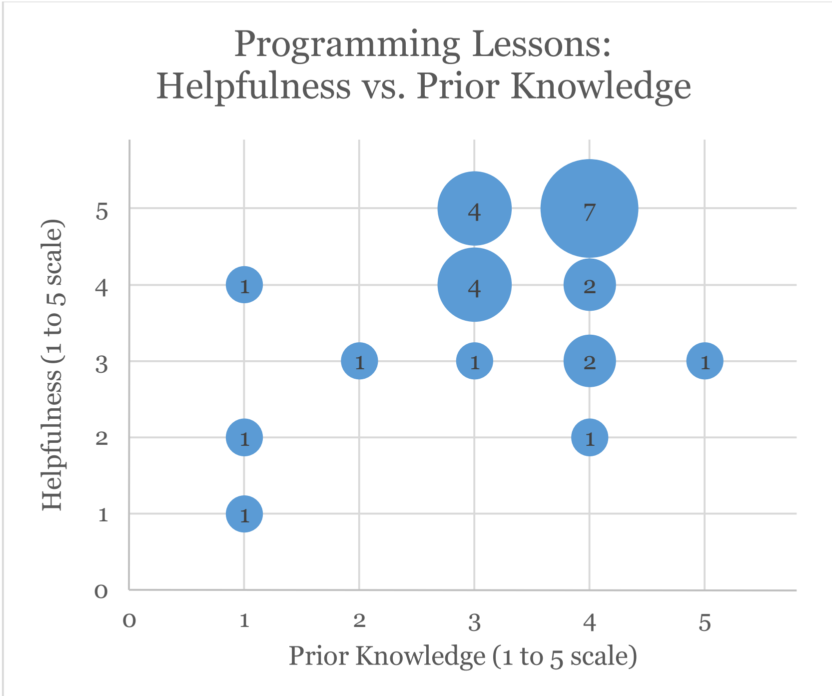

FIGURE 8.18: CHART OF SURVEY RESPONSES FOR PROGRAMMING LESSONS SHOWING HELPFULNESS VS. PRIOR KNOWLEDGE

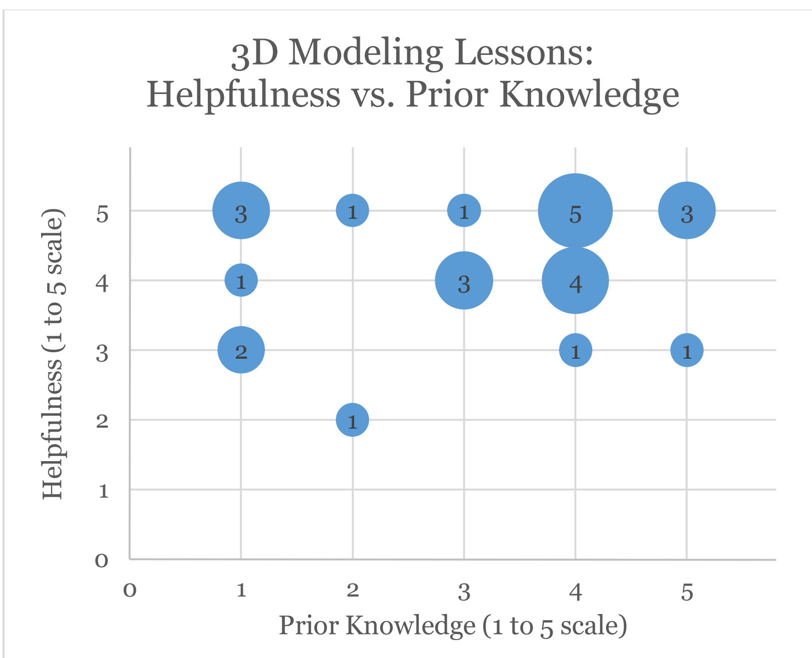

FIGURE 8.19: CHART OF SURVEY RESPONSES FOR 3D MODELING LESSONS SHOWING HELPFULNESS VS. PRIOR KNOWLEDGE

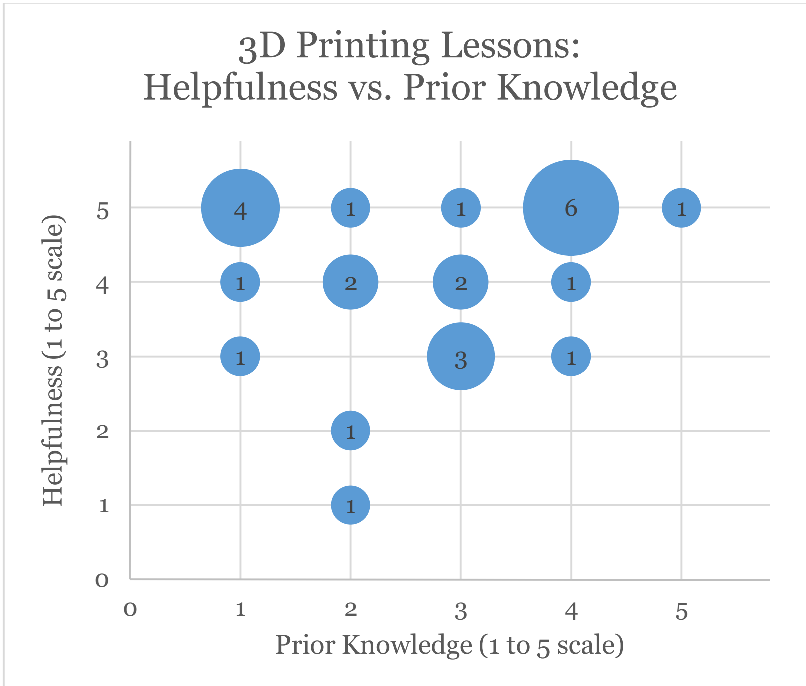

FIGURE 8.20: CHART OF SURVEY RESPONSES FOR 3D PRINTING LESSONS SHOWING HELPFULNESS VS. PRIOR KNOWLEDGE

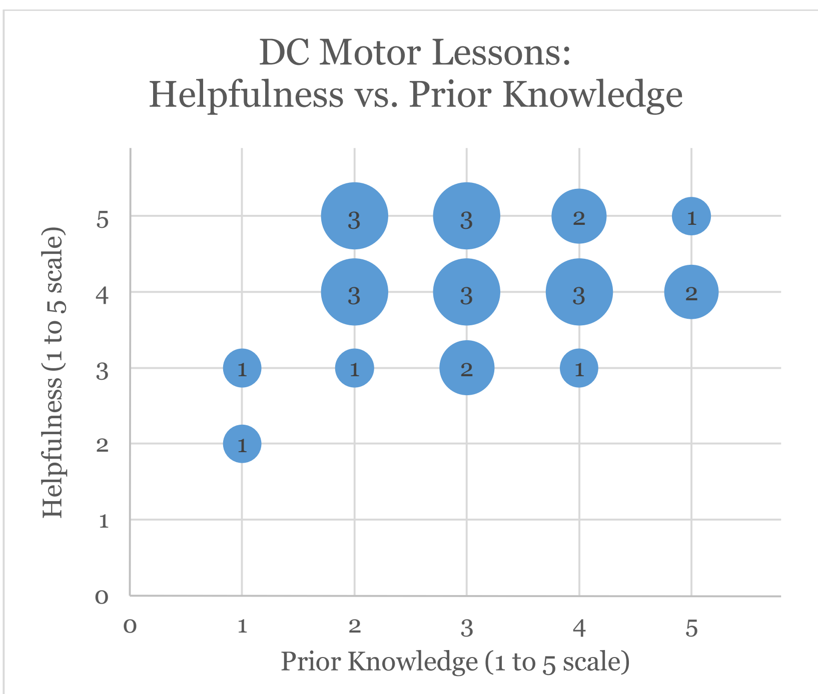

FIGURE 8.21: CHART OF SURVEY RESPONSES FOR DC MOTOR LESSONS SHOWING HELPFULNESS VS. PRIOR KNOWLEDGE

Appendix K: Student Discussion Questions

- What did you like or dislike about the club?
- What were your feelings about working outside of class?
- What were your feelings about working in groups?
- What are your classes like at Harry Fultz Institute, in general?
- Did you like the hands-on work?
- How did our lessons compare to lessons from your professors at Harry Fultz?
- If you do this again, would you prefer different projects for each group like was done this year, or one overall game where groups build robots to compete with each other?
- Do you feel like you are more capable of doing projects on your own after the club?kj
- For returning students, how did this year compare to last year?

Appendix L: Improvised Solutions to Club Problems

Situation: The parts that the club ordered for the drone team were not compatible and would not have allowed the drone to fly.

Solution: During our thanksgiving break, one member of our team found a local shop in Rome that had all of the parts required except for propellers.

Situation: Prints were not adhering to the 3d printer's build platform and not allowing us to print reliably, if at all.

Solution: After searching online and drawing from our experiences, we went to local stores to gather supplies to encompass any and every solution we could think of. We gathered supplies for solutions that had been proven as well as those that hadn't, just in case the first methods failed. The options for a build plate we explored and sourced included:

- Painters tape (many types)
- Packaging tape
- Dissolved ABS (acetone)
- Dissolved PLA (acetone, paint thinner, and rubbing alcohol-- all failed to dissolve)
- Hairspray
- Borosilicate Glass build plate
- Sand paper
- Copper build plate
- Aluminum build plate
- Differing build plate temperatures

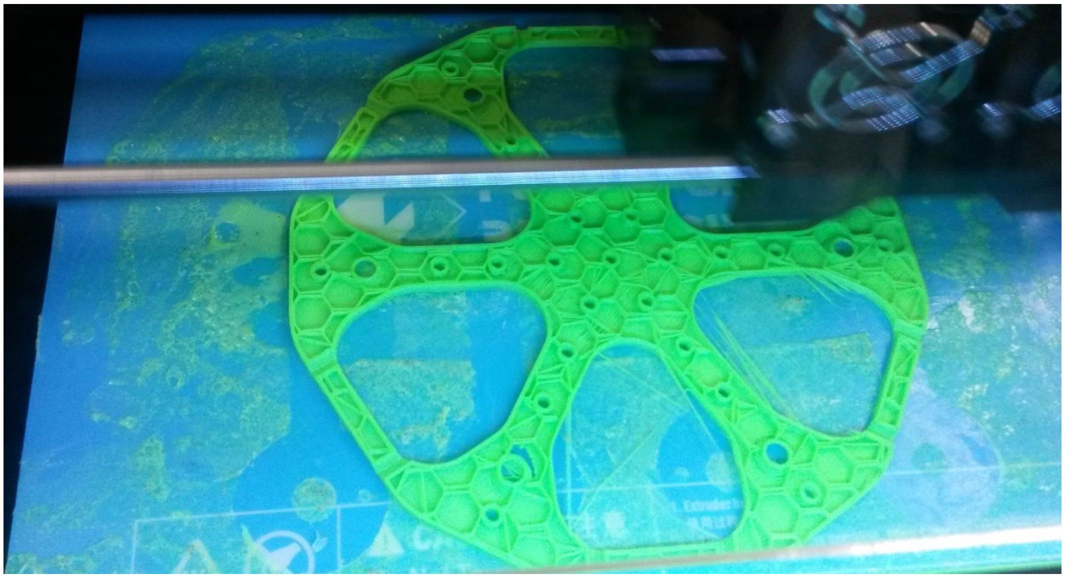

FIGURE 8.22: ABS BEING PRINTED ON DISSOLVED ABS

Tape worked for PLA while dissolved ABS worked very well for ABS.

Situation: The drone group did not have any propellers, or anyway to buy them without it being very expensive or taking too long to ship.

Solution: Our primary options were to attempt to either machine the propellers, or 3D print them. We decided that 3D printing would be the better option because machine propellers properly would be too difficult.

However, because 3D printers lay down consecutive layers of material, printing a propeller would cause it to be rough and inefficient. Similarly, because the parts are made in layers, they are strongest along the layers, but much weaker if the layers are being pulled apart. For both of these reasons, the propellers could not be printed in a conventional manner.

To solve this, we brought together three different technologies.

1. We had seen that one of our printing materials, PLA, became very soft and malleable when hot, but would harden again when cooled. This meant that we could potentially print the propellers flat so that the layers were aligned and bend them into shape afterward.
2. In searching for propeller options, we found that carbon fiber propellers are created from flat sheets that are shaped into the profile of a propeller with a relatively thin cross section throughout.

3. Lastly we needed to shape the propellers accurately and identically. This could be done by taking a negative of the shape we wanted and separating it into two pieces. In industry such a device is known as a die.

Combining these methods, we printed flat, thin propellers, and then shaped them precisely in a die modelled with the exact shape required.

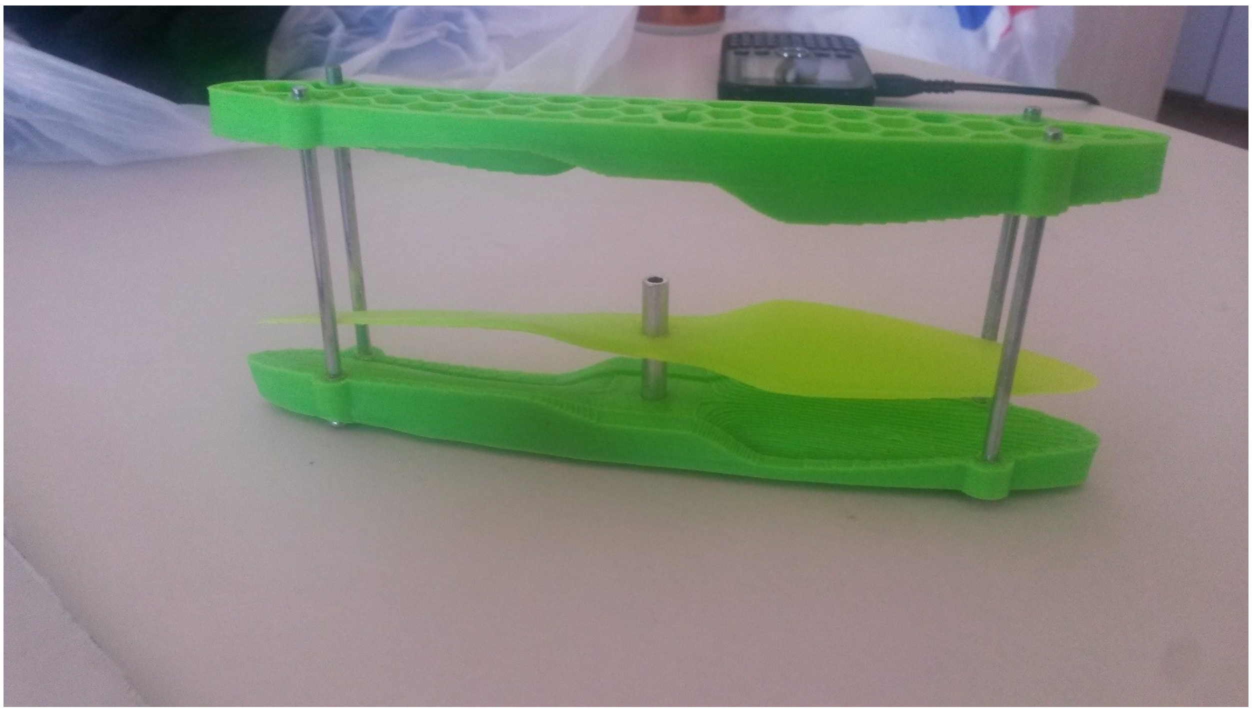

FIGURE 8.23: PRE-FORMED PROPELLER IN OPEN DIE

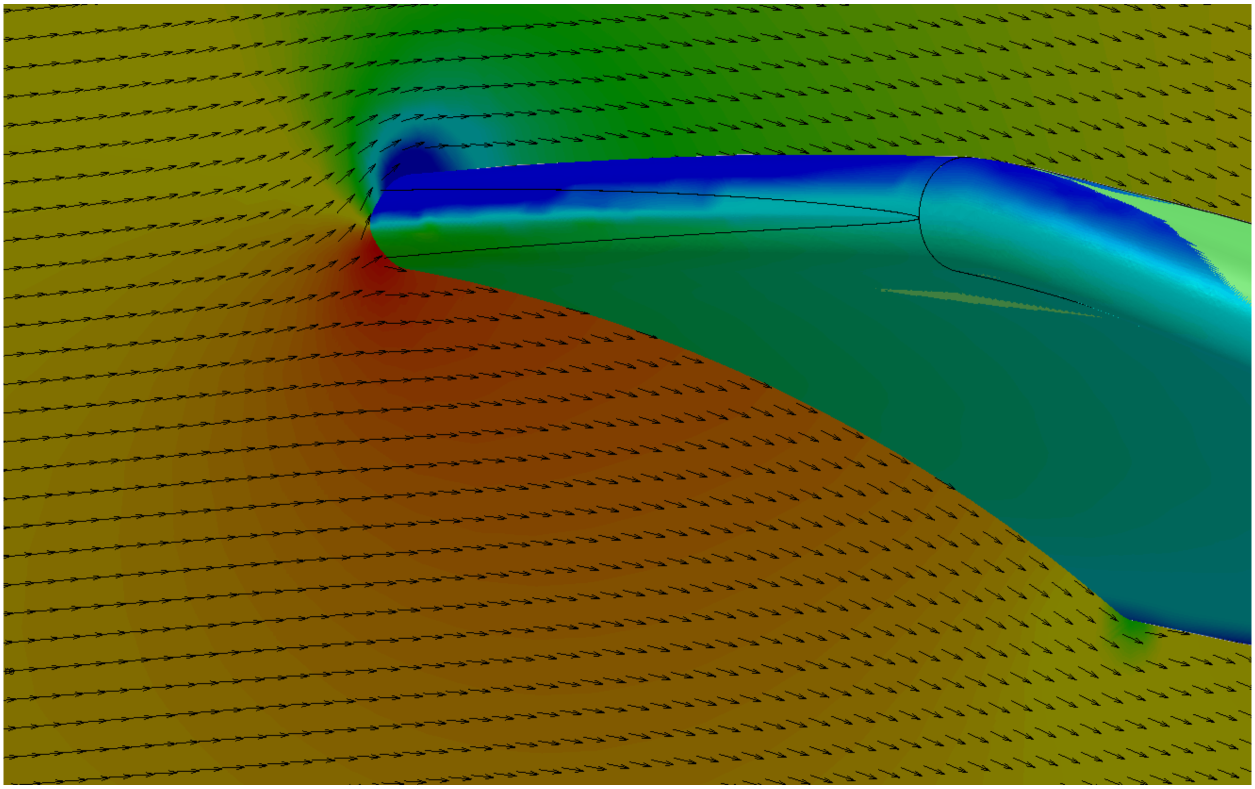

FIGURE 8.24: FLOW SIMULATION OF PROPELLER

Our simulations allowed us to design the propellers using very little material by using the curvature of the blades for strength. This allowed us to retaining a minimum Factor of Safety of 2.5, while weighing barely more than the carbon fiber equivalent.

Situation: The balancing robot group did not have any wheels.

Solution: Most matters of this nature would be easily solved by simply 3D printing the missing components. However, this method faced two major issues: the wheels the group needed were larger than the printer's build space, and the plastics we can print with have no grip on smooth floors. Once again, we solved this problem by combining technologies.

1. Parts that are larger than the build platform can be printed in pieces that are then connected
2. Acetone readily dissolves ABS parts and leaves the plastic behind when it evaporates
3. Self-vulcanizing or self-amalgamating rubber tapes provide excellent grip on smooth surfaces

Combining these technologies, we worked with the students to design a wheel that could be printed in four parts that connected by applying acetone to the mating surfaces. Then we added the self-amalgamating tape around the perimeter for traction.

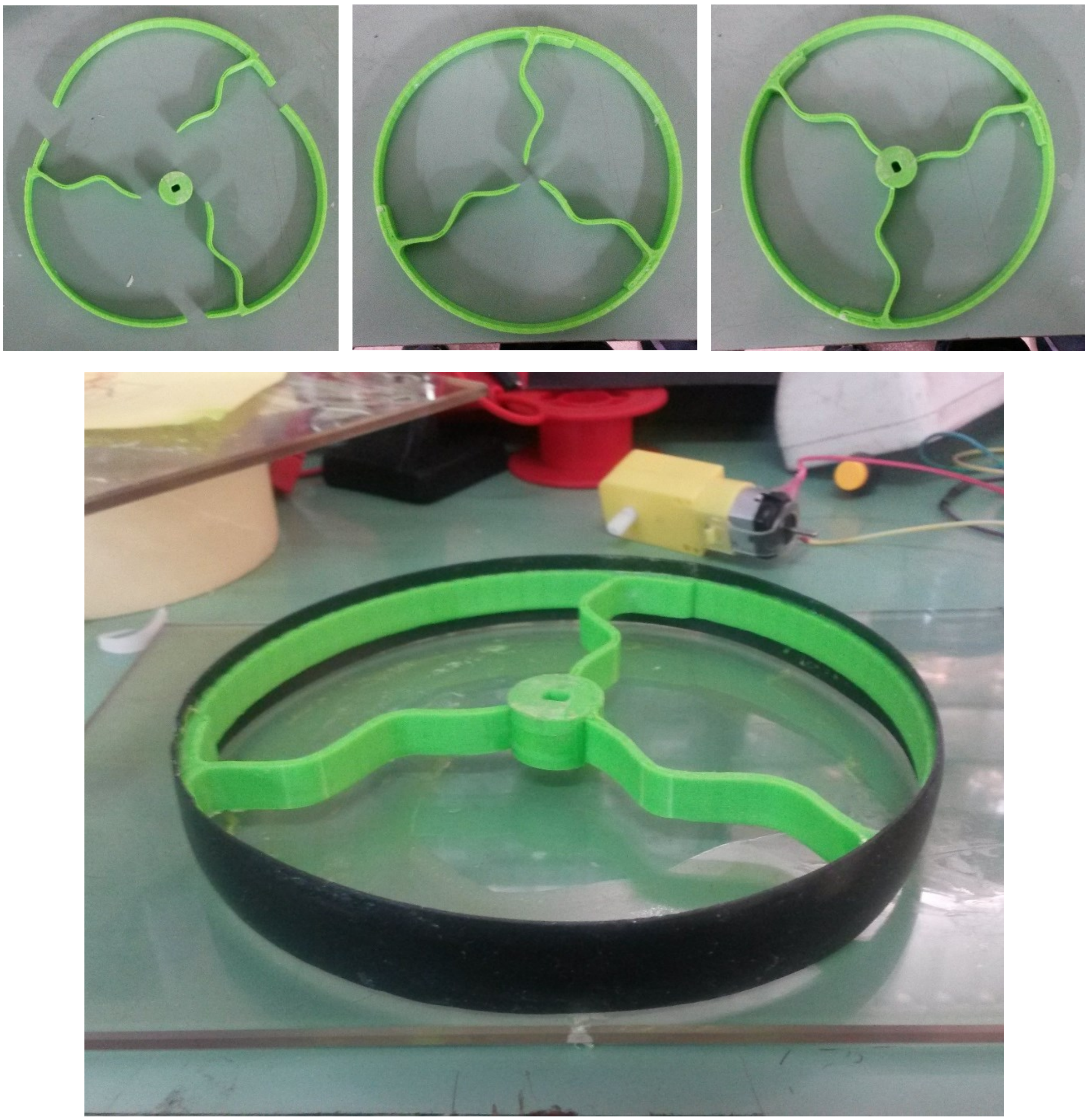

FIGURE 8.25: ASSEMBLY STAGES OF WHEEL

Situation: The Rover team wanted a tracked vehicle for all terrain purposes.
Solution: There are many 3D-printable tracks and drive sprockets online on websites like Thingiverse.com. However, none of these quite matched the team's specifications. Many of the designs used additional hardware to attach links together or required processing after the links were printed. To solve this, we designed our own track links which snap together directly after being printed. We also designed matching sprockets which include a hole allowing the motor mount screws to be adjusted without removing the sprocket.

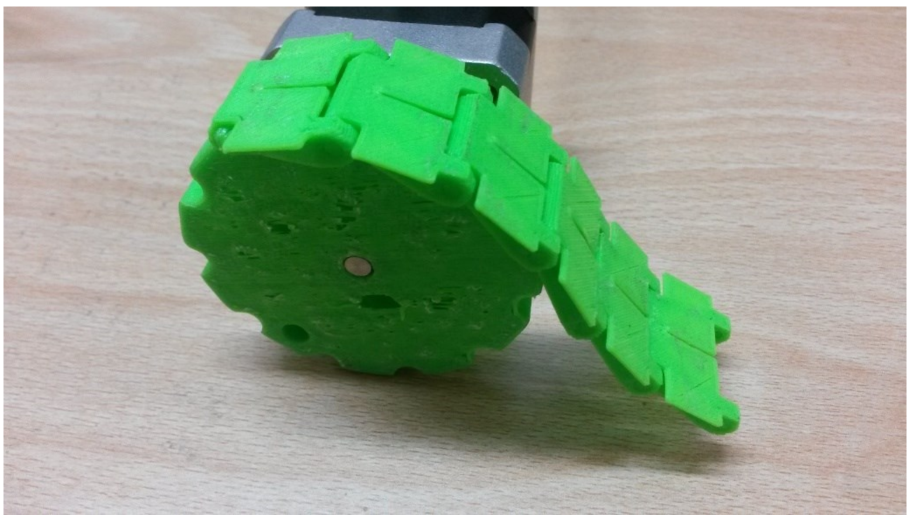

FIGURE 8.26: TRACK LINKS AND SPROCKET

Appendix M: 3D Printed Robot Parts

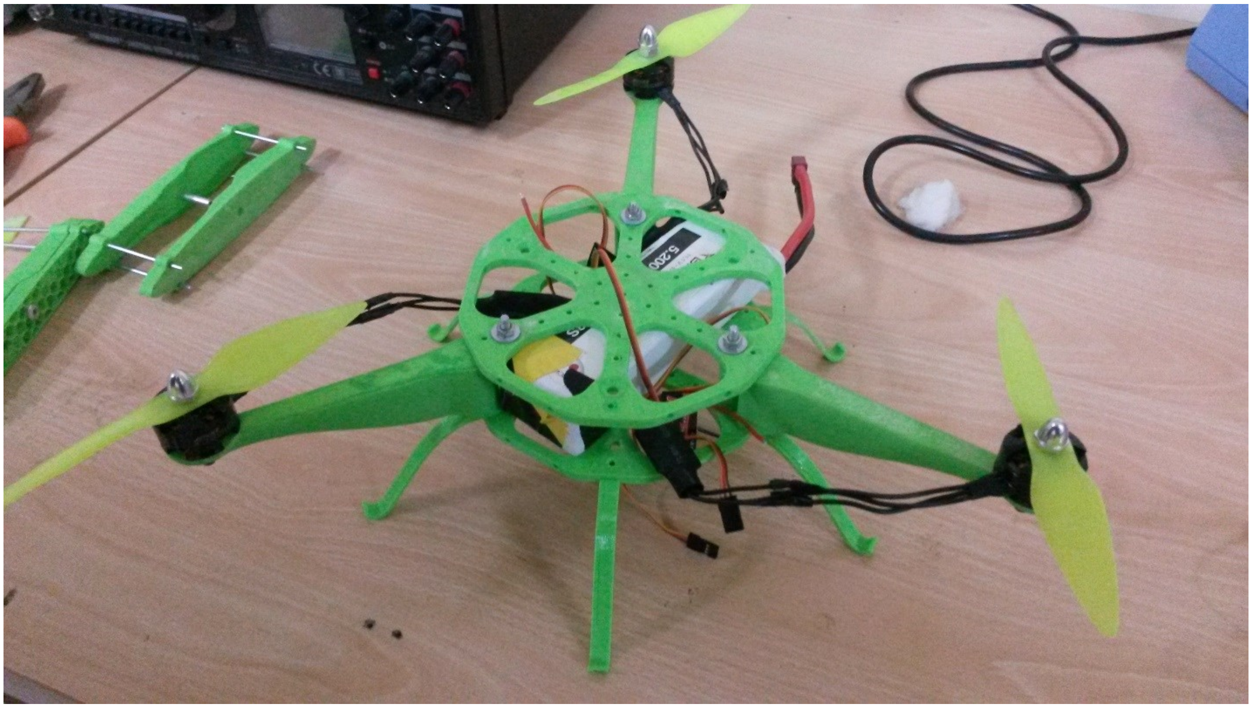

FIGURE 8.27: ASSEMBLED 3D PRINTED PARTS FOR DRONE GROUP

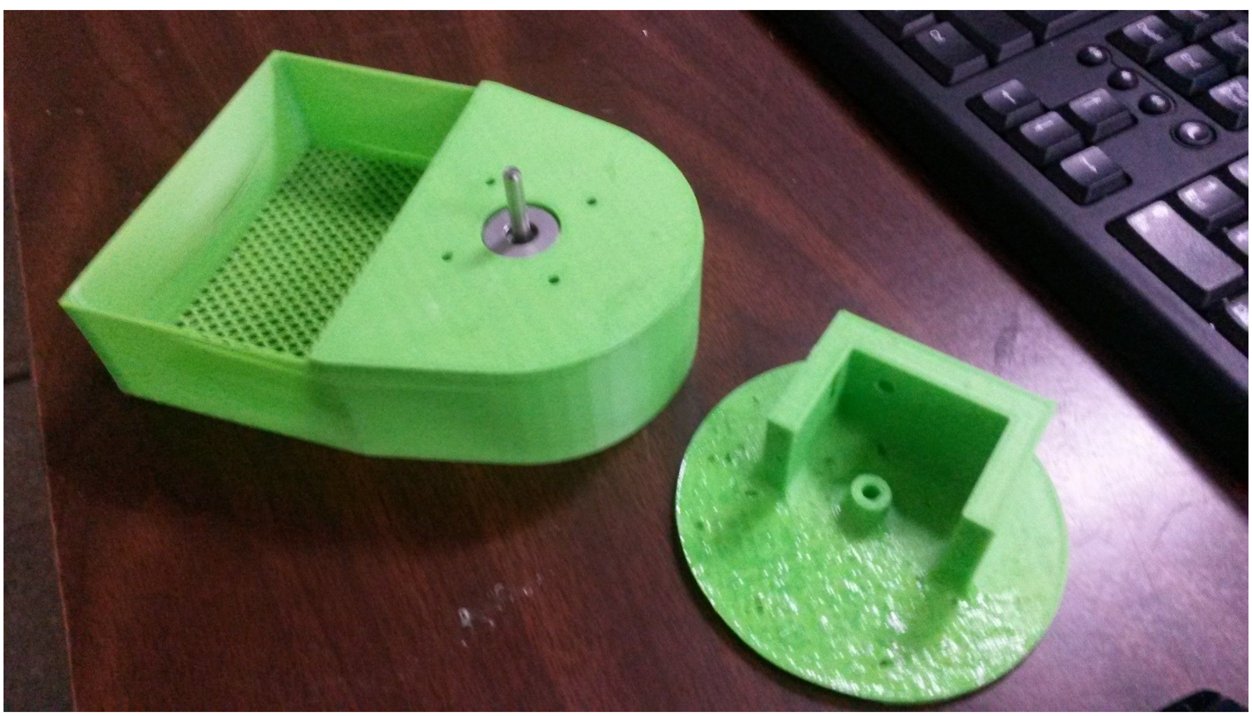

FIGURE 8.28: 3D PRINTED PARTS FOR ARM GROUP