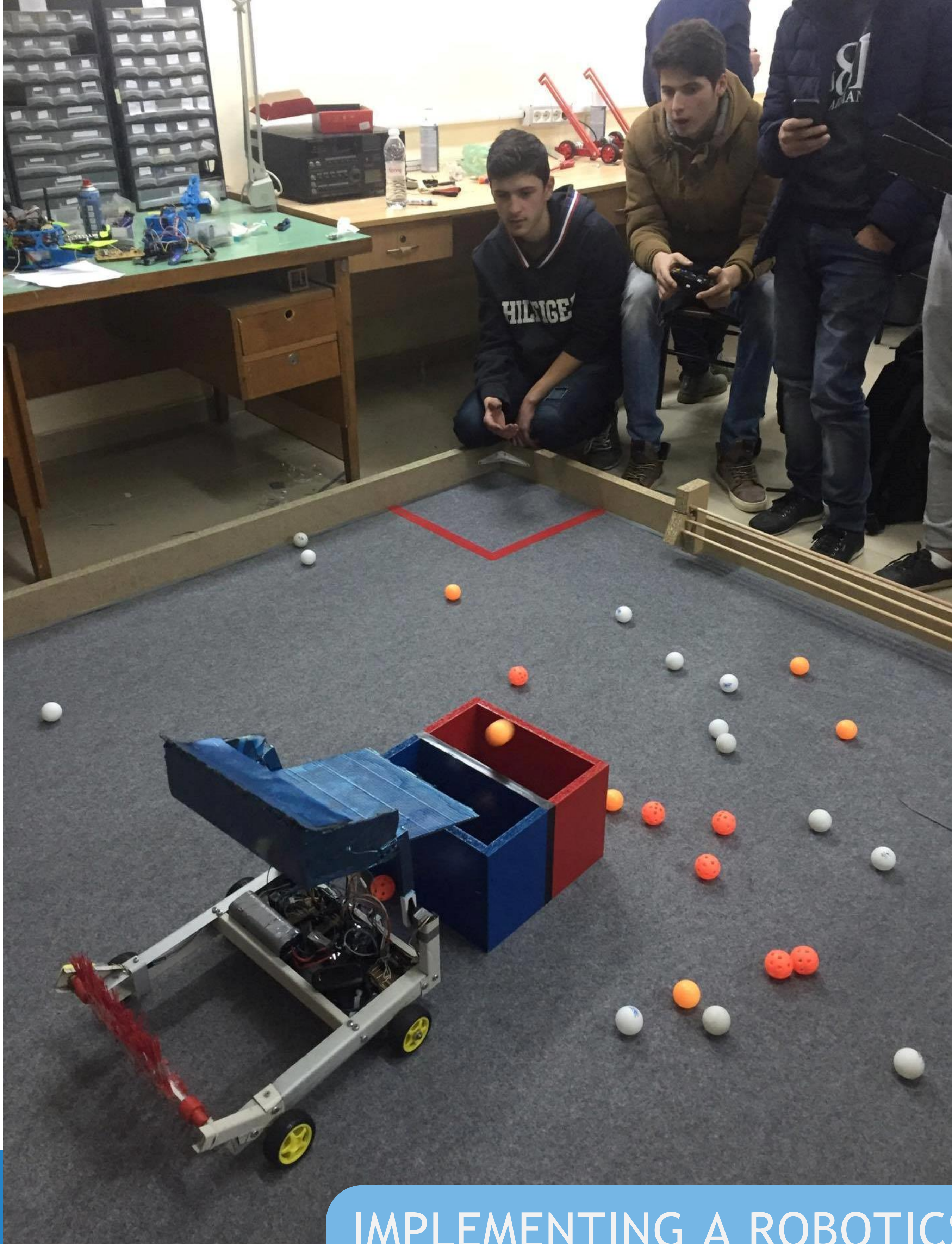

IMPLEMENTING A ROBOTICS COMPETITION AT THE HARRY FULTZ INSTITUTE

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THE HARRY FULTZ INSTITUTE

WPI

IMPLEMENTING A ROBOTICS COMPETITION AT THE HARRY FULTZ INSTITUTE

An Interactive Qualifying Project Report Submitted to the Faculty of WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Bachelor of Science

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ABSTRACT

Robotics competitions are a useful teaching tool, allowing students to apply what they learn in class and helping them develop social skills through teamwork. In cooperation with the Harry Fultz Institute in Tirana, Albania our team implemented a robotics competition for high school students. We created and taught lessons on electronics, programing and mechanics to guide teams of student through the robotics design process. As students faced challenges constructing their robots we provided guidance through mentorship. Overall, the element of competition motivated the students and fostered a sense of achievement. Using student feedback, we refined our teaching methods and created a plan to expand and improve the Savage Soccer competition for the future.

EXECUTIVE SUMMARY

MOTIVATION

In recent years, STEM (Science, Technology, Engineering, and Mathematics) fields have become important to the development of job growth around the world. Students who receive opportunities for hands-on learning have shown increased motivation and are more prepared for jobs in STEM fields. One of the most exciting ways to encourage hands-on learning is to have students build robots to compete in a robotics competition. This idea has seen great success in recent years with many international competitions springing up to meet this need. Effective robotics competitions not only include opportunities for students to test their hands on skills, but also, chances for them to develop important teamwork and communication skills ("Home | FIRST," 2016).

Figure 1: Student testing his robot

PAST PROJECTS

The sponsor of this project is the Harry Fultz Institute, a private technical high school and community college located in Tirana, Albania. This is the third consecutive year of a WPI student team working with the robotics program at the school. Under the supervision of Harry Fultz Professor Enxhi Jaupi, the first WPI team focused on the creation of necessary resources and structure for a successful robotics program of 24 students. The second project expanded the club to 32 students and focused on the advancement of technical knowledge within the club. The end result was the creation of eight unique robots that demonstrated the development of technical knowledge among students. Our project built on the work of these past teams and advanced the club further by introducing a robotics competition.

MISSION AND OBJECTIVES

Our mission was to create a challenging and rewarding robotics competition at the Harry Fultz Institute by teaching robotics topics to students, providing and creating a support system for the competition, and introducing cooperation and an element of competition into a learning environment. Our project objectives were as follows:

Objectives:

- ***Analyze the initial interests and perceptions of students and teachers regarding competition and robotics***
- ***Effectively teach robotics topics to the students at the Harry Fultz Institute***
- ***Develop the competition framework and needed resources for a robotics competition***
- ***Assess the effects of competition on team dynamics and student motivation both within and between teams***

CLUB EXPERIENCE

LESSONS

With our objectives in mind, we decided to implement lessons for the students in the robotics club at HFI. These lessons consisted of two parts; the first being a short lecture and the second being a collaborative hands-on activity. This provided the opportunity for students test the theory they learned in a direct way. The topics covered in these lessons were as follows:

- ***Introduction to robotics***
- ***Introduction Arduino***
- ***Introduction to the robot design process***
- ***Lifting mechanisms***
- ***Motor drivers and boost converters***
- ***Chassis design***
- ***Programming basics***

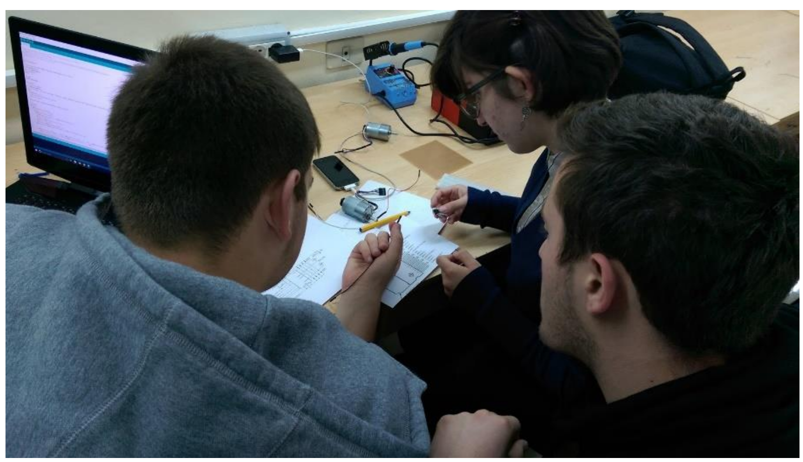

Figure 2: Team completing an in-class activity

During these lessons, students had the opportunity to ask questions and work at a comfortable pace. This encouraged them to take their time during the hands-on portions of the lessons, ensuring that all students in their group grasped the material. In order to measure the effectiveness of our teaching, we frequently asked for feedback from students and professors in the form of surveys and dialogue.

MENTORSHIP

An important part of the classroom experience was mentoring the students throughout the entire project. We mentored the students by asking leading questions when they came to us with problems. While the majority of students were comfortable asking questions and interacting with us, some were initially timid. We overcame this by being proactive and observing teams to see if any were struggling. If we observed a team who seemed like they needed help, we would encourage them to ask questions.

"The WPI students are sort of our mentors. They help us work through different difficulties we might face during the construction of our robot."

COMPETITION

For our project, we adapted a competition after an initial assessment of the resources available at the Harry Fultz Institute. Taking constraints such as available lab space, parts, and monetary resources into account, we determined Savage Soccer to be the best competition for the robotics program at HFI. Savage Soccer is a WPI based robotics competition created with the intent of providing schools an affordable and accessible competition format. This makes it a great option for developing robotics organizations, like the Fultz robotics club.

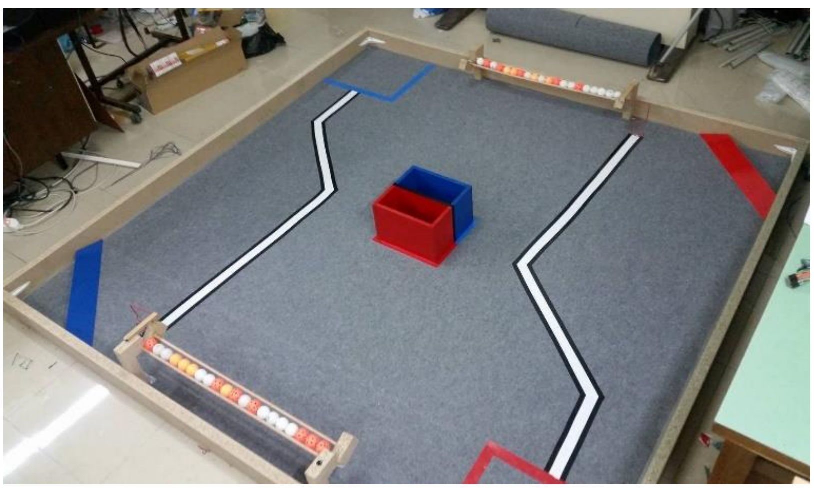

Figure 3: Competition field

We selected the 2014 Savage Soccer game as a starting point and modified the ruleset to better accommodate the students' technical skill level and time constraints. These modifications ranged from the provided parts to the dimensions of field elements. Students were given the full ruleset and field specifications during the second week in order to ensure they had ample time to digest the information.

The competition provided students an open-ended challenge with many viable solutions and ways to implement a design process. The only constraints placed on students were the competition rules and parts available. In order to facilitate an efficient and effective design process, we prepared a lesson reviewing different brainstorming formats. This provided students with relevant background knowledge while still allowing them to develop their own method for creating a design. Additionally, if students ran into any challenges, we gave them opportunities to seek our feedback on their designs.

RESULT

Through observations, and surveys it became clear that the students thoroughly enjoyed the incorporation of a competition into the club structure. Many, including Professor Jaupi, felt that the competition allowed students the freedom to choose their own designs and experiment while providing an incentive to outperform the other teams. A returning robotics club student remarked:

"The robotics club this year is very good. It's more beautiful than last year, because this year is a competition and we will make robot which is the best."

The structure of the club was ultimately effective in teaching students skills in robotics, teamwork, and problem solving. Students responded well to the lesson format of shorter lectures with longer, hands-on activities

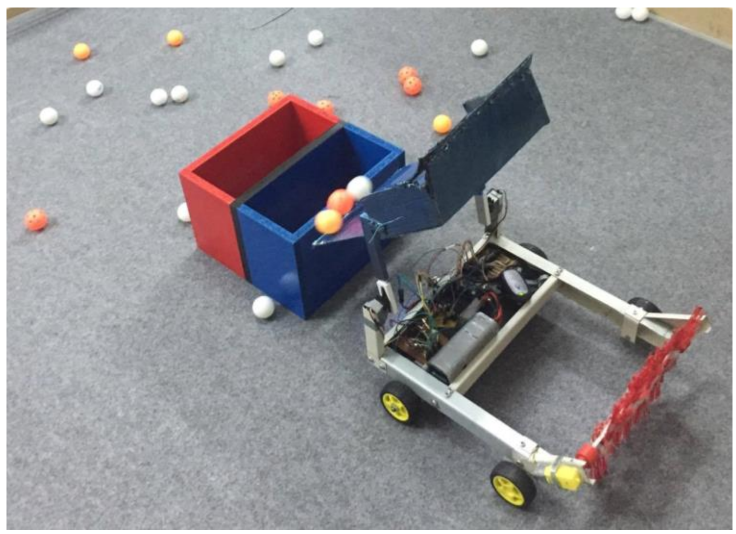

Figure 4: Final robot testing

However, student engagement during lectures varied initially due to the mix of experienced and novice members in the club. The discrepancy in student knowledge created a difficulty in setting a universal pace for the class. A few students expressed that they would have preferred more general lessons reviewing basic robotics topics. Others, especially returning students, wanted more challenging lessons and felt they could teach their own group members the basics. Towards the end of the class, we relied on the team leaders to fill the knowledge gaps present amongst their team members and therefore were able to cover more material during our last few classes.

FUTURE

Figure 5: Students in Class (Enxhi Jaupi, 2016)

In our many discussions and interactions with Professor Jaupi, it became clear that he will not be available to teach at the Harry Fultz Institute next year. Therefore, taking into consideration the transition of club leadership from Professor Jaupi to Professor Hoxha, we propose that next year's team focus on improving the competition structure that we introduced this year. From our experiences we learned that the structure of competition lends well to increased motivation, collaboration, and positive interactions among teams. Teams often ran into similar issues and they could therefore receive help from their peers as well as the professors. Students enjoyed this because it caused teams to work not only with their teammates but also with other teams. For these reasons we think the competition structure should be maintained.

We have several suggestions about improving the competition. Due to setbacks, our class started to fall behind schedule, which caused difficulty because the amount of time available to build and test robots was already brief. Implementing goals for the end of each week and having stricter deadlines would fix this issue and keep students on track. In regard to the organization of classes week to week, we recommend focusing on lessons for the first two weeks, beginning robot design and chassis construction in the third week. Also, we suggest having a drivable base robot in the fourth week so that the remainder of the class can focus on building and testing the game mechanisms. We also suggest starting construction of the competition field in the second week to allow students a better understanding of how their robots will interact with game pieces.

When teaching robotics topics, we found it is best to get to the point with lessons, as the team leaders will be able to explain the finer details. We also recommend getting to know the students early on through conducting informal interviews or by taking them out to coffee. This will make the WPI student team more approachable and more knowledgeable about how to help the students learn.

ACKNOWLEDGEMENTS

Our team would like to thank several groups and individuals for supporting our project. First, we would like to thank the Harry Fultz Institute for inviting us into their school and allowing us to work with their students. We would also like to thank Worcester Polytechnic Institute for allowing us to pursue this life-changing opportunity as a part of our coursework. We would also like to thank Professors Jaupi and Hoxha for easing us into our roles as teachers and lending their expertise to the club. Additionally, we are very grateful to our advisors, Professors Hersh and Christopher, who helped guide the direction of our project and acted as editors for our report. We are also appreciative of the students from the Polytechnic University of Tirana who came to the club as observers and helpers. Finally, we would like to thank the students who participated in the club. Their hard work and dedication was truly inspirational and without them none of this would have been possible.

AUTHORSHIP

All members of the team contributed to the completion of this paper. We outlined each section together before independently writing the sections. Editing each section was initially done individually and then was finalized in a group meeting.

Mechanical and design lessons were created and taught by Josie and Jacob.

Programming and electronics lessons were created and taught by Ben and Nathan.

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INTRODUCTION

Figure 6: Jacob helping students with their Arduino

In recent years, STEM (Science, Technology, Engineering, and Mathematics) fields have become an engine for job growth around the world. As interest in STEM jobs has increased, researchers have focused on how to adequately prepare students for these jobs. Much of this research suggests students needing to apply what they have learned in the classroom to hands-on projects in a group setting (Mills & Treagust, 2003).

Robotics competitions are one such way students can apply their knowledge to real life applications. These competitions have exploded in popularity internationally over the past ten years with over 500 thousand students competing annually in FIRST Robotics competitions alone (“Home | FIRST,” 2016). These tournaments incite high levels of excitement and energy among students as they compete alongside their peers. Unfortunately, these competitions are not as accessible to students lacking in monetary resources and the knowledge needed to be successful.

Figure 7: Student programming his Arduino

These competitions are also a good way for students to learn how to work in teams. Building robots requires knowledge of many different topics, which lends itself well to working on an interdisciplinary team. Each member of a group may have different areas of expertise, and most high school students have not had the opportunity to learn how to coordinate these skills. Creating a robotics competition for Albanian students will allow them to not only apply the concepts they learn in the classroom to a real project, but also learn interpersonal skills that will help them in a workplace environment.

The Harry Fultz Institute, a technical high school and community college in Tirana, Albania, has enhanced its existing education with hands-on STEM learning opportunities such as the robotics club. Over the past two years, the school has collaborated with WPI (Worcester Polytechnic Institute) students to establish an after school robotics program where students work on an in depth robotics project. Working alongside Professor Enxhi Jaupi, WPI students taught robotics topics with the goal of creating advanced robots such as a robotic arm, autonomous rover, and a hexacopter. Our project expanded the club by supplementing the lessons with a robotics competition between six student teams. This competition was meant to better teach the fundamentals of robotics and teamwork through real-world problem solving.

CONTEXT

We begin this chapter by giving an overview of the Albanian High School education system and in particular, the Harry Fultz Institute and past WPI project group involvement with the robotics club. We also consider the effects of competition on student engagement and learning. Finally, we discuss approaches that teach students the fundamentals of robotics for competitions and a give brief description of the competition we chose to adapt.

ALBANIAN HIGH SCHOOL EDUCATION

High school education in Albania consists of two distinct categories, academic (or regular) and vocational. Regular school focuses on preparation for higher education and most students graduate in three years, while vocational schools focus directly on preparing for a specific career path and most students graduate in 2-5 years depending on the degree ("Education System in Albania", 2016). In addition to the general education available at a regular school, students enrolled in vocational high schools choose a field they wish to concentrate in and then take specialized classes in that field to gain an understanding of their trade ("Education System Albania", 2012).

The Albanian school system provides students with a rigorous course load to prepare for the labor market or higher education. However, the bulk of this classwork is focused on theoretical knowledge rather than application of topics learned in class. As a result there are few learning opportunities, inside or outside of the classroom, that incorporate teamwork, hands-on activities, or projects. Instead, students are assigned independent, research oriented classwork (E. Jaupi, personal communication, October 26, 2016).

Our sponsoring organization, the Harry Fultz Institute, has acknowledged this challenge and is working to provide students with more opportunities to apply topics learned in class to real world situations. One way they have tackled this goal is through the creation of after school programs like the robotics club. A student from HFI explained the difference between the club and classes by saying

> *"The robotics club, is more hands-on. During the classes in our school you learn, you take lectures, but you don't touch things...This is what the robotics club gives to all the students...To touch the things you learn during the lectures, during the lessons." (Fultz Student, Personal Communication, Nov. 14th, 2016).*

THE HARRY FULTZ INSTITUTE

Figure 8: Front gate at the Harry Fultz Institute

The Harry Fultz Institute was founded in 1921 by the American Red Cross Association as the first Albanian vocational school. Since its inception, the school's goal has been to empower students to contribute to their communities by providing students with professional and technical skills (Fultz Institute Website, 2014). The Harry Fultz Institute started out small, with only 32 students in its inaugural class, but through outreach and effective teaching methods, the school quickly grew to 500 students in 1932 and developed a reputation as an outstanding technical high school. The modern day Harry Fultz Institute is divided into a private high school with around 900 students and a community college.

Figure 9: Machine shop at the Harry Fultz Institute

The Harry Fultz Institute has many facilities to provide a well-rounded learning environment for its students. The vocational high school at the Harry Fultz Institute is made up of several academic buildings which include resources such as: a library, traditional classrooms, and labs designated for hands-on classes. Other non-academic buildings such as a gymnasium and several sports fields are also available to students. Machine shops with a wide variety of equipment are incorporated into some of the school's vocational classes. Students in machining courses have access to manual mills, lathes, presses and other industrial grade machines as well as solar panels, cars, and air conditioning control systems. Students are taught to use, maintain, and install these machines, and they are actually responsible for managing the heating and cooling of the entire school. The campus is also home to a community college where adults come to take various academic and vocational classes.

The mission of the Harry Fultz Institute is to provide an education that incorporates both theory and practice. Due to its vocational nature, the Harry Fultz Institute includes technical branches such as electronics, programming, and automotives to supplement the more traditional sciences and language departments found at many other schools. Students at the school choose a focus in a field of engineering and then primarily take classes within that field. This allows the students to have a more in depth education on subjects that interest them. Through these technical courses the Fultz students are able to explore theory as well as apply the things they are learning in a professional setting. For example, students in electrical engineering courses not only learn the theory behind how circuits work, they also build and test the circuits that they learned about in class (Fultz Institute Website, 2014).

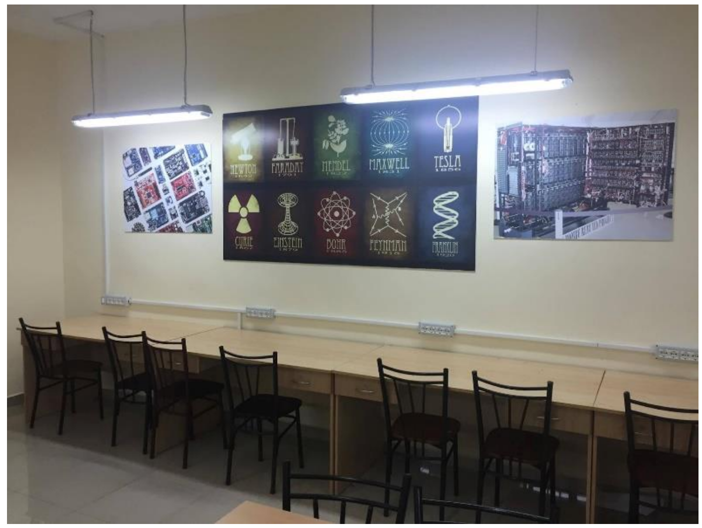


Figure 10: Robotics lab space

PAST PROJECTS

For the past two years, student groups from WPI have partnered with the Harry Fultz Institute to develop and advance the school’s robotics club. These groups were focused on experimenting with teaching styles and determining what methods work best within the Harry Fultz robotics curriculum.

The first WPI project group, in collaboration with Professor Enxhi Jaupi, established the robotics program at the Harry Fultz Institute. This project, completed in 2014, focused on teaching robotics topics through group work and hands-on projects. The students designed and built their own robots in teams. The WPI project team encountered several obstacles with the class. A budget restriction of $300 and shipping delays postponed robot construction until the final weeks of the class. Therefore much of the building happened in a short amount of time and continued after the WPI students left Albania. The WPI project team also faced challenges with designing an effective curriculum. They found that some of the Fultz students were more prepared than others, with some teams needing extra support in order to design and create their robots (Tomko, Sussman, McQuaid, & Hunt, 2014).

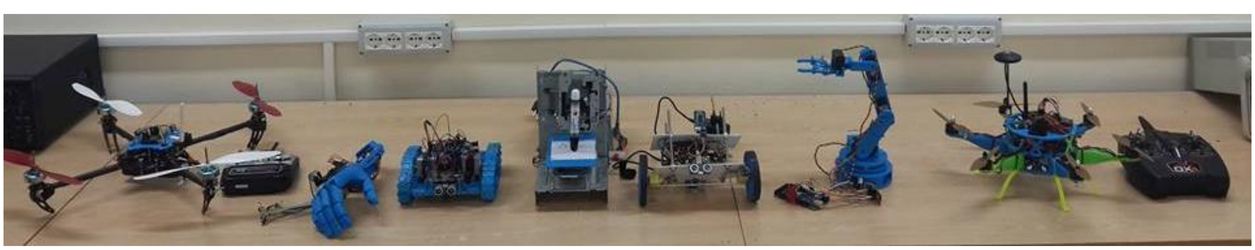


Figure 11: Robots constructed during the club's second year (Enxhi Jaupi, 2016)

The following year, the 2015 WPI project group worked to advance the club and focus on evaluating various teaching methods and their effects on project-based learning, group work, and self-directed learning. The group used these methods to create structured lesson plans in robotics topics such as 3D modeling, 3D printing, programming, motors, electronics, etc. The students then worked to apply their knowledge in a series of labs culminating in a final group project. For this final project each group designed and built a different robot of their choosing, including an autonomous hexacopter drone, an autonomous rover, a balancing and jumping remote controlled robot, a 3-axis CNC machine, a robotic hand, and a robotic arm. The 2015 WPI project group recommended that following years incorporate smaller teams and work to balance the students' skills within each team. They also had problems when ordered parts did not arrive on time, delaying the completion of the robots. The 2015 project group also recommended that future work with the robotics club should go towards forming a robotics competition for the school and possibly the surrounding area (Schifilliti, Landis, Jacobsohn, & Pontbriant, 2016).

Figure 12: Students presenting their projects

Currently, the robotics club at the Harry Fultz Institute is in an expansion phase. Due to an overwhelming number of interested students, the professors required students to apply to the club. From these applicants, students were selected based on their work ethic, grades and background knowledge. This year, 24 students were selected to join the club, and from these 24, 6 teams of 4 students each were created. Each team includes students proficient in the different disciplines of robotics, and each team also includes at least one student who was in the club the previous year. These students act as team leaders teaching basic concepts and keeping their team on track.

Teaching robotics topics historically has necessitated cooperation among different specialists since robotics encompasses many different STEM topics. Therefore students interested in robotics need not only to be prepared with the technical skills to build a robot, but also the interpersonal skills necessary to work in a team. Teaching methods such as project-based learning and self-motivated learning have been useful tools to develop teamwork and achievement because they incorporate the hands-on and open-ended problem structure of robotics (Altin & Pedaste, 2013). Similarly, competition has been found to be a successful teaching tool (Munoz-Merino, Fernandez Molina, Munoz-Organero & Delgado Kloos, 2014).

COMPETITION STRUCTURE AND ITS EFFECT ON STUDENTS

In order to introduce a competition into a learning environment, one must first understand what it means for student to compete. In studies, competition has been shown to produce several positive effects on classroom learning including increased motivation, interactions with teachers and interest in STEM fields (Piepmeier, 2013). Because of these benefits, many robotics curriculums have chosen to either develop or join a robotics competition.

POSITIVE RESULTS

Motivation among students is one the most important factors for achievement and success in schools. However, it is impossible to pin down a perfect formula to motivate a student because of the vast number of factors involved and the uniqueness of each student's response to attempts to motivate them. Some of these factors that contribute to motivational levels are the student's perception of their own achievement, teaching methodology, teacher-student relationships, cultural dynamics, and student autonomy (Munoz-Merino et al., 2014).

While competition is not a magical key to student achievement, it has been found to be a successful motivator by several studies. A 2010 survey taken by high school students in the United States addressed the question of students' attitudes towards STEM based on their after school activities. Students in the same academic classes were all asked about their attitudes and opinions on topics such as the importance of STEM and the likelihood they would pursue a STEM field. Half of the students were involved in after school FIRST (For the Inspiration and Recognition of Science and Technology) robotics competitions, while the other half was not. It was found that students involved in competitions were more motivated in school and gained skills outside those of robotics including a better understanding of cooperation with other students. These students stated that being able to apply skills learned in class to real world situations caused science to become more real to them and therefore more interesting (Welch, 2010).

A competition can also increase the interaction between students and teachers, as opposed to the one sided dialogue of lecturing. This promotes forming relationships within the classroom which can increase a student's motivation (Piepmeier, 2013).

Competition also helps promote women's involvement in STEM programs. A 2010 study stated that competition had previously been seen as a deterrent for girls, because it leads to potential situations where they feel alienated from their male peers. However, this study, which interviewed 140 females in robotics competition programs throughout urban tech high schools, found that competition actually attracted and helped retain female students. The students enjoyed the competitive but cooperative, informal learning environment. This "cooperative" competition is the key to a successful competition and to developing teamwork skills because it encourages students to work on more than just winning (Notter, 2010).

Many effective competition systems strive to incorporate this cooperative element among competing teams in order to capitalize on these positive effects. This is frequently done by making challenges that require the help of a partner team to complete. These challenges are designed to encourage collaboration and community among competitors while still having an element of competition associated with it. This idea is the basis for every WPI Savage Soccer, FIRST, and VEX challenge that is created each year ("Home | FIRST," 2016; K. Stafford, personal communication, Sept 29, 2016). For example, the 2015 Savage Soccer challenge required teams to form coalitions of two teams. During qualifying rounds, these coalitions were randomly assigned by event organizers and this helped create an atmosphere of friendly competition. Teams that played against each other in one match could find themselves on the same coalition in the next match, forcing cooperation and sportsmanship.

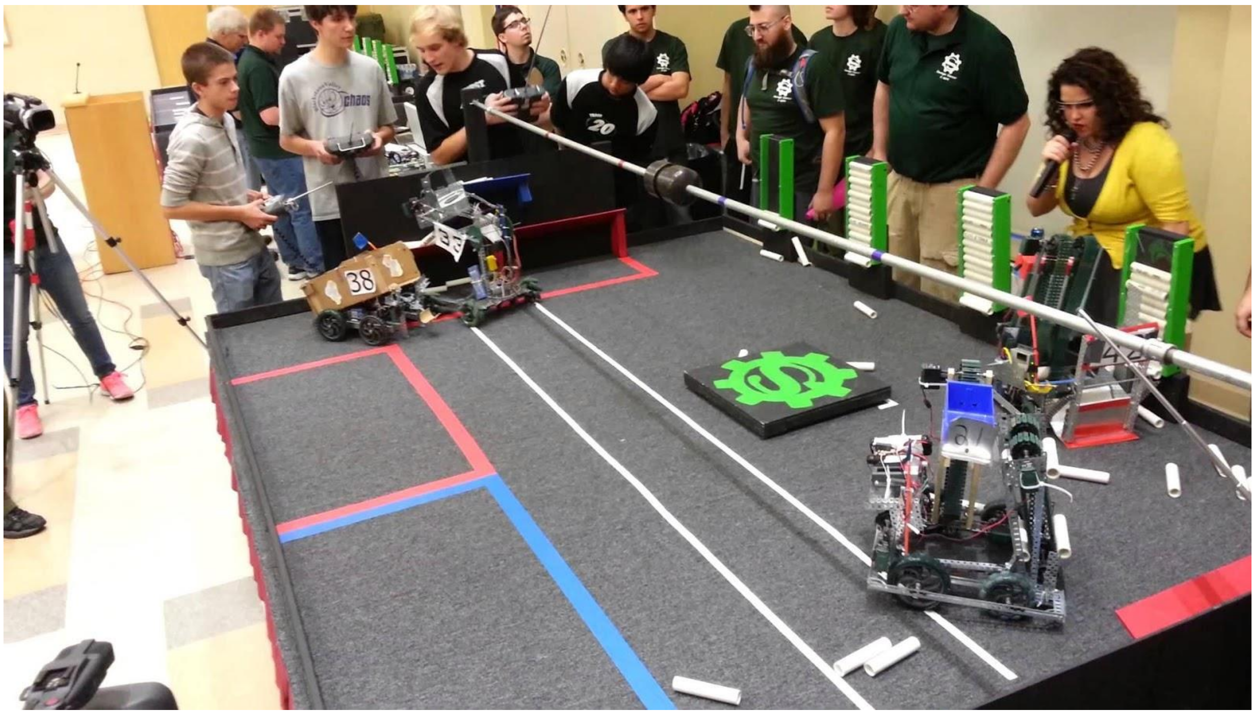


Figure 13: Savage Soccer competition match ("The intergalactic Savage Soccer", 2016)

These coalitions would compete in timed matches to see which side could score the most points. From there, these teams are ranked on their individual win/loss records ("The Intergalactic Savage Soccer", 2016). This is a structure that many competitions employ with very positive results. This incorporation of cooperation not only allows for the sharing of strategic ideas among teams, but also makes competing teams friendlier with each other.

NEGATIVE RESULTS

Many researchers have found that competition without the element of cooperation can have negative results. When competitions are structured in a combative way it becomes difficult for students to maintain motivation and it can have the opposite desired effects (Fitch & Loving, 2007). Frustration, anxiety and a lack of self-esteem in personal achievement have all been found to result from ineffective competitions and lead to decreased student interest in STEM (Munoz-Merino et al., 2014). One study from the Stevens Institute of Technology addressed the benefits and constraints of a class competition structure in an Introductory Robotics class. Students in the class criticized the fast paced class structure and feedback stated that "performance outcomes did not adequately reflect the students' efforts and the amount of material they had learned throughout the course." (Cappelleri & Vitoroulis, 2013, p. 73). Therefore, the class structure of labs and one final project (the competition) was replaced with ten smaller lab-like activities and three "decathlon" projects which were essentially projects that put to the test a wide variety of different skills. These projects were each one week and allowed students to show a wider range of learned concepts. This "decathlon" proved to be successful. There were fewer negative emotions, higher motivation, students didn't feel as overwhelmed and they were able to apply more concepts (Cappelleri & Vitoroulis, 2013).

In a competitive environment some studies argue that disagreements, conflicts, and disruptions are inevitable, unavoidable, and even necessary (Fitch & Loving, 2007). Negative interactions are always going to exist, but the resolutions of these issues are the determinant of whether the competition becomes cooperative or combative. A dialogical and respectful approach to resolving problems, as opposed to a close minded, conflictual approach leads to better teamwork skills and cooperation among students ("Home | FIRST", 2016). This is referred to as gracious professionalism in the FIRST Robotics Competition and is something that all teams strive to follow while competing. To incentivize this concept, FIRST crowns one team every year as the winner of the Chairman's Award, an award that goes to the team that best exemplifies these values ("Home | FIRST", 2016). By incentivizing and honoring teams that abide by this idea, FIRST is creating role models for other teams to follow which is key to creating a cooperative environment.

Research suggests that in order to have a cooperative competition, there needs to be a set of agreed upon rules and standards for fair play, so that students are aware that there is more to be gained from competition than simply winning (Fitch & Loving, 2007). Currently the most popular robotics competitions worldwide devise a challenge each year. With this challenge comes a defined rules document and competition field specs that all events must follow ("Home | FIRST," 2016; "REC Foundation,"donovan 2016). It's important that these rules allow for creativity of design and "an environment for motivating students, learning problem solving techniques, and promoting creative thinking skills" (Chung, & Anneberg, 2009, p. 625). This can be seen in New Zealand where several types of competitions were implemented varying from robot sumo wrestling to maze navigation. The actual tasks do not necessarily influence whether or not students are interested, but rather how they are presented and the rule set associated with the challenge. Therefore, it is important that we consider the best type of competition and teaching structure for our project so that we can promote motivation and teamwork skills among students at the Harry Fultz Institute in order to create the most effective competition possible.

SUCCESSFUL CLASSROOM AND COMPETITION MODELS

There are many existing classroom competition models that serve a variety of students in differing settings ranging from formal classes to summer programs. WPI has had three types of robotics programs throughout the years that teach the basics of robot design and then have students apply what they learned to a robotics competition. Table 1 below compares some of the elements of these three.

Table 1: Comparison of various classroom models culminating in competition

	RBE 1001	Frontiers	EBOT
Target	Mostly college freshman	High school juniors and seniors	High school students
Type	College course	Summer camp	After school program
Learning Period	7 weeks	2 weeks	3 seminars
Building Period	2 weeks overlapping end of learning period	1 week overlapping end of learning period	One month, after seminars
Purpose	To teach a foundation of mechanical engineering, electrical engineering, and computer science and prepare students for the next robotics courses	To generate interest in STEM, specifically robotics, among high school students	To improve education in science and engineering through the use of affordable robotics programs.
Awards	Improved Grades	None	None
Source	(K. Stafford, personal communication, Sept 29, 2016)	(K. Stafford, personal communication, Sept 29, 2016)	(Donovan, Hecht, & Woodard, 2005)

The courses are all similar in that they teach fundamentals of robotics and then have students implement those fundamentals in a competition. However, each course does this in a different way. RBE 1001 is a class that WPI students take for credit. Since it is a college level course, it assumes more background knowledge and pushes students more rigorously than a course aimed at high school students. Frontiers is a summer camp that lasts just two weeks. Although it only lasts two weeks, the students work on the course all day. The EBOT program is slightly different from these two in that the classroom section doesn't teach the students, but rather teaches mentors who teach the students. This program also has the longest building period, lasting four weeks, but the shortest teaching period, which is the opposite of the other two courses.

RBE1001

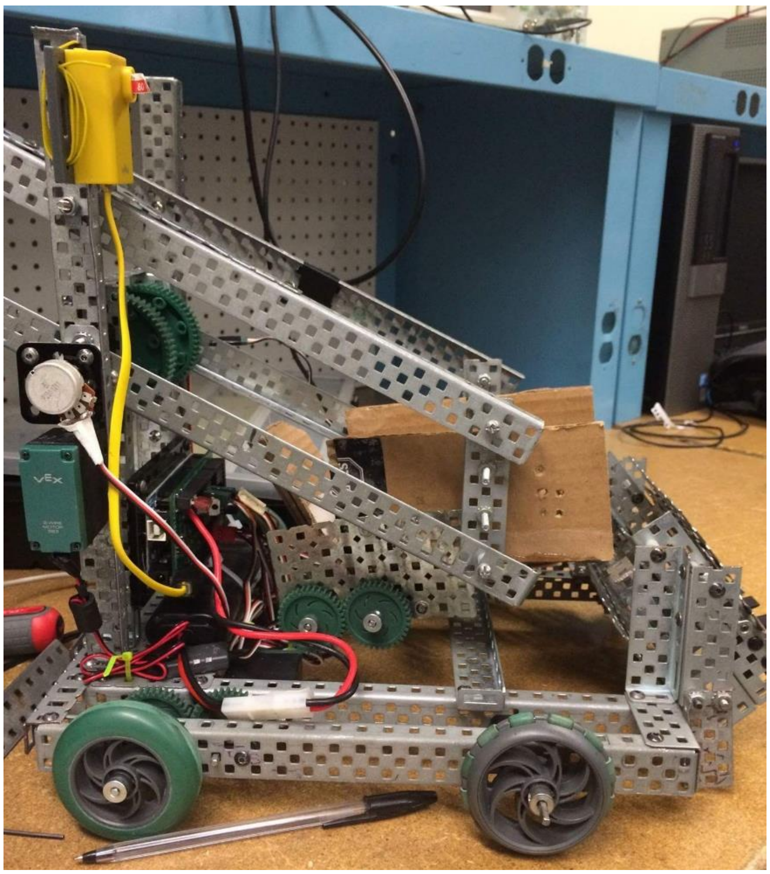


Figure 14: Robot constructed for the RBE1001 final challenge

The Introduction to Robotics course, taken by students at WPI, lasts one term (seven weeks) with one hour lectures being held four times per week in addition to a two hour lab that meets once per week. During class, students learn the technical side of building robots, such as calculating the forces on a robot, designing electrical circuits, and the basic programming concepts needed to control a robot. These classes are fairly rigorous and expect the students to have more background knowledge than courses aimed at high school students. In lab, students implement what they learned in class (K. Stafford, personal communication, Sept 29, 2016).

The first lab is devoted to building a robot that drives, the "base bot", while the following labs are more focused on applying techniques from class. An example includes creating a line detecting circuit and using this circuit to have the robot follow a line around a course. This course culminates in a demonstration of the final robot and a competition among the groups to see who built the best robot. The rules for this competition are adapted from the Savage Soccer rules and modified to emphasize building a functional robot over developing a winning strategy (K. Stafford, personal communication, Sept 29, 2016). In addition, students must demonstrate the autonomous and driver controlled functionality of their robot to the professor.

FRONTIERS

Frontiers is a two week summer program held at WPI. One section of the program is a course that focuses on the basics of robotics. In this camp, students learn and implement the fundamentals of robot design. At the end of the first week, the competition rules are announced and the building period opens. The topics covered in lecture cover the parts in the kits, programming concepts, implementing sensors, force analysis, control theory, and DC motors. In lab, students build a robot to compete in the challenge at the end of the program. The challenge completed in this program is very similar to the challenge at the end of RBE1001 (K. Stafford, personal communication, Sept 29, 2016).

EBOT

EBOT began as an IQP completed at WPI in 2005. This project included designing a low-cost curriculum to teach high school students robotics that ended with a Savage Soccer style competition between the teams. The ultimate goal of the program was to get students excited about STEM and robotics and to provide the students with real-world skills and experience (Donovan et al., 2005). The course starts with three workshops, the purpose of which was to familiarize the team mentors with topics and the kits used to build the robots. The first focused on mechanics fundamentals, the second on programming basics, and the third on advanced topics. The mechanics fundamentals workshop aimed to teach the mentors the basics of mechanical design and give a general idea of what is possible with the kits. The programming basics workshop aimed to teach the fundamentals of C programming without going into too much detail, which proved to be a mistake. The final workshop on advanced topics, had two functional robots built during the presentation as well as a lecture on sensor use. After the workshops, the four week long build season began. This build season saw six teams each design and build their own robot with the guidance of one of the mentors who was taught in the workshops. The mentors' jobs was to help overcome obstacles in the design process, and to keep the students from harming themselves or damaging the equipment (Donovan et al., 2005).

The EBOT program emphasized the following points that enable it to stand out among the many other robotics programs and competitions out there. The first of these is cost. Typical robotics competitions can easily surpass $1,000 to run every year while the EBOT program uses a kit that costs just $800 and is it is expected that future versions of the competition will use cheaper kits. The build season is just 4 weeks, which is a much shorter time frame than most other robotics competitions. The IQP group taught local workshops for the mentors in order to ensure that the mentors had the necessary background knowledge to help the teams build their robots. Another positive aspect of the EBOT program is the short learning curve. The robots were simple enough for students to design and build them in 4 weeks with little to no previous experience but sophisticated enough to allow variations in design and strategy among the teams (Donovan et al., 2005).

2014 SAVAGE SOCCER GAME

The challenge we chose to use as the base for the club competition at the Harry Fultz Institute is the 2014 Savage Soccer Game. This game is played with two coalitions of two robots each. For the first 20 seconds of the game, robots operate in autonomous mode and for the next 120 seconds they operate under remote control. After 60 seconds of remote control operation, control of each robot is transferred to another driver. This allows for more student involvement during matches.

The primary game pieces used for scoring are ping pong balls, which are stored on a ledge supported by a peg. Robots must knock down the peg to release the ping pong balls onto the field. This is typically done during the autonomous period since robots can follow a line leading to the peg, and more points are awarded for completing this action autonomously. Once the ping pong balls are released, robots can attempt to score in an angled chute. Robots also have the opportunity to raise the chute as an endgame challenge to gain additional points. The final score is determined by the number of ping pong balls in the chute. An isometric view of the field can be seen in Figure 15 below.

Figure 15: 2014 Savage Soccer game field

PROJECT GOALS AND OBJECTIVES

The goal of our project was to create a challenging and rewarding robotics competition at the Harry Fultz Institute by teaching robotics topics to students, providing and creating a support system for the competition, and introducing cooperation and an element of competition into a learning environment. Our project objectives were as follows:

- Analyze the initial interests and perceptions of students and teachers regarding robotics
- Effectively teach robotics topics to the students at the Harry Fultz Institute
- Develop the competition framework and needed resources for a robotics competition
- Assess the effects of competition on team dynamics and student motivation both within and between teams

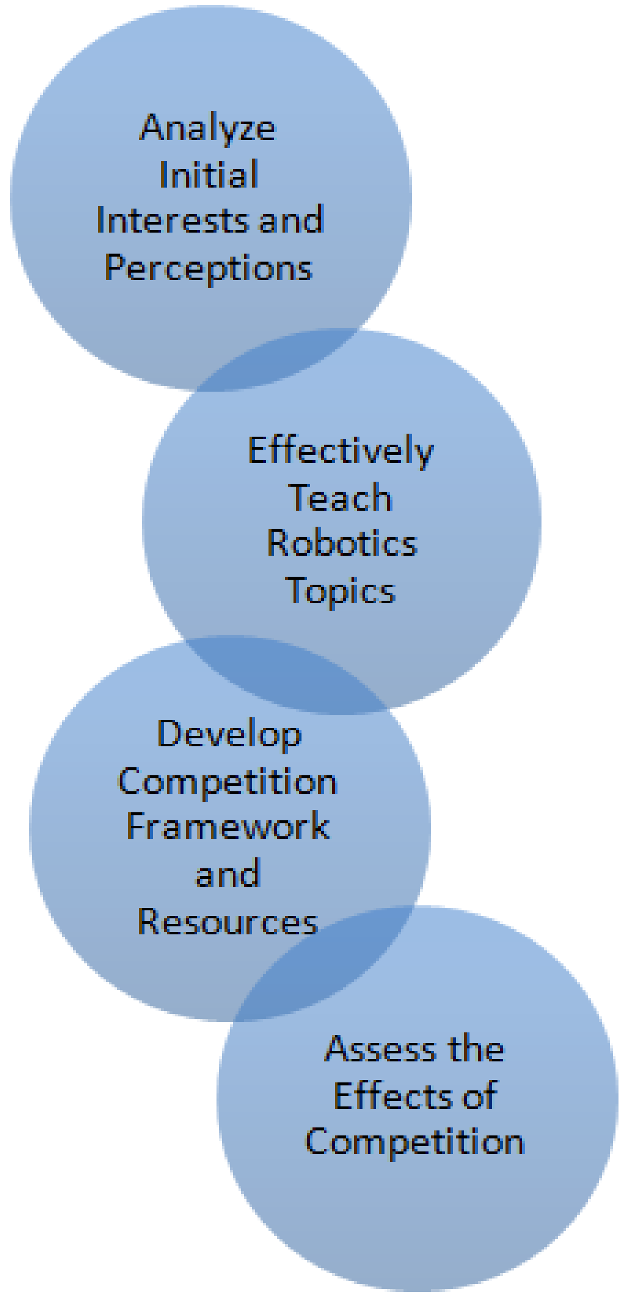


Figure 16: Project goals

GAUGING STUDENTS' SKILLS AND INTERESTS

One of the first things we did after starting at the Harry Fultz Institute was determine the current knowledge and interest levels of the students regarding robotics and competition. We wanted to gauge interest levels and commitment to the club as well as student perspectives about competition. To do this, we employed a variety of research methods outlined in Table 2 below.

Table 2: Project stakeholders and the relevant research methods

Stakeholders	Interviews	Freelisting	Observations
Robotics Club Students at the Harry Fultz Institute	✓	✓	✓
Professors at the Harry Fultz Institute	✓		✓

We first utilized a freelisting exercise with our sample of 24 students at the Harry Fultz Institute in order to gain an understanding of the students' experiences with robotics. Freelisting is one of several structured interviewing techniques designed to elicit systematic data about a cultural domain, a set of items all of the same type. In these exercises, participants are asked to list as many words or phrases they can about a cultural domain. These results are used by researchers in order to understand the contents and boundaries of the domain being studied. This information can then summarized in three main ways; frequency of response, rank of response and salience. Salience "indicates which concepts or categories should be given the most attention in later parts of a study" (Gravlee, L,. 1998). In this context, it is calculated using the equation in Figure 17. This equation helps us combine frequency of response and rank of response in order to summarize the information using a calculated number.

$$\frac{\sum_{n=1}^{N} \frac{ln-pn}{ln}}{N}$$

L_n = Number of items in a freelist
P_n = Position of activity on a freelist
N = Total number of activities in a freelist

Figure 17: Equation for calculating salience

The majority of students included the word “fun” in their responses despite the fact that they also claimed to have little experience with robotics. This implies that students came into the club expecting a positive experience despite many not having experienced robotics for themselves. Returning students were also excited. One returning student stated,

“It's my second time being part of the robotics club and I'm really enjoying it. I guess this year will be better!”

After seeing the freelisting responses, we were able to center our observations on specific questions such as why the students felt passionate about robotics. The results of this freelisting exercise are shown in Figure 19 below.

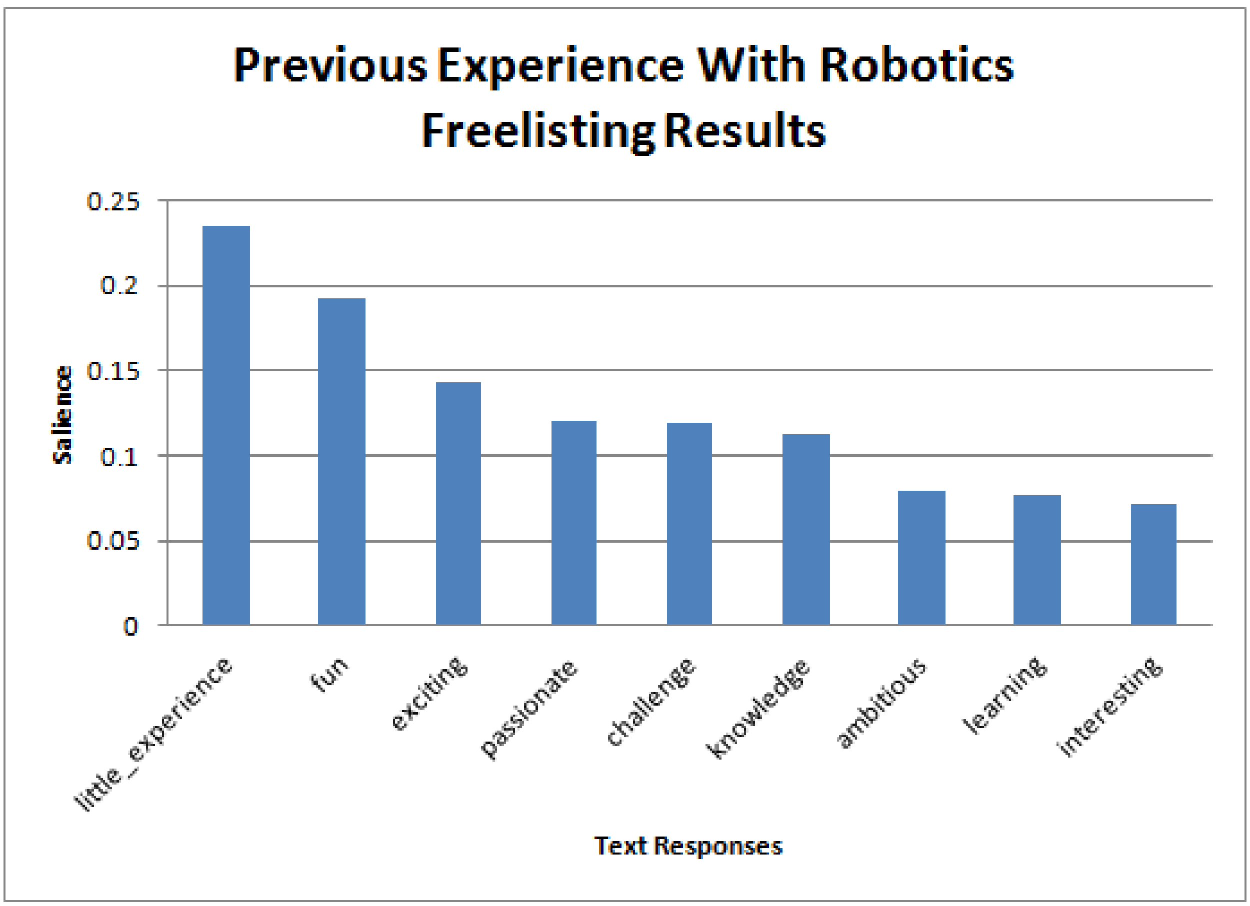


Figure 18: Freelisting results for previous robotics experience

Initially, students were timid and we had difficulty getting a grasp on what knowledge they possessed about robotics topics. We talked with each team individually, which provided an opportunity for students who may have felt uncomfortable speaking in front of the class to ask questions. One student inquired about computer vision tracking, a very complex function for a robot to effectively execute. Some other students asked questions about what we thought would be the biggest challenge that they would face while building a competitive robot. From these inquiries we gathered that many of the students understood that they would face challenges.

Additionally, these conversations revealed there was a knowledge gap among the students. Returning students clearly demonstrated their experience in simple conversation whereas first year students either did not ask questions or did not have questions. Despite this apparent gap in knowledge, there was no doubting the students' enthusiasm and passion.

"I am very passion about robotics. I like robotics a lot. As a kid I have made little things and I just want continues in years."

All observations of interactions between students can be found in **Appendix A:** Observations. Our observation process can be seen in Figure 19. While observing the students, we tried not to disturb team dynamics but disclosed our purpose in conversation if prompted. Data collected during observation was kept confidential and names were not associated with any given observations.

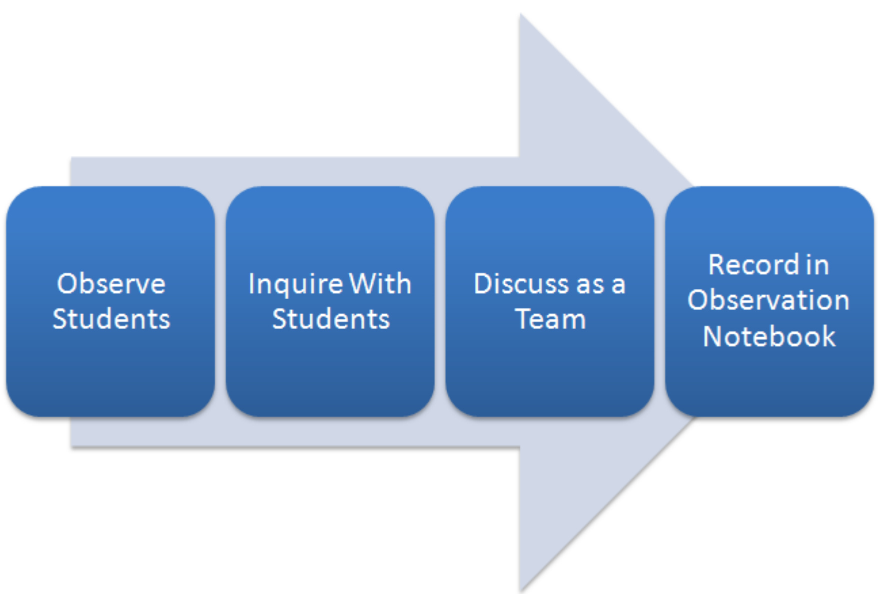
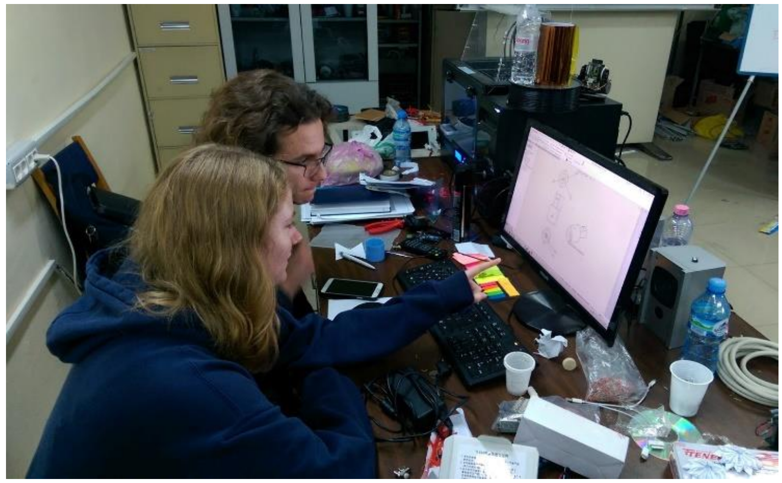


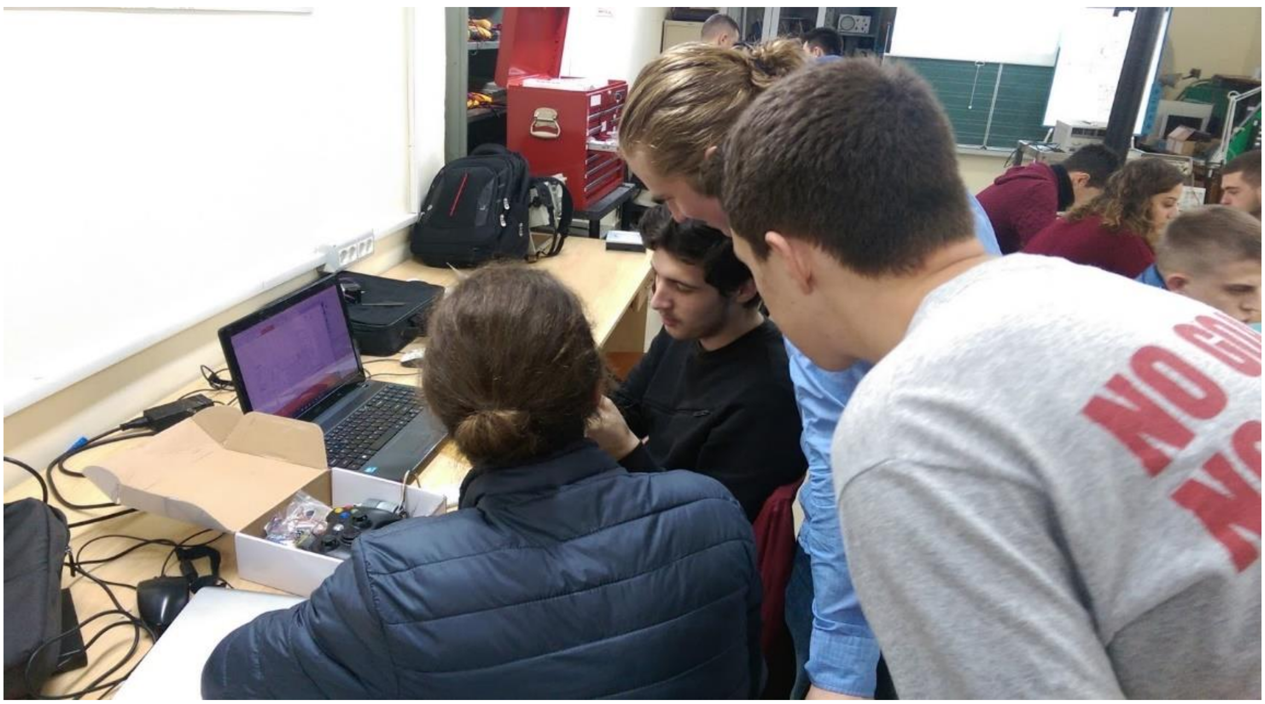
Figure 19: Observation process

These observations prompted us to inquire about why these students were so passionate and why they decided to be involved in the club. The WPI Marketing team conducted interviews with the students during the second week of classes and we were able to obtain the recording of these interviews. In addition, we provided questions for the marketing team to probe topics we wished to investigate. When one student was asked about why he chose to become involved in the club he replied:

"That's because I wanted to try something new...something way better than I have ever done here and this was the best chance. So why not? [The club] has a lot more than what here schools in Albania can offer. It's way more." another replied "I really love electronics and robotics is my passion."

CLASSROOM EXPERIENCES





"The WPI students are sort of our mentors. They help us work through different difficulties we might face during the construction of our robot."

LESSON DESIGN AND ADAPTATION PROCESS

Before the students could begin designing and building their robots, we needed to teach them some fundamentals of robotics, such as basic mechanical, electrical and programming topics. During our teaching preparation, we identified a few potential challenges that we might face. These challenges are summarized in Figure 20.

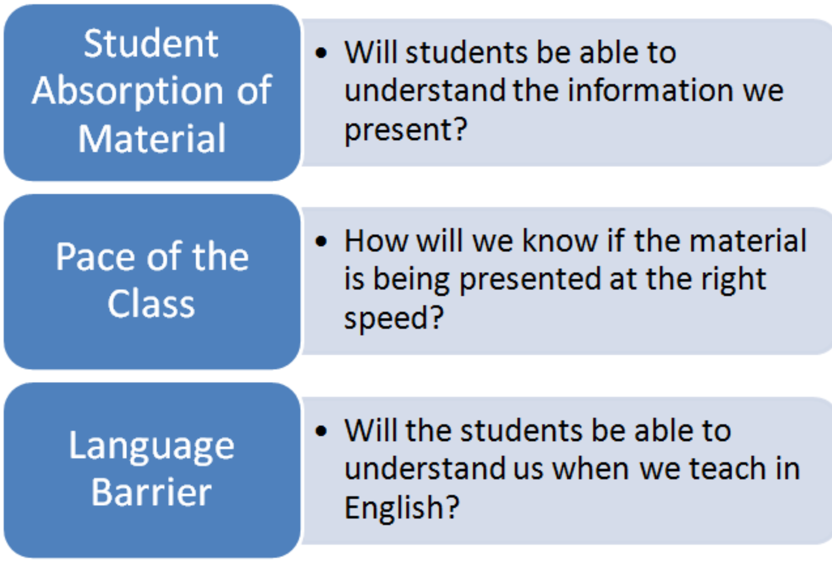


Figure 20: Challenges we anticipated going into the class

The biggest concern we had going in was that we would not be adequately explain lessons to the students. Robotics topics have many different parts that draw upon the fundamentals of physics and math. We did not know how well the students understood these topics before starting the classes.

No member of our team had prior teaching experience, therefore, we anticipated a steep learning curve associated with teaching our class effectively. In trying to alleviate this challenge, we researched how past WPI teams structures their lessons, and also spoke with WPI Professor Ken Stafford about his experiences teaching robotics in a college environment. These discussions gave us some insight on successful teaching.

Another challenge we anticipated was that the students would have trouble understanding us when we talked due to a language barrier. When discussing with Professor Jaupi before coming to Albania, he assured us that this would not be a major issue. With this in mind, we knew we needed to be flexible and consider the needs of all students.

Figure 21: WPI students teaching a robotics lesson

We designed lessons based on robotics classes at WPI and last year's class at HFI. First, we identified all the topics students would need to understand in order to make a successful competition robot. We then took these topics and created two-part lessons. The first part being a short lecture and the second part being a hands-on lab activity. Figure 22 shows examples of lecture slides and activities in class.

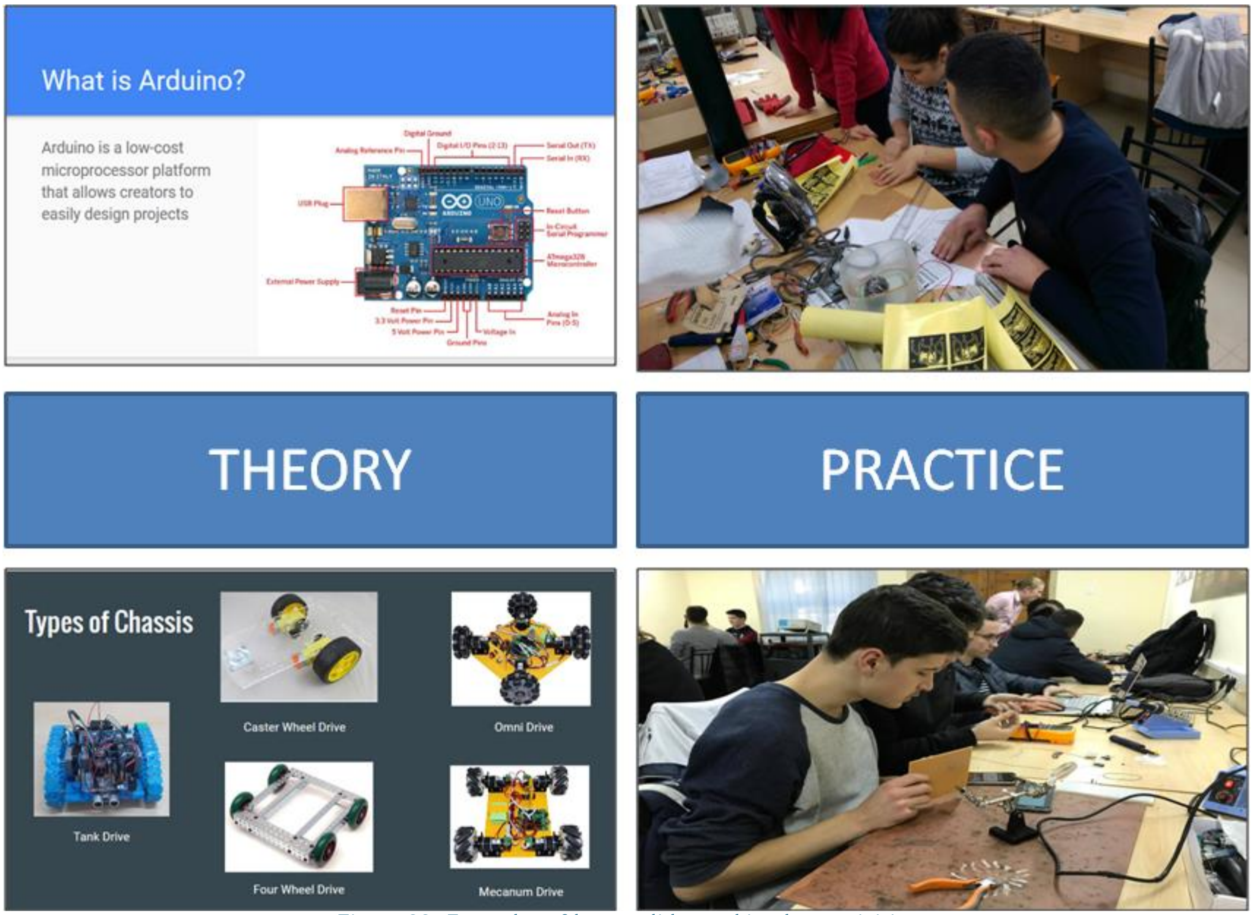


Figure 22: Examples of lesson slides and in-class activities

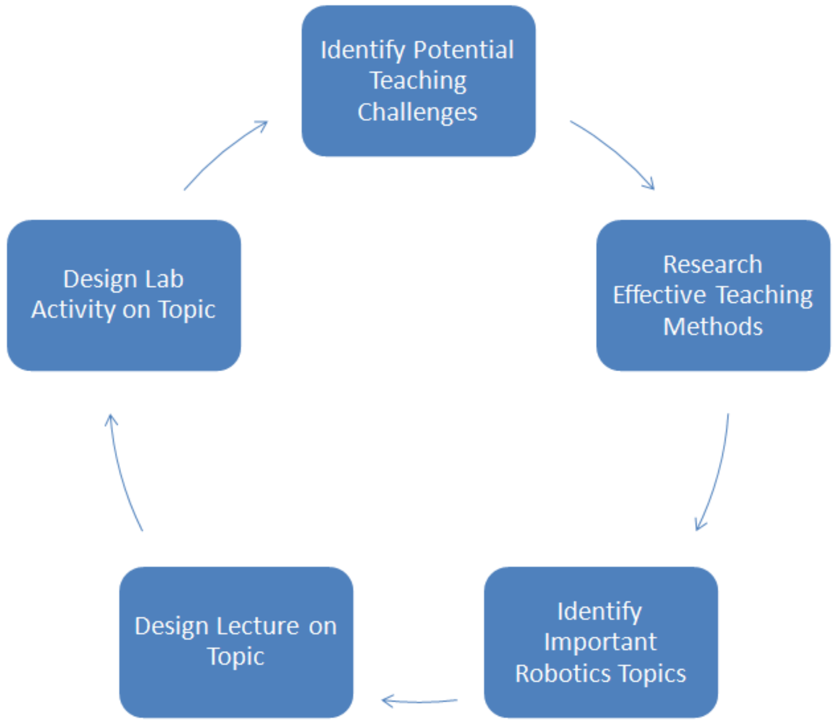


Figure 23: Lesson design process

Lesson plans can be found in **Appendix B:** Lesson Plans. The lesson design process can be found in Figure 23.

On some occasions we had to modify our lesson plans to keep students engaged. We did not anticipate the effect that the returning students in each group would have on the classroom experience. While experienced team members in each group were able to assist other students when some questions arose, they also were easily distracted and bored when basic material was taught. This knowledge gap caused some difficulty setting a pace for the class that worked for all students.

One way that we tried to overcome this was by meeting with team leaders after most classes to learn their views of each lesson. This feedback was useful when adapting future lessons. After one lesson, we were told that many students wanted to learn more about the concept of four-bar linkages. As a result, we adapted lesson on mechanics to include this topic along with a chance for the students to test the theory through a lab activity. Conversely, there were several lessons during which students were distracted due to a lack of interest. A returning student remarked:

> *"Lessons could have been shorter in my opinion...maybe I have more experience than the others who are younger. But still I think it would have been better to just to explain it as fast as possible, because we can use time better in order to advance with the robot construction."*

After hearing this feedback, we sped up the lecture and gave more time for hands-on experimentation. A flowchart of the lesson design process can be seen in Figure 24 below.

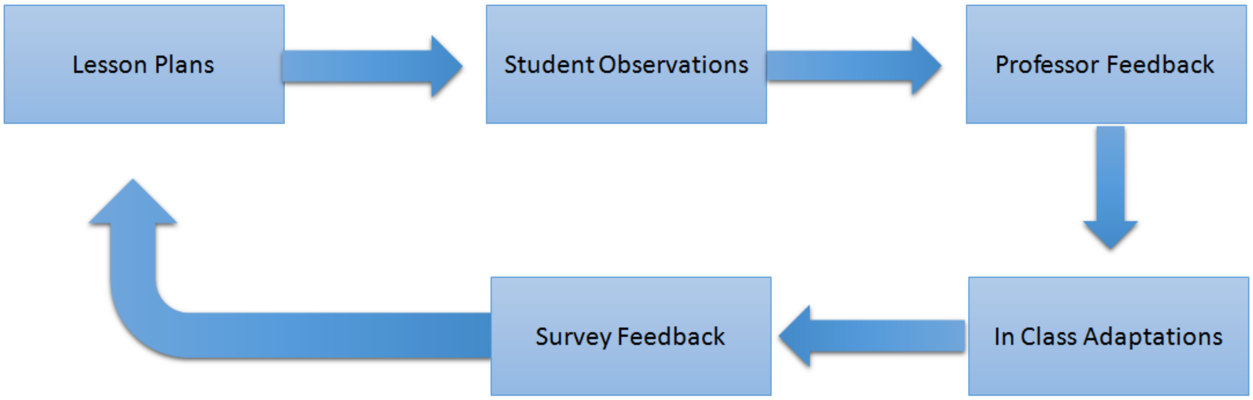


Figure 24: Lesson design feedback loop

In addition to observations and meetings with team leaders, we used a short survey to assess whether our teaching provided the information that students needed to build a successful robot. The biggest thing we learned from these surveys was that students who had more experience with a topic had very mixed responses. Whereas students who had little experience tended to say that they enjoyed the lessons. A summary graph can be seen in Figure 25.

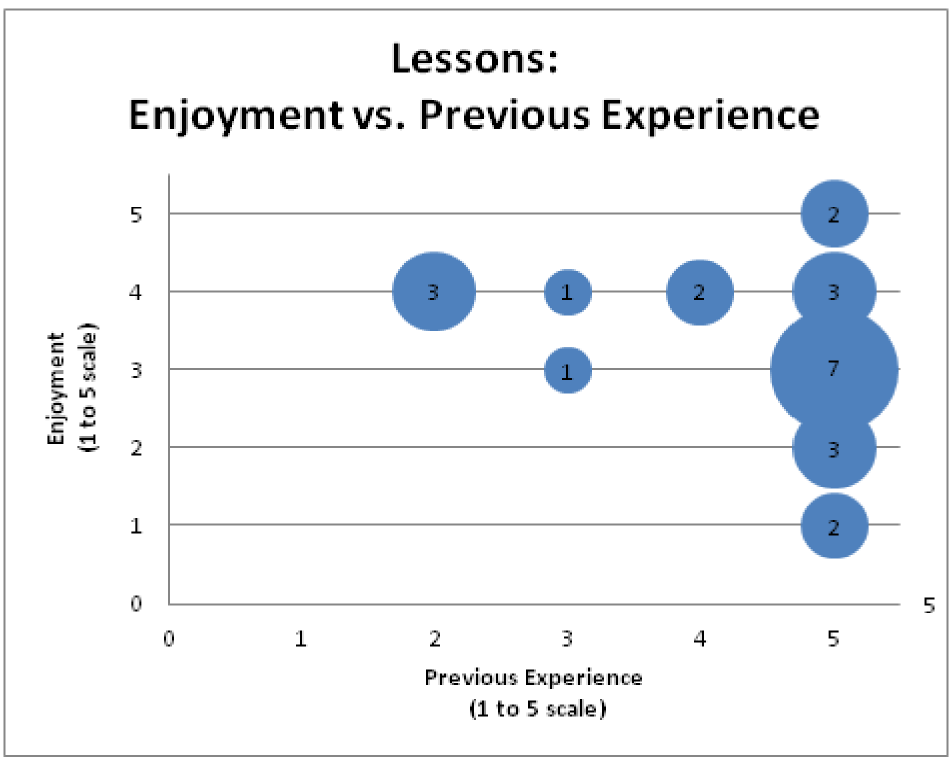


Figure 25: Enjoyment during lessons vs previous experience of topics

When we sent out the surveys, team leaders acted as conduits to the rest of the class. We would send surveys to them and they would forward and discuss the email with their group members. These survey questions can be found in **Appendix C:** Short Survey Questions. Professor Jaupi was also very helpful in the lesson adaptation process. After each class we met with him to ensure that all of his expectations were met and that things were on track.

While this process worked well, we fell behind schedule because electrical lessons took longer to teach than we expected. The topics presented in this section were very advanced and most students needed time to digest the information. Many teams struggled to create functional circuits such as boost converters and motor drivers. These circuits were crucial to the function of their robots as their purpose is to provide the correct voltage to the different motors, servos, and sensors on the robot. As a result, the students could not proceed until these circuits were completed. More teaching time was spent on these topics than we predicted. In order to overcome this challenge, we provided students with pre-built motor drivers and boost converters.

Figure 26: Preparing for a lesson

MENTORING

Figure 27: Josie explaining how to make a CAD drawing

An important part of the classroom experience was mentoring the students during the building process. One student referred to us as their own personal "secret weapon" who would always be willing to provide insight and guidance when needed. This sentiment was commonly shared between all students in the club. One student remarked:

> *"[When the WPI students] come, I just wanna ask them about the things I'm really curious about and sometimes they don't know how to answer but they always find it [for me]"*

We focused on asking leading questions when problems arose, allowing students to come to their own conclusions about the best solution. One student described this process positively saying:

> *"We tell them 'we have this problem' and they help us by trying to find the [solution to the] problem ourselves."*

Figure 28: Ben clarifying a lesson


Figure 29: Nathan debugging code

If we observed a team who seemed like they needed help we would encourage them to ask questions. This approach worked well as several teams opened up when we showed interest in their progress and challenges they were facing.

ADAPTING SAVAGE SOCCER FOR THE HARRY FULTZ INSTITUTE

While Savage Soccer is designed as a high school level competition, we still needed to adapt the rules and field design to fit resources available at HFI. Primarily we changed what materials and parts the students were allowed to use to build their robots to match the parts that were available. This included setting strict limits on the number of motors, servos, and wheels that they were allowed to use due to limited resources of the program. A breakdown of major rules adaptations can be found in Figure 31 to the right.

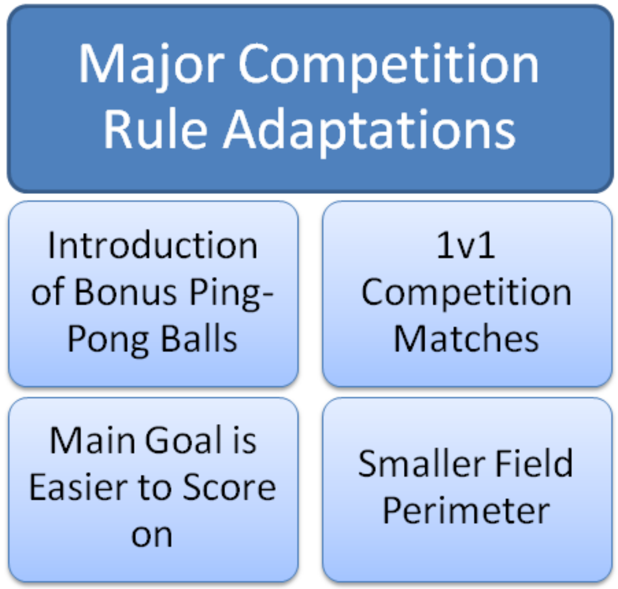


Figure 31: Main changes we made to the 2014 Savage Soccer game rules

We additionally cut coalition sizes from two robots to one since there are only six robots competing total in our competition. Because of this change, we also deemed it necessary to make the field smaller since fewer robots would be on the field at one time. Additionally, from our own personal experiences, the chute posed a significant challenge to scoring since it required precise positioning. Instead of the chutes, we decided to have a central box measuring 20cm in height. These changes in the field can be seen in Figure 30 below.

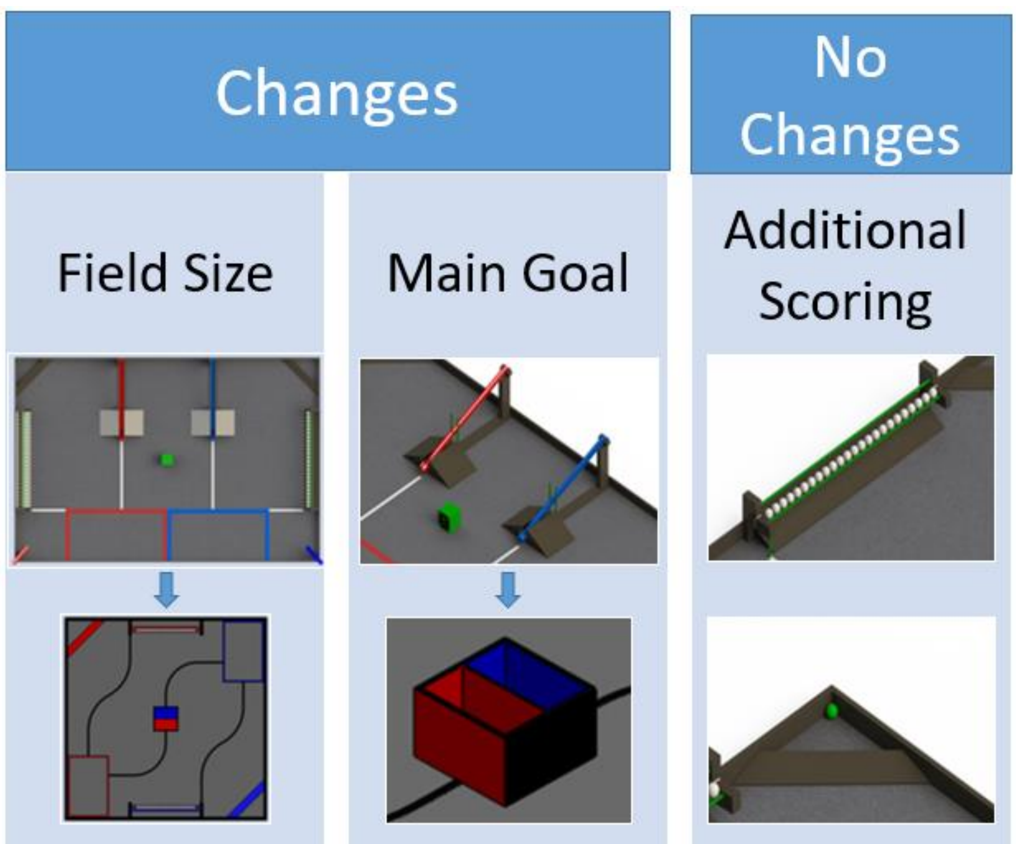


Figure 30: Changes made to 2014 Savage Soccer field

Scoring was also modified slightly. Shown in Figure 32 is the adapted scoring guidelines. Finalized rules can be found in **Appendix D**: Competition Rules.

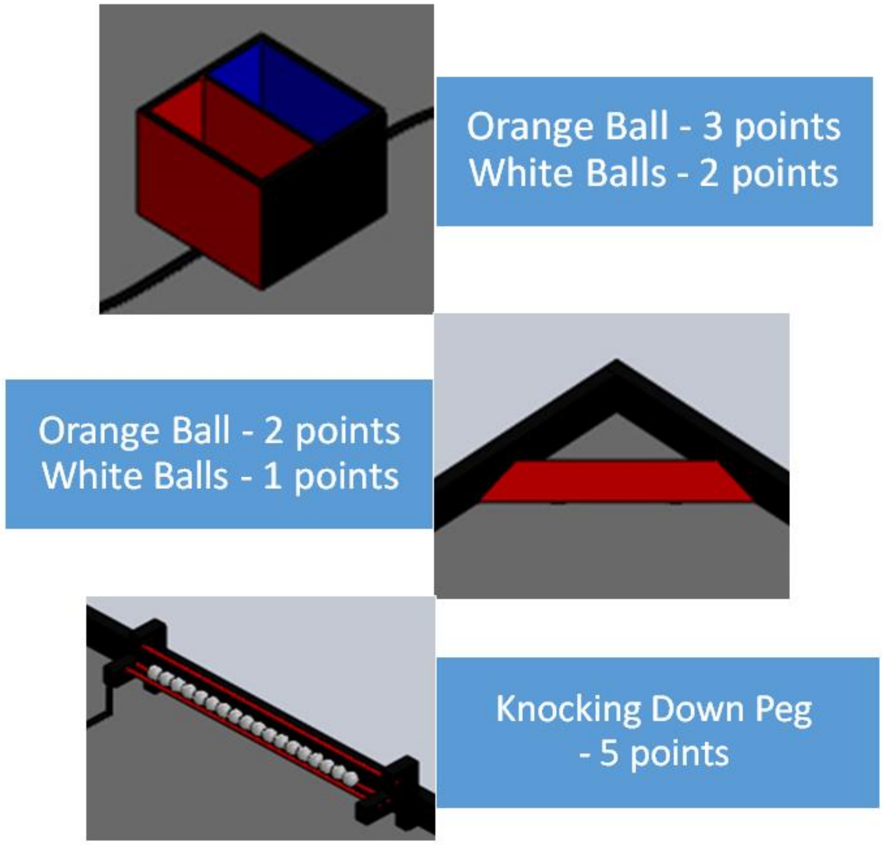


Figure 32: Modified scoring breakdown

In order to ensure that the students had a grasp on the ruleset and competition objectives, we sent out a survey to complete at home which focused on understandability, challenge and the excitement factor of the competition. These survey questions are located in **Appendix C**: Short Survey Questions. For each question, students were asked to rank the validity of each statements on a scale of one to five, with one being strongly disagree and five being strongly agree. Students overwhelmingly agreed that the competition was exciting to be part of and a majority of students fully understand the task before them. Results are shown below in Figure 33.

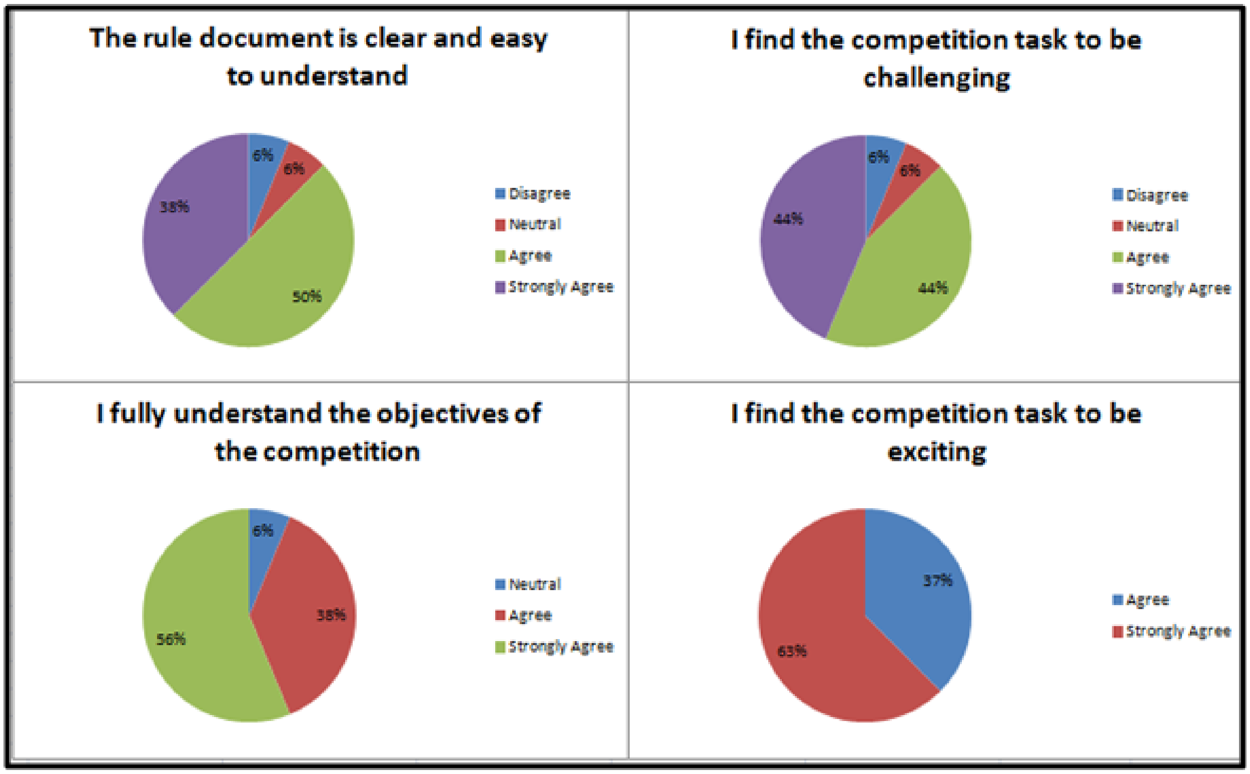


Figure 33: Rules understanding survey results

SUPPLEMENTAL RESOURCES FOR STUDENTS

In order to have a successful competition, students must have the necessary parts to build their robots. All parts for the robotics club needed to either be ordered months in advance or bought in the US and taken on the plane to Albania. Upon arriving at the school we identified parts that we still needed for class, such as materials to build the robot frames. To create these resources for students, we went through our own engineering design process. Our goal was to provide the missing necessary materials in order to ensure that all students had adequate resources to build.

One of the first issues we faced was the lack of materials and parts needed to construct a basic, drivable robot. We created basic, stock chassis pieces which could be cut to fit each of the teams' designs. Each team received six 40cm long C-channels and four 40cm long L-channels for which we created engineering drawings. Drawings can be found in **Appendix E**: Technical Drawings of Chassis Parts. These parts were manufactured by a professor in the machine shop from inexpensive extra materials. As shown in Figure 34, these parts were modeled after the VEX structural pieces.

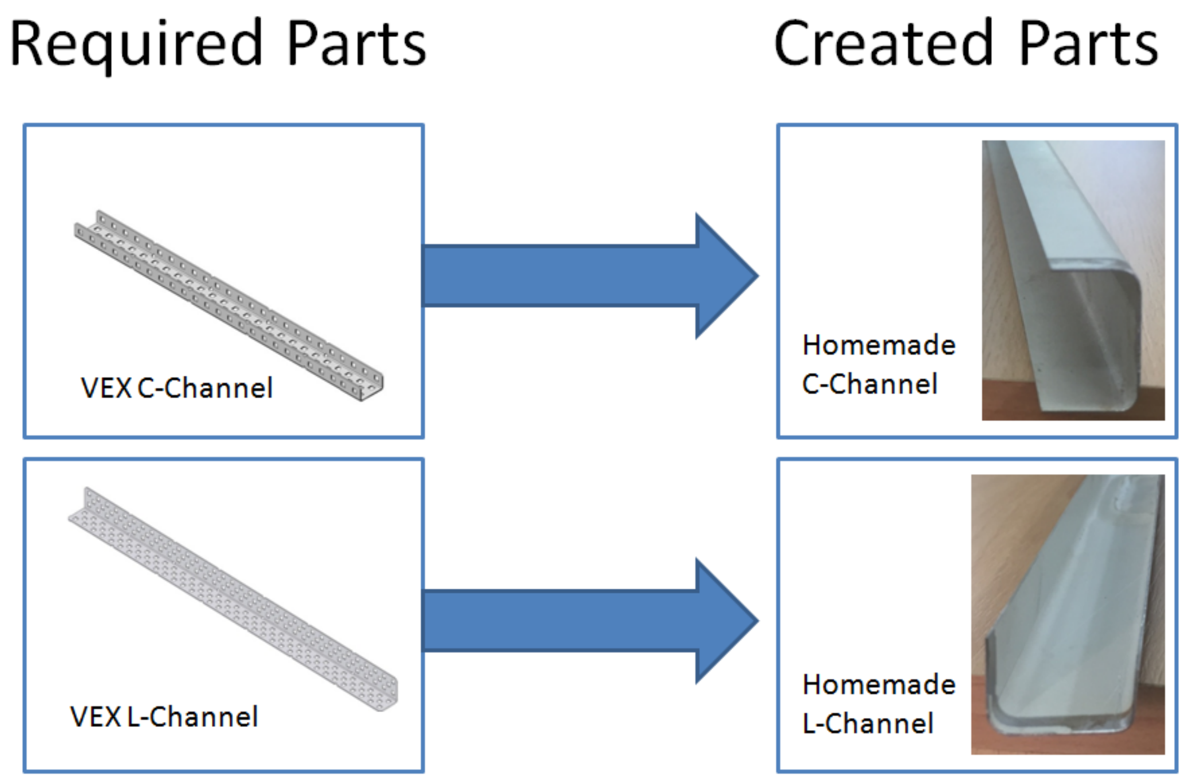


Figure 34: Supplemental chassis parts designed

However, we decided not to include the typical pre-cut grid of holes since this would increase manufacturing time, further delaying construction. We provided the students scaled drawings to plan out the placement of mounting holes and connection points. One of these drawings can be found in Figure 35 on the next page.

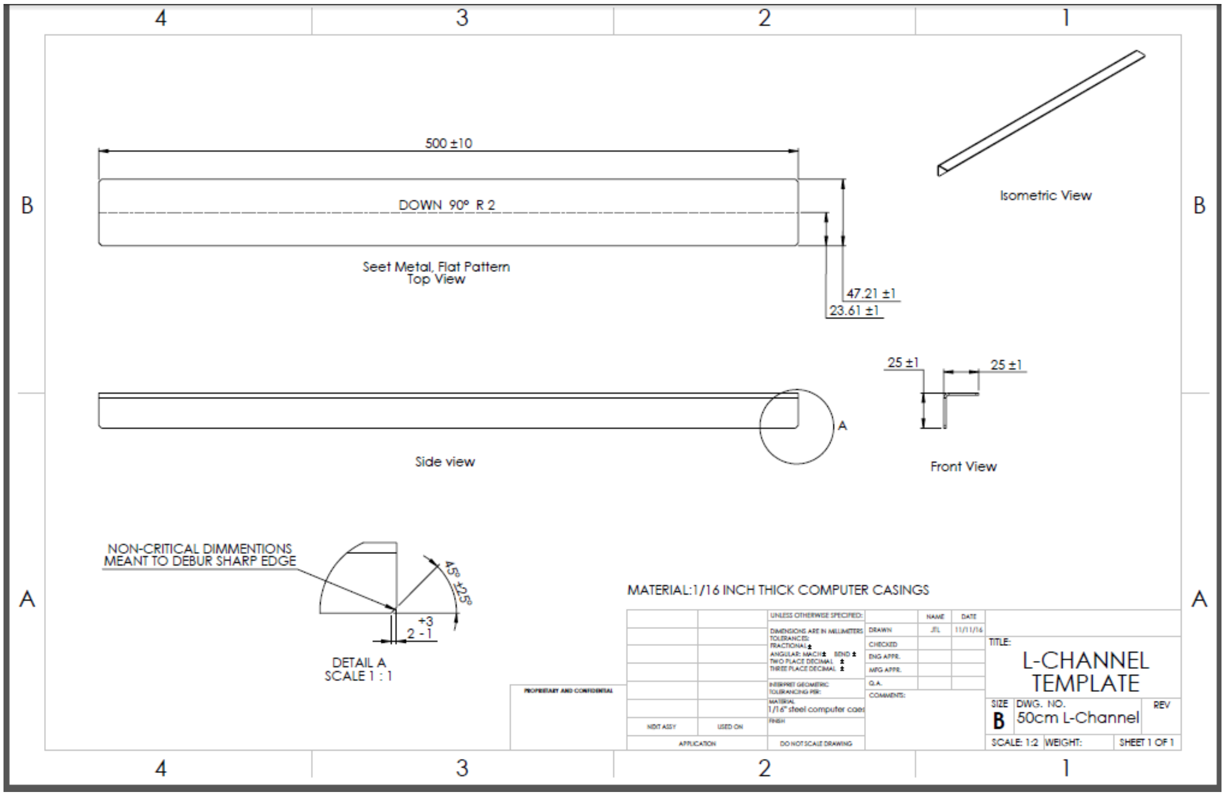


Figure 35: Technical drawing of an L-channel piece

The generic chassis parts allowed for greater freedom when designing and helped to provide more opportunities for students to be more creative in their robot design.

Another issue we ran into regarding materials was a lack of parts to attach the wheels to the motor and chassis. In order to save money and avoid long wait times on part orders, we designed a 3D printable part to attach the motors to the wheels.

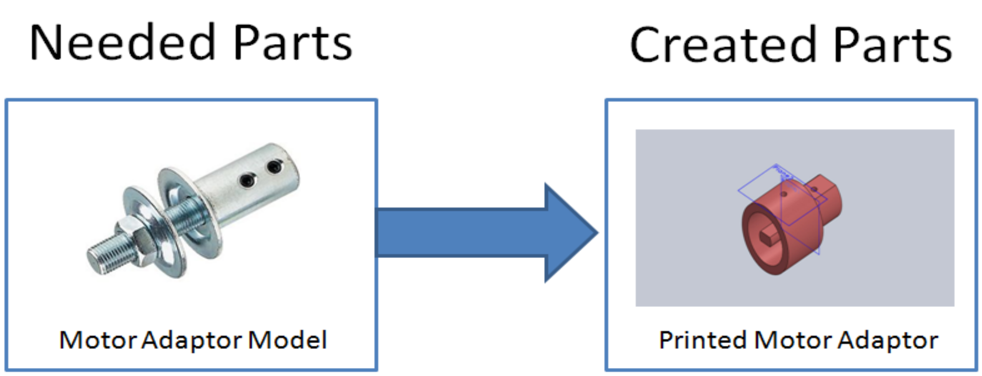


Figure 36: Supplemental motor-to-wheel adaptor design

After several iterations, we found a design that seemed to work well. Even still, the torque from the motor would sometimes break the plastic adapters. Additionally, due to printing errors the parts would sometimes print incorrectly causing the parts to be useless. We changed a couple features of the part including printing with a stronger material and this seemed to resolve the issues. Figure 37 shows some of the issues with early iterations of the adaptor design.

Figure 37: The main issues with designing motor-to-wheel adaptors

Students were able to incorporate both the motor adaptors and building pieces into their final design with great success. Figure 38 shows both the completed wheel adaptors and L and C-Channel successfully implemented into a competition robot.

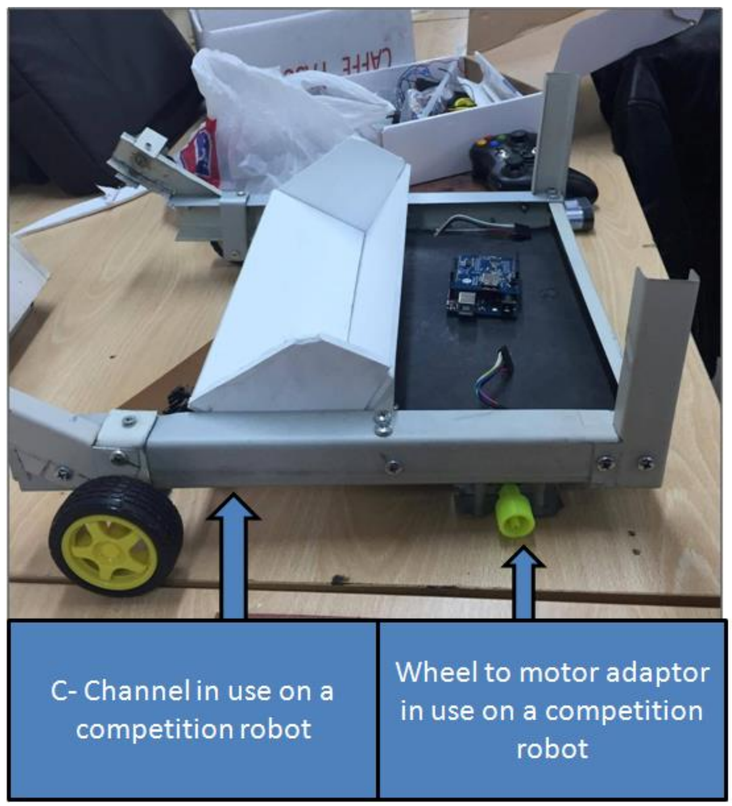


Figure 38: Supplemental parts implemented on a robot

An issue we anticipated while planning our lessons was determining the best method of teaching programming concepts. In order to save time teaching the students the intricacies of programming, we created a code library for them to use. This library let the students easily control their DC motors, USB shield and Xbox 360 controller receiver, and stepper motors without having to write the more complex code to control these devices.

However, when creating this, we ran into some issues of our own. The first version of the library we distributed did not compile because of a corrupted file caused by a merging error. We fixed this by finding and replacing the corrupted file with one that worked. After this fix, we distributed the new library to the students.

The second version of our library worked for most of the teams, but some the teams still encountered an issue because they used a different style motor driver that required 3 control pins instead of the 4-pin variety we assumed they would use. Because of this, we created a third version of the library for 3-pin motor drivers as well as 4-pin motor drivers. Some teams received errors when compiling the library, such as a function from a core library could not be found. To fix the missing function error, we simply updated the Arduino IDE to the latest release. This finalized library can be found in **Appendix F**: FultzLib Programming Library.

HOW TEAMS DESIGNED THEIR ROBOTS

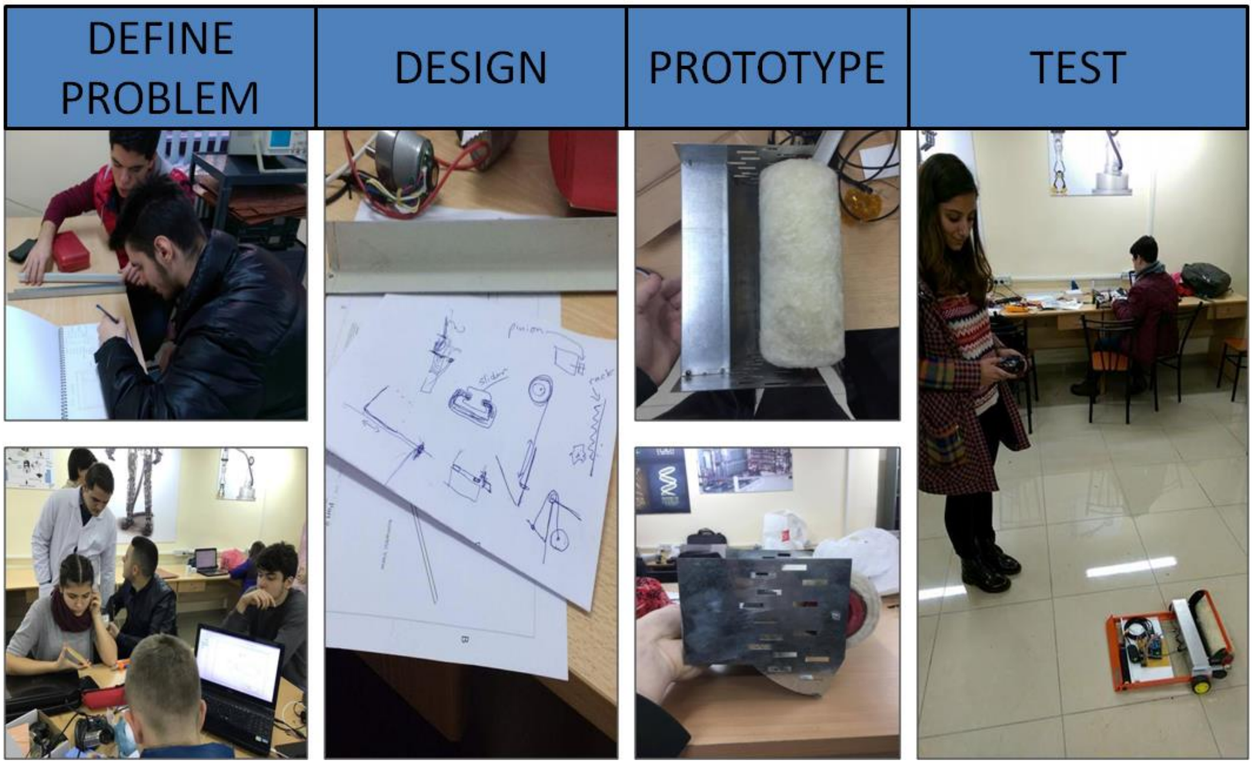


Figure 39: Breakdown of general student design process

When beginning their design processes, we wanted to ensure the students knew how to tackle engineering problems. After communicating with team leaders, we decided that an overview of the design process was necessary because they had little experience working in teams to create an engineering design. Providing them with an example format would therefore show a path for them to develop ideas and help keep students on track.

The second point was especially important due to our limited time with the class. We prepared a lesson to review different brainstorming formats while still allowing them to choose their own process for creating their own design. As a result, each team went about completing the challenge differently. The main structure of each team's design process consisted of: strategies, compartmentalized list of mechanisms needed, narrowing down of the design, adaptation of design for construction, testing, and redesign. This cycle is shown in Figure 39.

STRATEGY


Figure 40: Student team discussing possible strategies

Teams began designing by discussing strategies and evaluating the rules. We gave general instructions about how to come up with a strategy and, as a result, observed several interpretations of the process among teams. Each team started this process individually by evaluating the rules and available parts, which can be found in **Appendix D:** Competition Rules and **Appendix G:** Kit of Parts, respectively. From these parameters, teams then discussed their strategy, or how their robot could win the game. Some interpreted this as what their robot needed to do to score the maximum number of points. Others thought more broadly about how their robot would interact with its surroundings, including other robots. Half the teams focused solely and scoring while the other half evaluated the potential for team offense and sabotage. Teams also varied in the amount of strategies they discussed. One team weighed the benefits of three different strategies while another team chose one strategy quickly, then moved on to the designing stage.

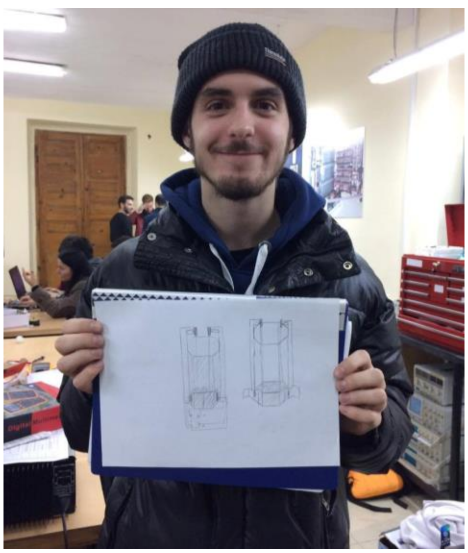


Figure 41: Student with sketch of mechanism

Some strategies discussed by students include:

- ***Stealing other teams ping pong balls from the floor***
- ***Scoring balls in the center goal***
- ***Using a vacuum to suck ping pong balls out of the opposing team's goals or robots***
- ***Incorporating a ball storage area in the robot to reduce the time spent collecting ping pong balls***

Only two teams discussed the strategy of pushing balls into the corner goals. Of those teams, both ruled it out quickly because it offered fewer points than the center goal.

These strategies show the students' competitive and determined attitudes toward the game challenge. Half of the teams came up with offensive tactics to play the game rather than staying focused a robot that could score effectively. This led us to modify the rules to ensure that teams focused solely on outscoring their opponent. After discussing possible strategies with teams, we decided they should not be allowed to pin or trap other robots or steal balls from the other team's goals. We made these rules to encourage each team to build a robot that would score the most points instead of one that would attack its opponent.

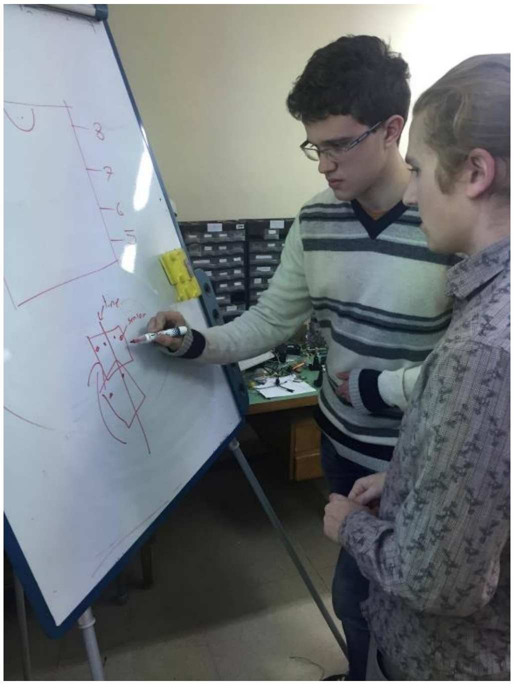


Figure 42: Student discussing strategy with Nathan

We found that strategy discussion was the only stage of the design process in which every team chose to involve all their members. Groups communicated with each other about what their robot should do, but some teams chose to pass on the details of the design to their designated mechanical expert. One team's robot was designed, modeled, and built entirely by a single team member, while the other members of the team focused on building the needed electrical circuits or programming the Arduino.

However, most teams incorporated design input from everyone in their group. We think this is due to each team member's specialization. Professor Jaupi created the groups with each student's skills in mind. He faced issues with unbalanced teams in the past and wanted to ensure each group had a student knowledgeable in electronics, programming and mechanics. This specialization lead some teams to split up all the work based on who could do it best. When this happened, we stressed the importance of communication as a tool for successful design and encouraged each group member to explain what they did to their teammates.

CREATING A LIST OF GAME MECHANISMS

Once the teams chose a strategy, they moved on to the specific mechanisms needed to complete the game challenge. Some teams were overly ambitious and chose very complex designs for their robots. This is a challenge that inexperienced robot builders commonly face. As an example, one of the teams wanted to build a vacuum like mechanism that used suction to pick up balls from the floor. While a clever idea, it was not feasible given the constraints. After we explained that the club did not have the required material for this design and pointed out this design's unnecessary complexity, the team chose to pursue a robot that could be built with the materials provided more easily.

"My group members all had ideas but in the end we chose the most perfect...we looked it up on the network [researched it] and looked at videos of robots, we saw that the crab [a design] was better."

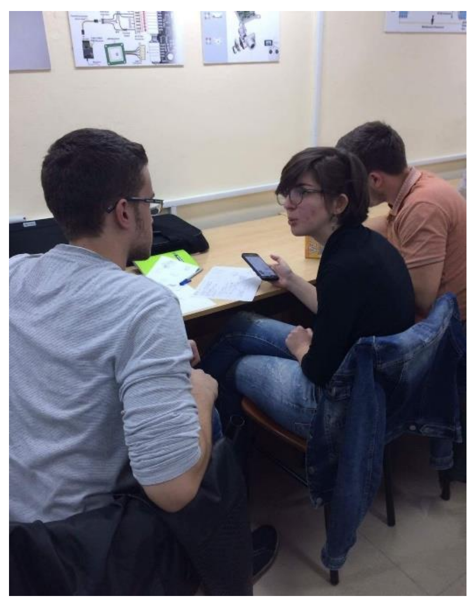


Figure 43: Student team discussing their possible mechanism

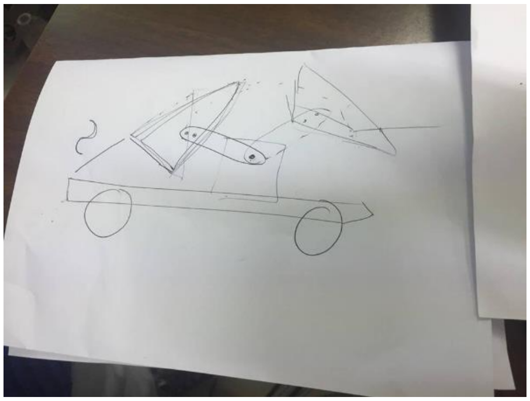


Figure 44: Initial design for ball deposit mechanism

After discussion with the students, we found that each team considered three tasks their robot must complete: drive, pick up and store balls from the floor, and deposit balls in the center goal. The next step we recommended was to make a list of each mechanism category (ball intake, ball storage, and ball deposit, etc.) and come up with a list of possible designs for each category. Half the teams chose to do this. One team had each group member come up with an idea for the mechanisms and as a result ended the process with more than ten potential designs. Other teams started with one design for each mechanism and focused on making it better rather than exploring different options.

NARROWING DOWN DESIGN IDEAS

The teams then narrowed down their ideas into one final design. Groups either did this together or designated the choice to one person. Teams who chose their final design together reported that it helped their process to discuss ideas as a group. When narrowing their ideas into one comprehensive design, teams were encouraged to create more detailed mechanism drawings containing dimensions and multiple angle views. Some teams made models of their robots using a CAD (Computer Aided Design) software, most commonly autoCAD, while others chose to simply draw on paper. The teams that used CAD to model the robot had a better idea of construction and ended up making fewer changes than teams who modeled ideas by hand. The first team to finish building their robot frame was also the first team to complete their CAD model of a design.

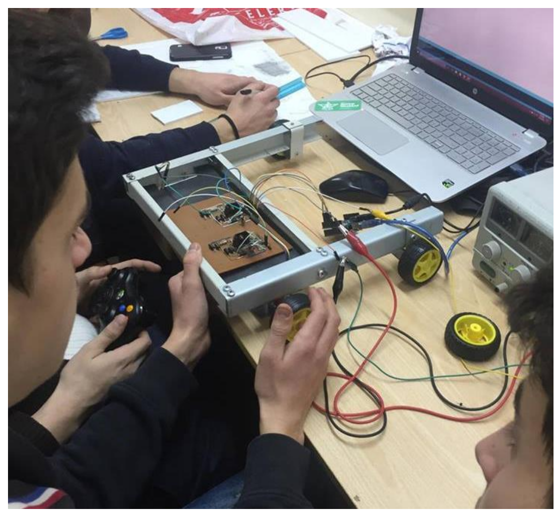


Figure 45: Testing drive motors

ADAPTING DESIGNS FOR CONSTRUCTION

Figure 46: 3D printed plastic (right), C- and L-channel pieces (left top), and foamcore (middle bottom)

Some teams faced many difficulties in this stage, particularly when choosing a final design. One team reported that they changed their design every week until they needed to start building. Changes in design became necessary once teams considered potential materials needed to build the robot.

The three main materials used by students shown above in Figure 46 are: metal C-channel and L-channel parts we designed, polycarbonate, and poster board. Teams also had the option to 3D print parts. This required access to a CAD software and knowledge of how to use it.

Most of the design process occurred before we gave instruction about potential chassis each team could make. We did this so that every group would have an idea of what would be mounted on their frames and therefore know how to design their frame to best integrate it with the game mechanisms.

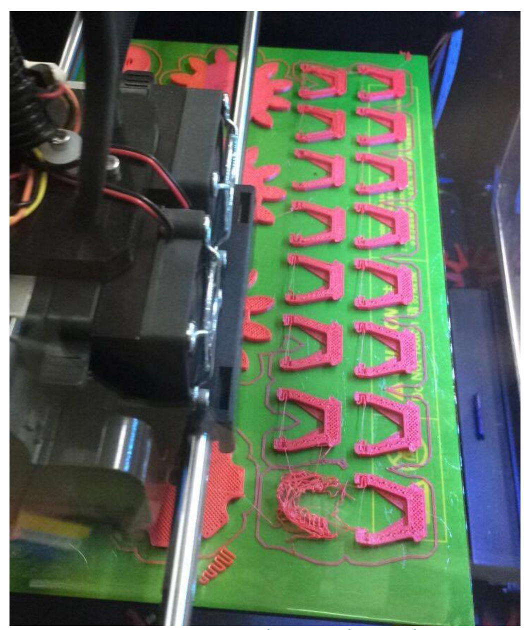


Figure 47: 3D printing a chain and sprocket

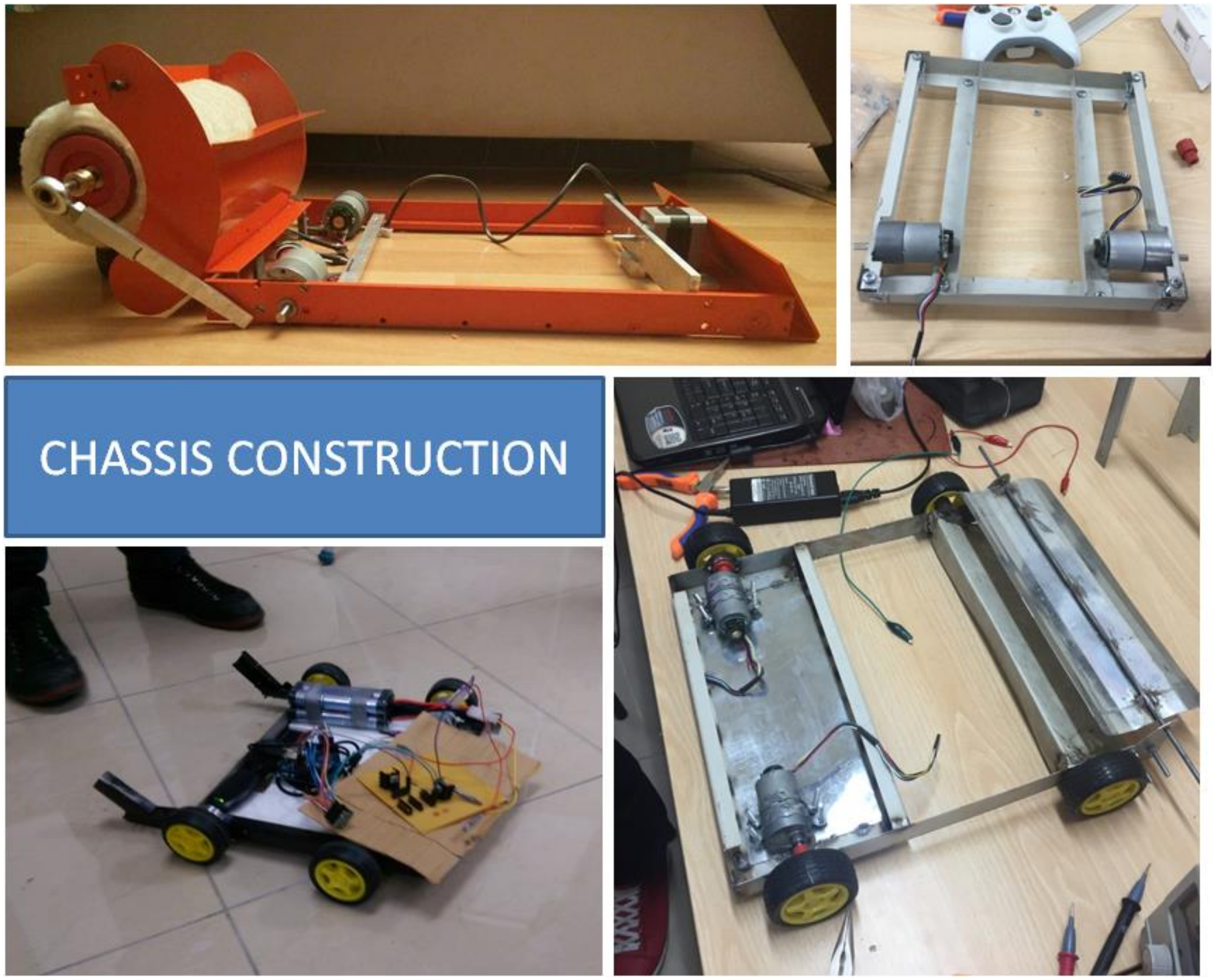


Figure 48: Robot chassis constructed by various teams

Once the teams built their chassis, they moved on to constructing the mechanisms needed to play the game. This part of construction varied widely for each team due to design differences and material choice. When selecting materials, there were a few factors teams had to consider. The first factor was motor selection. Teams had to be careful when selecting a motor for their mechanism to ensure that it was powerful enough. Another factor was material strength and weight. 3D printed plastic is lighter than the metal chassis parts we supplied, but is also weaker. Time was an important factor for teams to consider as well. Some teams wanted to 3D print parts, but did not have experience with CAD software. Instead, they opted to use methods they knew to construct their robot faster. These parts were modeled in a CAD software and then printed using the lab's 3D printer.

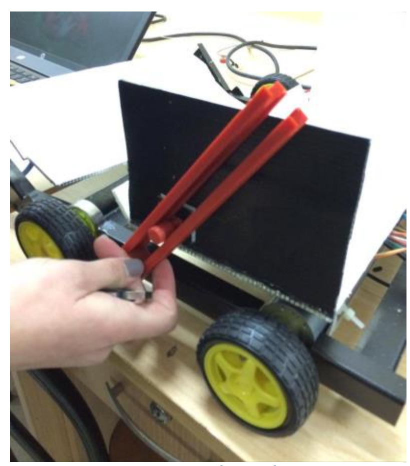


Figure 49: 3D printed mechanism

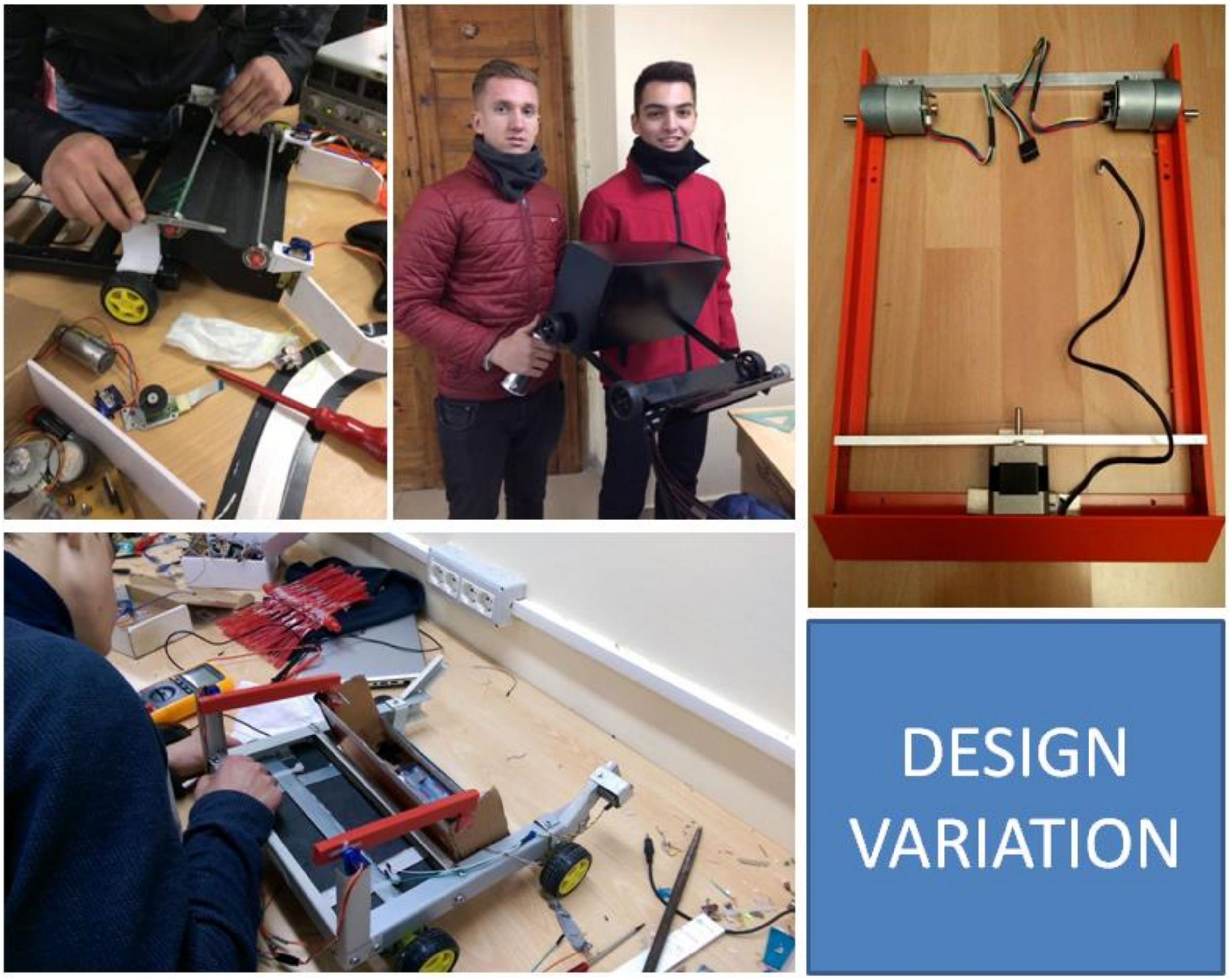


Figure 50: Variety of robot designs

All the teams were encouraged to be creative and were given the option to bring in other materials to build with. One team decided to laser cut all their chassis pieces and brought in a paint roller to serve as their intake. Some design variations can be seen in Figure 50.

TEAM DYNAMICS

We distributed a freelisting exercise to gain insight as to what students thought of an ideal group partner. This time, the cultural domain was the qualities of a good teammate. Top student responses are shown in Figure 51. Many students felt that the best project partners were hard-working and communicate well.

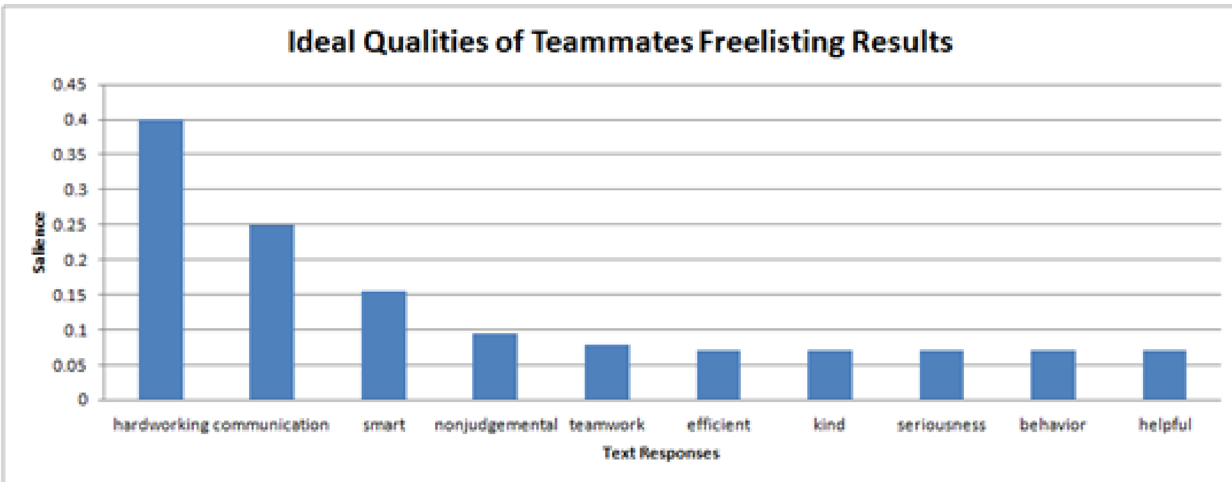


Figure 51: Salience of positive team member qualities

We continued to see this trend as we investigated team dynamics further. At the beginning of the second week of class, students were asked to create a team charter within their group. This charter was designed to reveal initial team dynamics within each group and strategies each team planned to use to address challenges related to the competition. At the end of the competition, we will have the students reflect on their answers for their initial team charters. What we found was very interesting. Many teams anticipated no discrepancies among team partners heading into the project. When asked how they would solve disagreements about robot plans, one team replied, “We will always agree about our plans” while another team answered the question “how will your team address unacceptable work?” by saying “We will always have acceptable work.”

When asked to reflect on their team charters at the end of the class, some student’s perceptions of their team dynamics. Teams that predicted there would be no problems within their group revealed that they did actually encounter problems.

“We were at times, disappointed by borders and arguing errors and sometimes picked little fights to tell whose fault it was.”

Despite these unexpected issues, students admitted that they were able to overcome them through communication in the end.

These team charter results strengthen the conclusions we were able to draw from in class observations of the students. We met with each team at the beginning of class in order to assess their progress with their robot. Here we were able to see that many teams had a cohesive team dynamic that took advantage of each other's strengths. These quotes from students capture this.

“Each different member of the group has different opinions and we are trying to let each other express that opinion and work together discuss towards that common goal that we have”

“We help each other, what they don’t know I teach them, and what I don’t know they teach me.”

Competition also played a big part in the dynamic between teams. In one instance, a team showed up to class with a completed chassis. Other teams saw that one team was ahead, then two more teams had completed their chassis the next day.

COMPETITION RESULTS

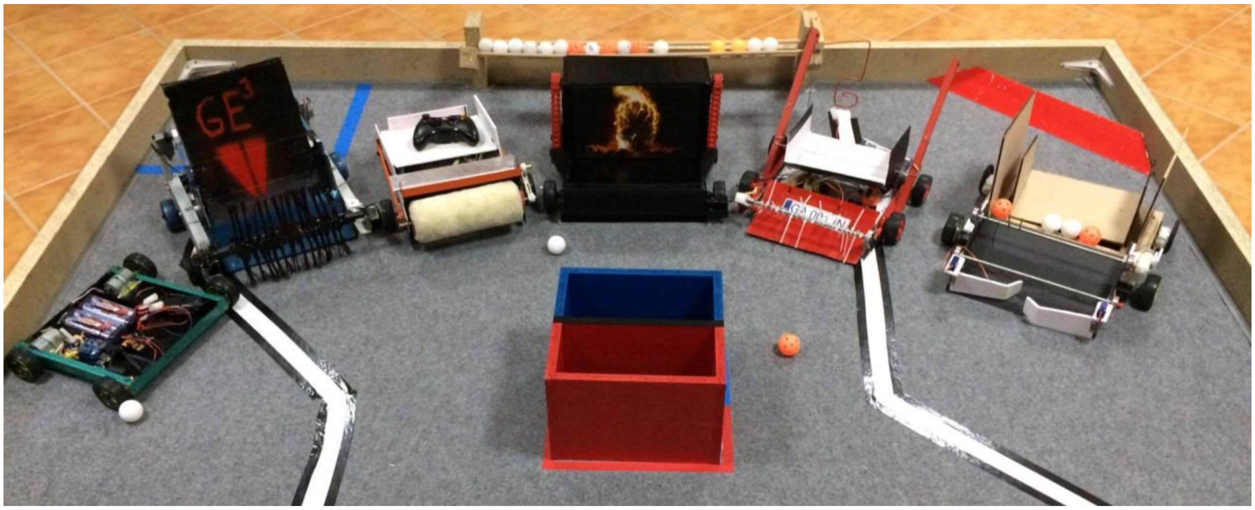


Figure 52: Competition robots

Students were provided with an objective (scoring points) and needed to navigate many open ended ways to achieve the goal. This real world problem solving helps to prepare student for their futures in engineering, when they will have to produce an effective solution while working under a variety of constraints. One student remarked that they preferred the competition because the thought of winning the competition excited them.

> *“Yeah [I am excited] you compete with another group so you do your best to achieve and win also. Because I mean each of group thinks of winning the competition.”*

Another explained how they thought this competition allowed them to be as creative as possible, because there were some many ways to play the game.

We asked the students about their feelings towards the competition as a part of the informal interviews, results of these interviews can be found in **Appendix H**: Semi Structured Interview Results. All of the students interviewed stated that they enjoyed having the competition as a goal to work towards.

> *“The competition was very different and challenging. If a team was ahead of us, it would give us a strong feeling to work even harder.”*

When the students were asked how important winning they felt that winning the competition was, none of the students replied that they were solely motivated by winning. In fact, the most frequently cited reason for their motivation wasn't winning, it was testing themselves to see what they were capable of. Another important motivation seen was a desire to learn, it was clear from many of their responses that they felt that the project was already a success because they had learned a lot about working on robots.

"Competition was really helpful for us. It pushed us to go beyond the limits of our knowledge. We were motivated to learn more than we ever had. "

We also used the interviews to determine how the competition affected the way that the students on different teams interacted. All but three of the students we interviewed reported some level of communication with other teams, with a large number of them stating that they had both given and received help from other teams. From observing the students and their own reflections we found that teams often shared thoughts about electronics and programming with other teams. The few students who stated that they didn't communicate with other teams explained that it was out of fear that the other teams would steal their ideas. This was particularly interesting because other students from the same team as the students afraid of having ideas stolen reported sharing details of their design with the other teams.

Figure 53: Professor Jaupi at the opening ceremony

RECOMMENDATIONS

After discussing the direction of the club with Professors Jaupi and Hoxha, we understood two main ways the Harry Fultz Institute would like this program to grow. The school's goal for this program is to establish HFI as a hub for robotics education in Albania and provide interested students with the opportunity to advance their knowledge of robotics topics. To accomplish this, Professor Jaupi has considered either making the program larger by adding a second class or incorporating this club into an existing, international competition.

Professor Jaupi proposed increasing the size of the robotics program by making two classes. This second class would potentially be open to interested and qualified students from other schools. Due to the large number of students, this idea would either require two WPI student teams or incorporate students from the Polytechnic University of Tirana as mentors. However, expanding the club at such a rapid rate would not be practical for next year. Professor Jaupi, who founded and has been running the robotics program, is planning to leave Harry Fultz next year. If he does, there will be a large gap in knowledge in instructing the class and a smaller more manageable size would be better. We recommend keeping the program the same size of 24 students is best.

Another direction for the program is to eventually join an established international competition, such as FIRST Robotics Competition or FIRST Technical Competition. Because of the limited resources at the Harry Fultz Institute, we recommend this for the far future. Joining robotics competitions such as these require extensive travel, a developed catalog of parts, and a large pool of knowledge among both the teachers and students. In order for the club to prepare students for this rigorous competition structure, we recommend including more first and second year students into the club. This would allow students to return from year to year and gain the needed experience to thrive in one of these competition programs. Returning students would also be able to teach younger students, as evident to us through our observations with this year's group of team leaders.

Taking into consideration the transition of club leadership from Professor Jaupi to Professor Hoxha, we propose that next year's team focus on improving the competition structure we introduced this year. Through discussion with the students, we found that they greatly preferred this year's class structure of each team designing a robot to compete in the same challenge as opposed to last year's structure where each team chose a different robot. From our experiences we also learned that the structure of competition lends well to increased motivation, collaboration, and positive interactions among teams. All teams ran into similar issues and groups could therefore receive help from their peers. Students enjoyed this because it caused teams to work not only with their groups but also with other teams. For these reasons we think the competition structure should be maintained.

There are several things we suggest when considering improving the competition. First, we recommend modeling the competition and rules after an existing Savage Soccer competition. This model has many positive aspects for small, beginner robotics competitions including an easy-to-build field and the ability for all teams to score points easily. In improving the competition there are several things we suggest doing differently. Due to setbacks, our class started to fall behind, which was difficult because we already had a short amount of time for the students to build and test their robots. Implementing goals for the end of each week and having stricter deadlines would fix this issue and keep students on track. In regards to the organization of classes week to week, we recommend focusing on lessons for the first two weeks, beginning robot design and chassis construction on the third week, having a drivable base robot on the fourth week and spending the remainder of the class on building and testing. We also suggest starting construction of the competition field in the second week to allow students a better understanding of how their robots will interact with game pieces.

When teaching robotics topics we found that students understood the lessons better if we gave an overview of general topics. The more experienced team members were a great resource for instructing the class and allowed us to progress through lessons at a faster pace. Therefore, in the following years, we think it is best to get to the point with lessons, as the team leaders will be able to explain the finer details. We also recommend getting to know the students early on through conducting informal interviews or taking them out to coffee. This will make the WPI student team more approachable and more knowledgeable about how to help the students learn.

CONCLUSIONS

Figure 54: Students and professors at the competition

We went into this project with the intention of bringing a competition to the Harry Fultz Institute that the students would find challenging and rewarding. We wanted to set out to effectively teach them robotics topics and see how this competition would affect the students. From our findings, we conclude that we achieved our goals and objectives.

Our lessons were effective in giving students at least the minimum knowledge required to build a competition robot. While some the more experienced students felt the lesson pace was too slow, the younger students gained the necessary knowledge. This was evident by the creation of their robots. We were also able to effectively develop the needed supplementary resources for the competition including the field and necessary parts for students.

Students were highly motivated by the competition. Consistently, they showed their desire to see what they could accomplish and learn. They were challenged by the constraints of the competition and had to think outside of the box to achieve their goals. The introduction of the competition didn't enable any noticeable negative effects on the learning process. The low stakes of the game encouraged the students to remain friendly with each other even if they were on different teams. While teams still wanted to be better than their opponents, most students were happy to help other teams with their robots. You could frequently find students from different teams working together to conquer their challenges.

Figure 55: Competition robots

This experience working with the students and faculty at HFI has been a very challenging and rewarding one. Over the course of the past eight weeks we have worked closely with the students in order to help them achieve their goals. In this process, we have gained a great appreciation for those who undertake teaching roles as a career path. It has been inspiring to see all the things that the students have accomplished. The passion and dedication that they go about their work with is something that we won't forget. In the process of mentoring these students, they became our friends. Their struggles with robotics became our struggles. We will always remember our experiences and are incredibly grateful to have had this opportunity.

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APPENDIX A: OBSERVATIONS

Compiled Class Observations

Coding Key:

(IN) = Interactions with Students

(TR) = Teaching Results

(COMP) = Competition

(MNT) = Mentoring

(TD) = Team Dynamics

(DP) = Design Process

CLASS 1: INTRODUCTION

- **(IN)** Students seemed shy at first but after going around all had questions about us and our backgrounds in robotics.
- **(IN)** Some students remained silent and were shy but many opened up and were very friendly

CLASS 2: COMPETITION RULES AND BRAINSTORMING

- **(TR)** The professor explained some parts of our lecture in Albanian for clarity and students seemed to have a good understanding of the rules.
- **(TD)** Questions in English mainly came from second year robotics club students.
- **(TD)** Team leaders seemed to be engaged and helped the group stay engaged in the tasks at hand.
- **(DP)** Many students immediately when given the challenge went to the internet to find example robots that have done similar tasks.
- **(DP)** Many students sketched robots similar to the robots shown in our powerpoint.
- **(DP)/(COMP)** No teams interacted with other teams during the brainstorming process. They worked as a teams and it looked like everyone was involved in the process.
- **(COMP)** All students seemed very engaged in the competition and seemed driven to create the best robot….without the mention of a competition prize.
- **(DP)/(COMP)** Each team had very high expectations for their robots...some had very ambitious ideas which that may not even be possible.
    - Vacuums to steal other teams stuff
- **(COMP)** Many students challenged the rules and asked questions about how far they could push the limits. (Example...descoring the other teams points)

- **(DP)** Two or Three teams designed strategies that would limit the other teams scoring abilities instead of focusing on creating a robot that scored faster than the other teams.
- **(DP)** Some teams started right away with sketching ideas while others didn't start sketching or documenting ideas until they had looked at examples/ videos of past robots

CLASS 3: INTRODUCTION TO ROBOT CONSTRUCTION BASICS

- **(COMP)** When students were asked to present ideas for robot designs to the class, they refused because they didn't want other teams to steal their ideas
- **(IN)** When the students presented to us, it was usually only one student talking and this was usually the group leader or a 4th year student. (5/6 groups)
- **(DP)** Most designs were simple and efficient using a variety of concepts. These designs were more feasible then the designs first suggested during initial brainstorming.
- **(IN)** Many groups (4/6) asked for feedback on their design. In addition, these groups understood many of the challenges they would face with the design.
- **(COMP)** All teams appeared had a grasp on the rule set for the game.
- **(DP)** Preparation and care put into initial design ranged from fully drawn sketches with force diagrams to very rough sketches and concepts.
- **(TR)** During teaching, most teams already understood basic topics like turning radius, motor limits, forces etc. and seemed bored.
- **(TD)** The team leaders seemed to spread the information on new topics to the rest of their team efficiently.
- **(TR)** Many students seemed disinterested in basic topics and seemed bored, especially the 4th year students.
- **(TD)** Discussion between teams seemed balanced and no one person dominated discussions.
- **(MNT)** Many team leaders disagreed with the rules about motor limits. They felt that they should be able to use anything they wanted to. (Reoccuring theme)

CLASS 4: LIFTING

- **(IN)** One of the groups didn't ask for clarification on the assignment until after we had started walking around and talking to groups
- **(DP)** Many groups went above and beyond ideas presented and looked for more complex models of lifting mechanisms
- **(TD)** Teams all seemed to share responsibilities among all teammates
- **(TR)** All teams were able to understand why the lesson presented was relevant to their own robot design
- **(TR)** Many students enjoyed the hands on part of the lesson since it gave them a chance to test out some of their own ideas

CLASS 5: ELECTRICAL CIRCUITS (TAUGHT BY JAUPI)

- **(TR)** Students were very attentive and listened well when the professor spoke.
- **(TR)** The professor taught the class in Albanian

- **(DP)** Students received their kit of parts and immediately started playing with the parts and experimenting
- **(DP)** Many teams still felt they had insufficient motors to complete the task

CLASS 6: ELECTRICAL CIRCUITS 2 (TAUGHT BY JAUPI)

- **(TR)** Students were shown how current effected motor function which cleared up a lot of confusion that many students were experiencing
- **(TR)** Students seemed to struggle with many of the concepts associated with boost converters and motor drivers. This led many students to ask a lot of questions about concepts that were very complex.
- **(IN)** Students seemed very discouraged and tired after working on their circuits
- **(IN)** Students seemed to struggle to convert the circuit schematics to real life circuits
- **(IN)** With these electronics topics many students asked the professors in Albanian instead of asking us

CLASS 7: ELECTRONICS CIRCUITS 3

- **(IN)** The professor and the students are noticeably discouraged that they haven't finished the circuits yet
- **(IN)** Despite being behind, all of the groups continue to push forward
- **(TD)** A team was able to complete all three circuits and was sharing tips on how to get it completed with other opposing teams
- **(TD)**We noticed increased collaboration as the tasks got harder and harder
- **(IN)** Many students needed explanation as to how to take the example code they were given and make it do what they wanted it to do

CLASS 8-14: ROBOT CONSTRUCTION

- **(TD/COMP)** Students in one team started a “lunch bet” with another team. The winner of the competition would buy the other team lunch.
- **(TD/COMP)** Students were very willing to assist other teams with debugging robot problems if they needed help.

APPENDIX B: LESSON PLANS

LESSON 1: INTRODUCTIONS

- Introduced ourselves and our relevant experience in robotics
- Explained why we are here
- Met with each group individually in order to introduce all of the students and let them ask any questions they may have had

LESSON 2: WHAT IS ROBOTICS?

- Explained what a robot is.
- Gave examples of competition robots for existing competitions
    - Robots from FIRST, Vex, and savage soccer competitions
- Explained the competition
    - What the field will look like
    - How scoring will work
    - General rules
- Explained the engineering design process briefly
    - Explained how to brainstorm
- Gave students time to design preliminary ideas for their competition robots
    - Visited groups to discuss the rules and assess any design challenges

LESSON 3: INTRODUCTION TO ROBOT DESIGN

- Began with students explaining their ideas for competition robots
- Gave the students a list of parts they will receive to build their robots
    - Kit of parts not handed out, just discussed
- Explained how different parts of the robot is connected with a block diagram
    - What things are connected to what on the robot
- Explained different types of chassis and their pros/cons
    - # of drive wheels
    - Turning radius
    - Center of gravity
- Explained a block diagram of the electrical system of a robot
    - What parts are connected to what electrically
- Explained an overview of sensors
    - What they are
    - Why we use them
    - What different sensors are used for

- Intended to begin working on an overview of circuits, but ran out of time

LESSON 4: ARDUINO BASICS

- Began with students updating us on final robot designs
- Brief overview of what an Arduino is
- Described the different data types and what they are used for
- Described how you can read inputs on Arduino
  - Use of reading signals for sensors
  - Differences between analog reading and digital reading
- Described when you use outputs with Arduinos
  - Use of outputs for peripheral control
  - Described how pulse width modulation works
- Showed the anatomy of an Arduino program
  - Described what goes into the setup
  - Described how to use sensors to control peripherals in the loop
- Finished with students working through examples on their own

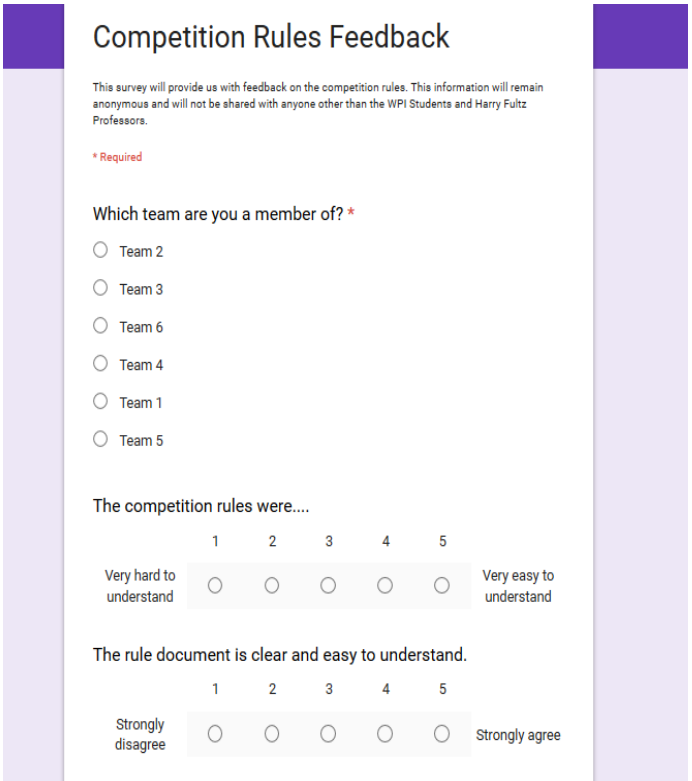
LESSON 5: LIFTING MECHANISMS AND TORQUE

- Began with distributing materials for a mini project later in class
  - Cardstock, scissors, pins
- Explained different types of lifting mechanisms and their pros/cons
  - Bar linkages
  - Scissor lifts
  - Extending linkages
- Went into detail about four-bar linkages
  - Explained different links
  - Talked about different motion paths for links
- Reviewed torque concepts
- Assigned mini project for them to complete during class
  - Construct two different four-bar linkages
    - Parallelogram linkage
    - Crank-rocker linkage

LESSON 6: MOTOR DRIVERS AND BOOST CONVERTERS

- Taught by professors Klarensi and Enxhi in Albanian
- Professor Klarensi explained motor drivers and H-bridges
- Professor Enxhi explained step-up and step-down converters

APPENDIX C: SHORT SURVEY QUESTIONS



Competition Rules Feedback

This survey will provide us with feedback on the competition rules. This information will remain anonymous and will not be shared with anyone other than the WPI Students and Harry Fultz Professors.

* Required

Which team are you a member of? *

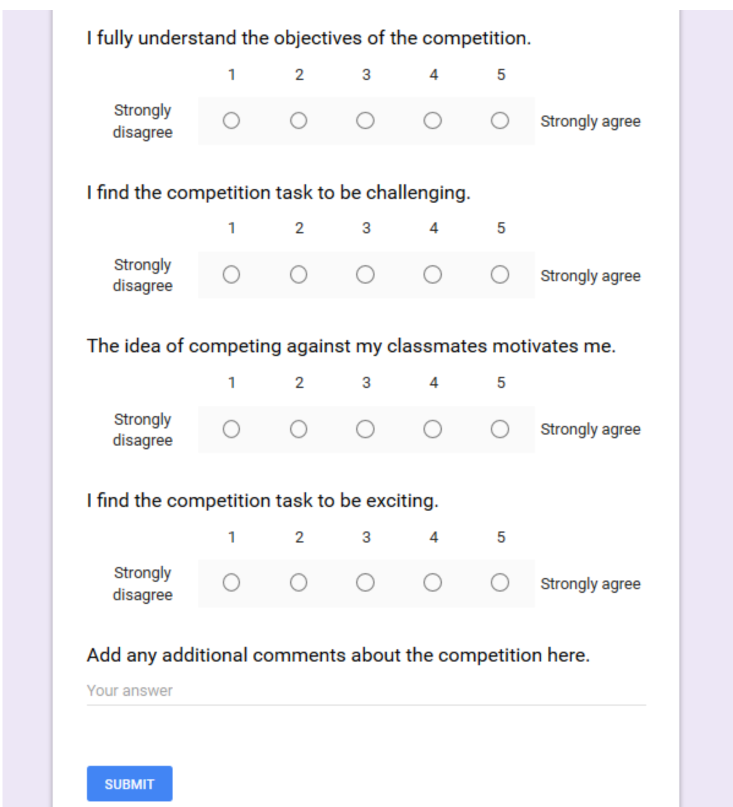
- Team 2
- Team 3
- Team 6
- Team 4
- Team 1
- Team 5

The competition rules were....

	1	2	3	4	5	
Very hard to understand	○	○	○	○	○	Very easy to understand

The rule document is clear and easy to understand.

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree



I fully understand the objectives of the competition.

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I find the competition task to be challenging.

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The idea of competing against my classmates motivates me.

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I find the competition task to be exciting.

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Add any additional comments about the competition here.

Your answer

SUBMIT

"What is Robotics" Lesson:

Description (optional)

This lesson was helpful. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I enjoyed learning about this. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

What is your prior knowledge in robotics? *

	1	2	3	4	5	
Not very knowledgable	○	○	○	○	○	Very knowledgeable

Do you have any questions or comments about the lesson?

Long answer text

"How to Construct a Robot" lesson:

Description (optional)

This lesson was helpful. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I enjoyed learning about this. *

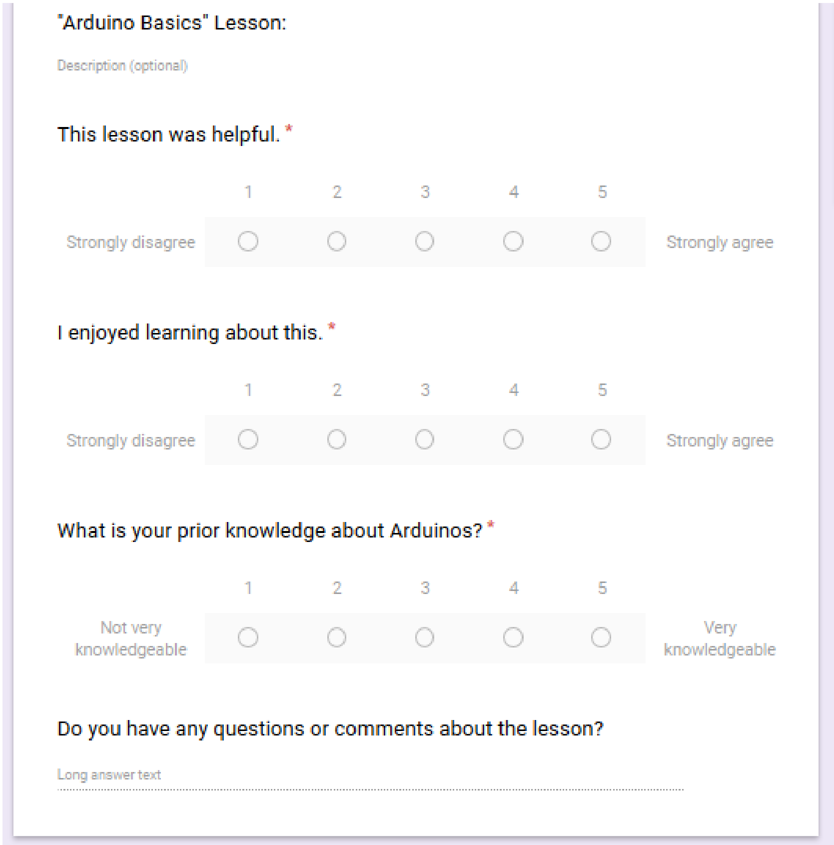
	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

What is your prior knowledge about chassis and how to construct a robot? *

	1	2	3	4	5	
Not very knowledgable	○	○	○	○	○	Very knowledgeable

Do you have any questions or comments about the lesson?

Long answer text



"Arduino Basics" Lesson:

Description (optional)

This lesson was helpful. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I enjoyed learning about this. *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

What is your prior knowledge about Arduinos? *

	1	2	3	4	5	
Not very knowledgeable	○	○	○	○	○	Very knowledgeable

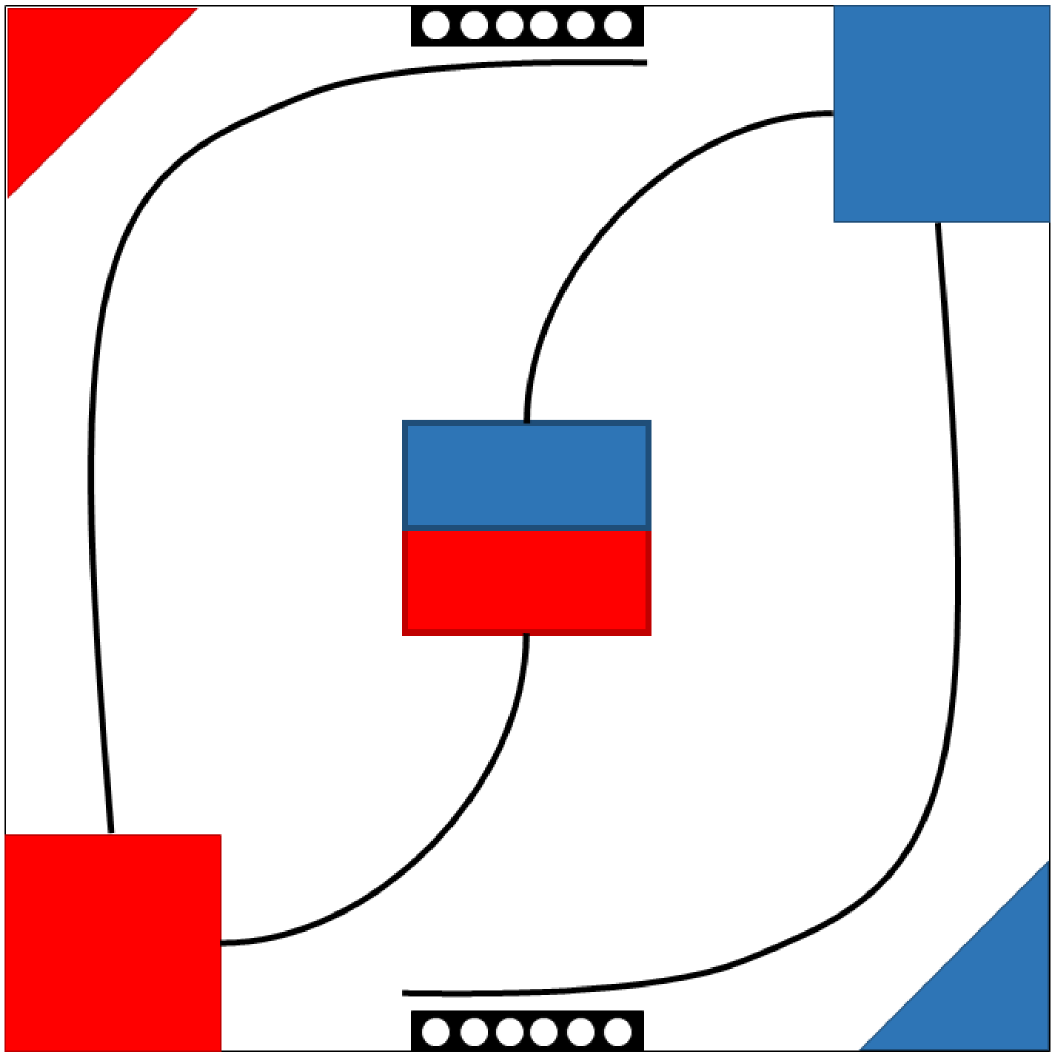
Do you have any questions or comments about the lesson?

Long answer text

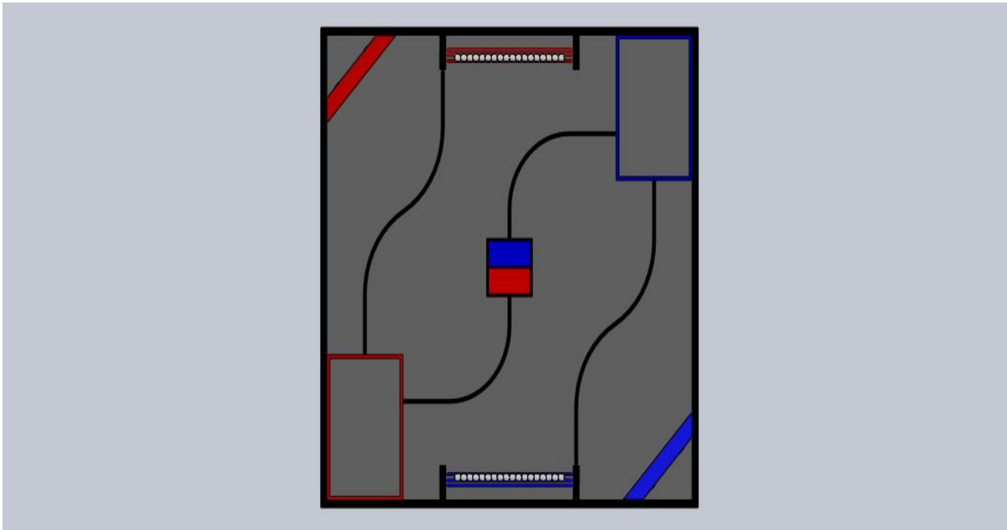
APPENDIX D: COMPETITION RULES

Adapted from the 2014 Savage Soccer Game Rules

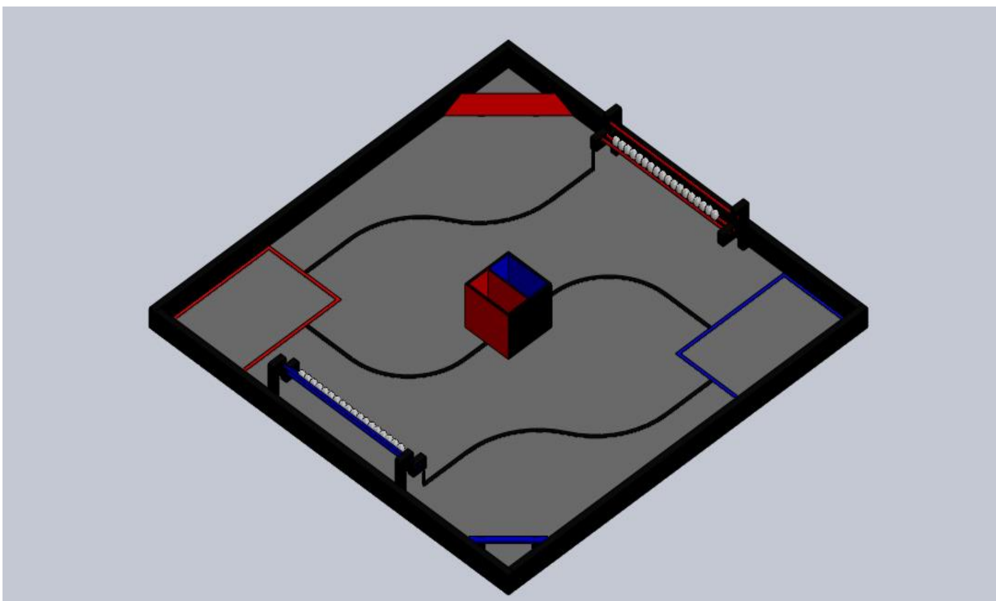
1. Game Objective: Two teams of one robot each will compete in timed matches to see who can score the most points.



Savage Soccer Overhead Conceptional View of the Field



Savage Soccer Overhead View, Solidworks Model of the Field



Savage Soccer Isometric View, Solidworks Model of the Field

2. Field Description
   2.1. The field is 250cm x 250cm. A wooden frame that is approximately 10cm high and 2cm thick forms the field wall (the outer boundaries of the playing area).
   2.2. The surface of the playing area is carpet that may have minor bumps and surface irregularities.
   2.3. Starting Zones: One 50cm x 75cm taped area, including the tape, for each team located in the corner of the field where robots begin the match.
      2.3.1. Robots will begin the match with every part of their robot within the boundaries of their Starting Zone, and at least some part of their robot touching the field border. Teams will be designated as either "Red" or "Blue" on a match-by-match basis as noted on the match List.

2.4. 18 balls start in each ping pong ball holder. 8 of which are orange and the other 10 are white. Each team is provided with one ball for preloading at their discretion. Any balls not preloaded into a robot are placed on the field before the start of the match.
   2.4.1. A ball is legally preloaded if it is in contact with exactly one robot and is completely within the Starting Zone.
2.5. Goal zones
   2.5.1. The Center Goal is a 30cm x 30cm x 20cm cube in the center of the field where the ping pong balls can be deposited for points. The Center Goal is divided into two regions, one for the Blue team and the other for the Red team.
   2.5.2. The Corner Goal is a triangular region bordered by two sides of the field and a ramp. Balls can be pushed or guided into this zone to score points. The ramp that borders this goal has an incline of 23 degrees.

3. Match Scoring
   3.1. Scoring will be calculated at the end of the match once all objects and robots have come to rest. Teams get point based on how many balls are in their colored goals at the end of the game, regardless of which team places the ping pong balls in the zones.
   3.2. Points scored in autonomous will be worth three times its normal point value.
   3.3. Scoring balls in your color section of the Center Goal will be worth the following point values:
      3.3.1. Orange ball (3 points)
      3.3.2. White ball (2 points)
   3.4. Scoring Balls in your color Corner Goal will be worth the following point values:
      3.4.1. Orange ball (2 points)
      3.4.2. White ball (1 point)
   3.5. Knocking down your teams ping pong ball holder is worth 5 points.

4. Match Schedule
   4.1. Autonomous (20 sec)
      4.1.1. Each Robot is allowed to start with 1 ball in the robot.
      4.1.2. Robots then have the option to line follow to knock the ping pong ball holder down or line follow to deposit balls in the center cube.
      4.1.3. Points during this time are worth three times their normal value.
      4.1.4. Drivers are not allowed to control their robot during this time.
   4.2. Teleoperated (60 sec)
      4.2.1. Robots will be controlled by each team using a remote.

5. Robot Construction Rules
   5.1. A robot must be designed to operate by reacting only against features within the confines of the playing field boundaries.
   5.2. Gaining traction by altering the playing field is not allowed and will be subject to disqualification.
   5.3. Teams must have their team name clearly marked on their robot.
   5.4. Building Constraints

5.4.1. Modifications are permitted to the mechanical parts, however, teams may NOT modify any of the given electronics or motors.
5.4.2. Teams may use any 7.2V battery, but only one battery may be used on the robot at a time.
5.4.3. Teams are allowed up to a combination of 6 motors and servos on their robot.

6. Robot Size Restriction
6.1. At the start of each match, every part of the robot must fit, unconstrained, in a stable position, within a box 40cm by 40cm by 50cm any orientation. The robot must be fully self-supported, in contact only with the horizontal, carpeted (or taped) surface of the playing field.

7. General Rules
7.1. All referee decisions regarding rules of play and judgments are final.
7.2. Rule Definitions
7.2.1. Pinning: A robot is considered pinned when it is being held against a field obstacle or another robot by a robot from an opposing coalition and cannot move in any direction. The closest referee will begin counting the pin from the moment the pin begins.
7.2.2. Penalty: A deduction of 5 balls (or all if team has fewer than 5 balls).
7.2.3. Disqualification: Robots may be disqualified based on their actions that violate the rules of the game. If a referee calls for a disqualification the offending robot will receive a loss.
7.3. Robot and Field Interaction Rules
7.3.1. Any game element which leaves the playing area during a match will be returned to the field in a non-scoring position as close to where it exited the field as possible.
7.4. Robots may not intentionally tip or damage an opposing team's robot. The offending robot will be disqualified from the match if, in the referee's opinion, they initiated a lifting action that results in tipping. In incidents where the tipped robot initiates the action or both robots are in motion, the involved robots may be disabled.
7.4.1. Robots will be disabled for physically interacting with anything outside of the field.
7.4.2. If a robot is pinned for five seconds, the pinning team must immediately disengage and move at least 12” away from the pinned robot. Failure to do so will result in an immediate penalty, as well as a penalty for each additional 5 seconds. Robots that accumulate multiple pinning penalties in a match are subject to immediate disqualification from the match.
7.4.3. All parts of the robot must remain attached to the robot for the duration of the match and must not cause any hazard of entanglement to the other robots. Any infraction of this rule may result in an immediate disqualification. Minor pieces that unintentionally become detached from the robot, do not affect the outcome of the match, or are the result of improper design/construction will not cause a disqualification.

7.5. Once an object has been scored in a goal, it cannot be removed. Teams who attempt this strategy will assessed a penalty. In addition, any removed scoring objects will be placed back into the goal they were removed from.

7.6. Safety Rules

7.6.1. Team members may interact with their robot during a match only through the transmissions of the radio-controller. Only designated Drivers may be in contact with the controls during the match.

7.6.2. Referees may request that teams alter any portion of their robots that are considered safety hazards or damaging to the playing field or scoring objects at any point during the competition. It is the right of the referees to prevent teams from playing in matches until such changes are made to the robot.

7.7. Competition Structure

7.7.1. The winner of the match is the team that has the highest total points. If the teams have the same number of points, the result is a tie.

7.7.2. All teams will play in the same number of matches.

7.7.3. Team members will rotate driving the robot in each match.

7.7.4. At the end of the matches, teams will be ranked based on the following:

7.7.4.1. Greatest number of wins (a tie is considered half of a win)

7.7.4.2. If there is a tie, the greatest amount of total points scored will serve as a tiebreaker

7.7.5. Qualification Round:

7.7.5.1. Every team will compete against each other in a round robin style competition. There will be 15 matches total.

7.7.5.2. Teams will be randomly assigned colors, opponents and competition times.

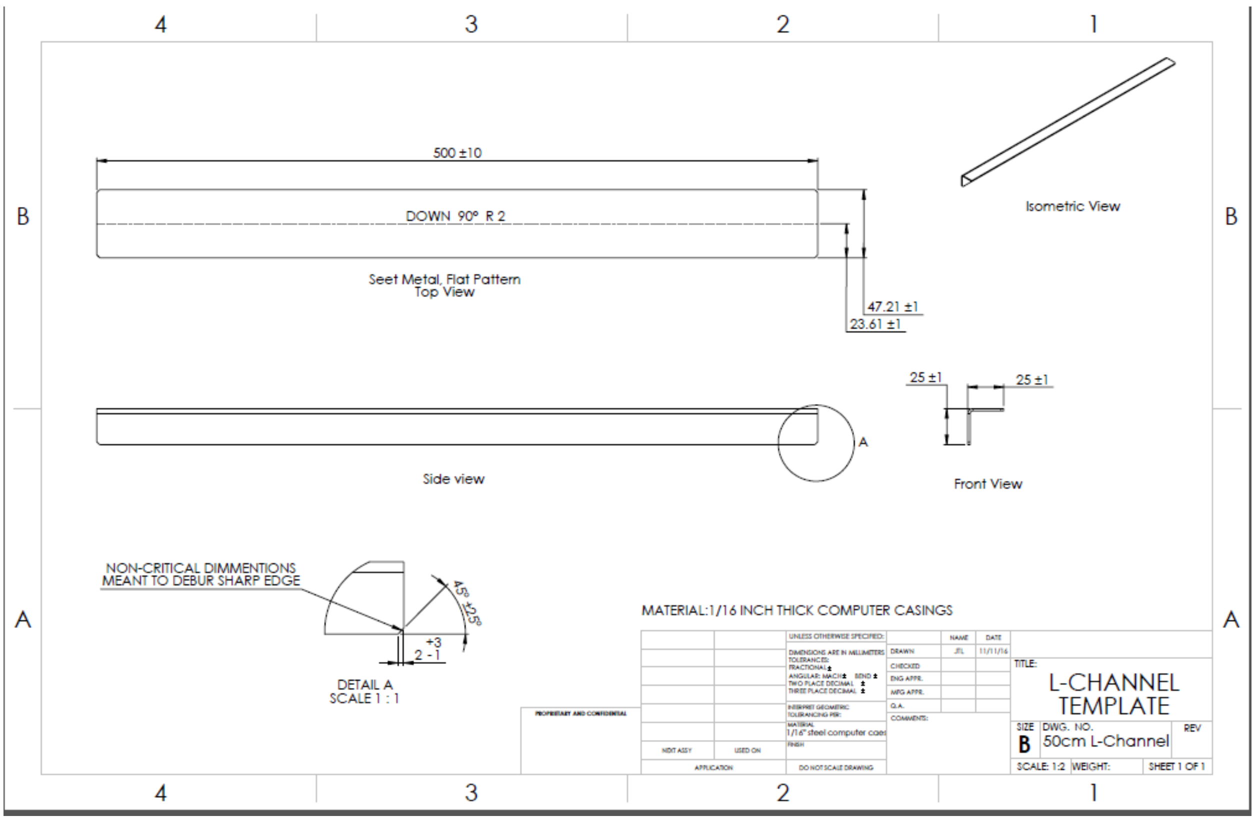
7.7.6. Final Round:

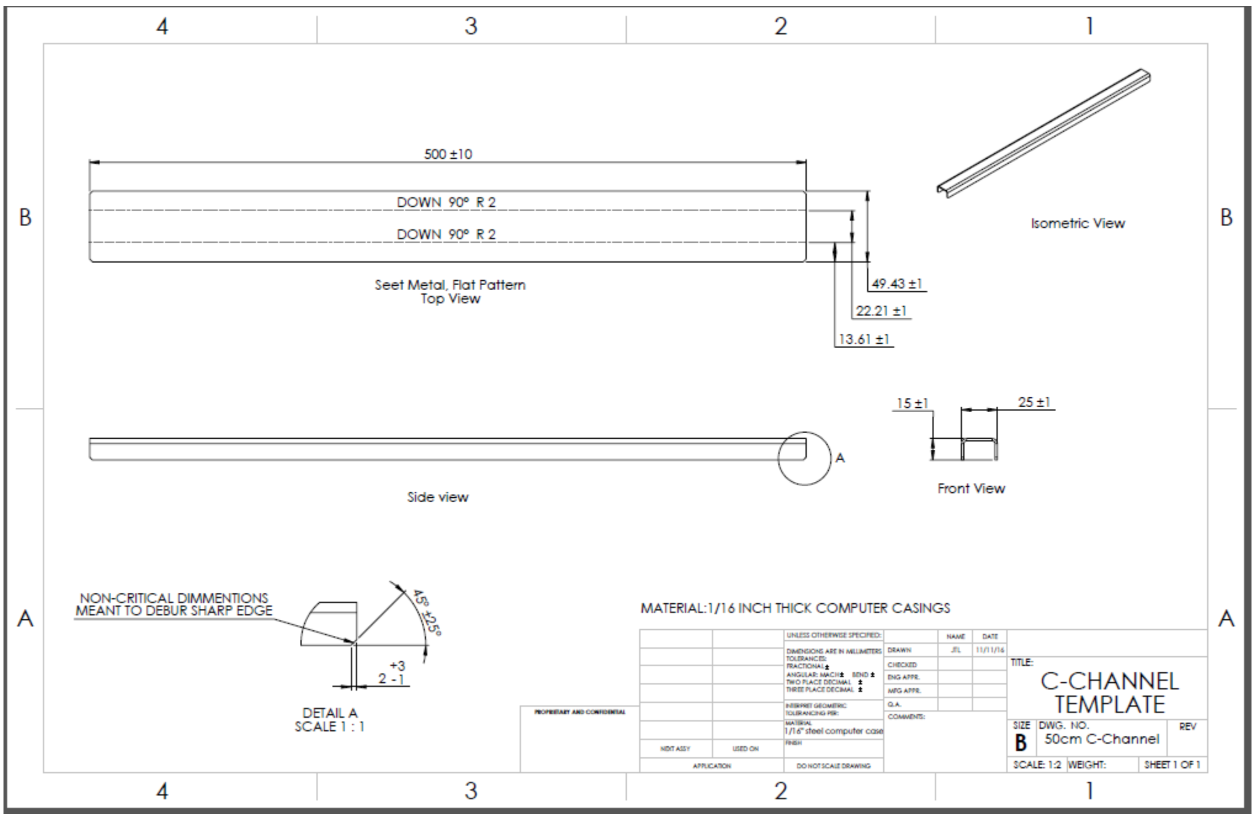
7.7.6.1. The two highest ranked teams will compete against each other in three finals games to determine an overall winner.

7.7.6.2. In these games each team will be randomly given a color that will stay the same for all three games.

7.7.6.3. The winner of the competition is the team who wins the majority (⅔) of the Final Round matches.

APPENDIX E: TECHNICAL DRAWINGS OF CHASSIS PIECES

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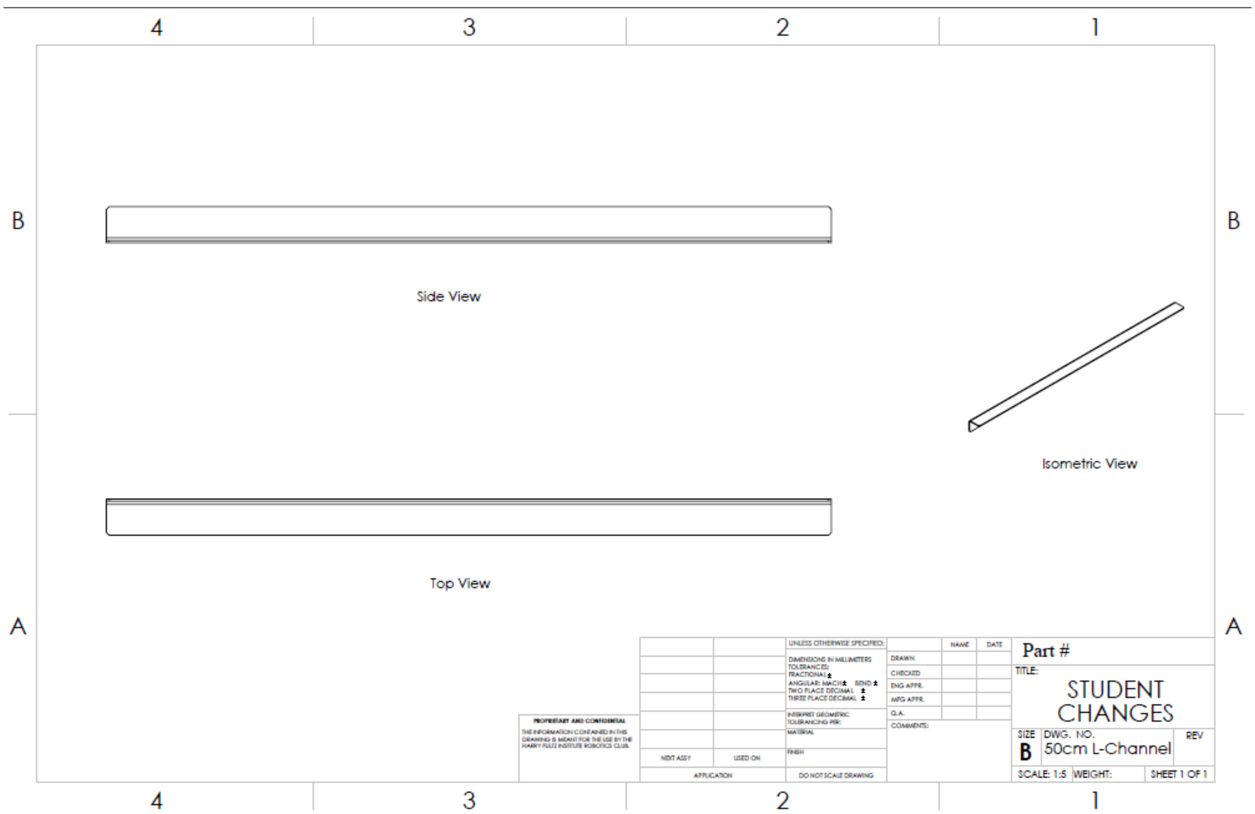

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Top View
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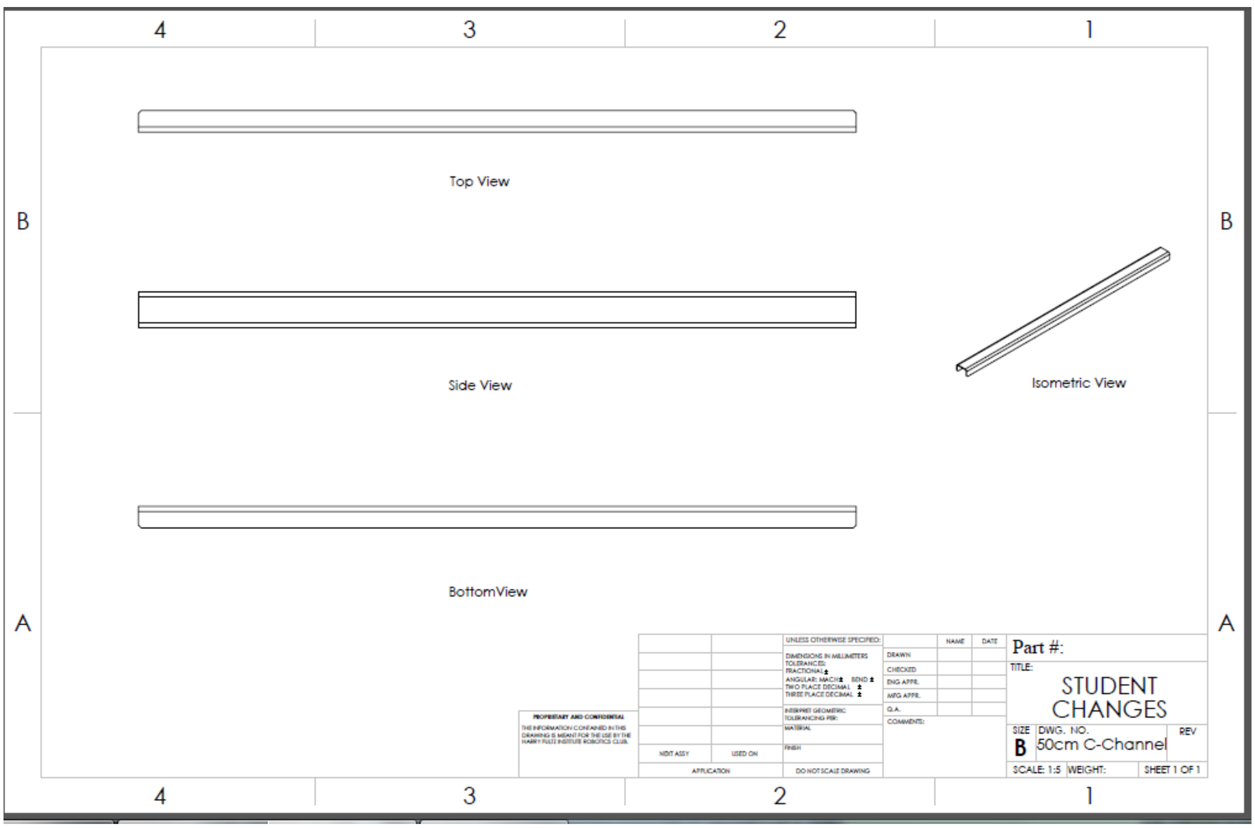
SHEET 1 OF 1


Top View
Side View
BottomView
Isometric View
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS MEANT FOR THE USE BY THE HARRY FULTZ INSTITUTE ROBOTICS CLUB.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
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SHEET 1 OF 1

APPENDIX F: FULTZLIB PROGRAMMING LIBRARY

FULTZLIB.H

```
#ifndef MASTER_H
#define MASTER_H

 #include <DCMOTOR.h>
 #include <XBOXRECV.h>
 #include <STEPPER.h>

#endif
```

DCMOTO.H

```
#ifndef DCMOTOR_H
#define DCMOTOR_H

#include <Arduino.h>

class DCMOTOR{
	public:
	DCMOTOR();
	void attach(uint8_t pwmPin, uint8_t dirPin1, uint8_t dirPin2, uint8_t
enablePin);
	void attach(uint8_t pwmPin, uint8_t dirPin1, uint8_t dirPin2);

	void motorEnable(void);
	void motorDisable(void);
	void motorBrake(void);

	void motorRunCW(uint8_t pwmIn);
	void motorRunCCW(uint8_t pwmIn);

	enum MotorState {runCW, runCCW, brake, disabled};
	MotorState getState(void);

	private:
	uint8_t pwmPin;
	uint8_t dirPin1;
	uint8_t dirPin2;
	uint8_t enablePin;

	uint8_t pwmVal;
	bool dir1State;
	bool dir2State;
	bool enableState;
	MotorState state;
};
#endif
```

DCMOTOR.CPP

```
/////////////////////////////////////////////////////////////////////////////////////
//////
/*
*This library was written by Nathan Beeten on October 28, 2016
*It was last updated on October 31, 2016
*This library was created for the Harry Fultz Institute's Robotics Club
*/
```

```
/////////////////////////////////////////////////////////////////////////////////////
//////
#include "DCMOTOR.h"

	DCMOTOR::DCMOTOR () {} //default Cunstructor to create the object

	void DCMOTOR::attach(uint8_t pwmPin, uint8_t dirPin1, uint8_t dirPin2, uint8_t 
enablePin){ //method to set up the object
		/////////////////////////set driver pins to the ones 
sepecified////////////////////////
		this->pwmPin = pwmPin;
		this->dirPin1 = dirPin1;
		this->dirPin2 = dirPin2;
		this->enablePin = enablePin;
		///////////////////////////Initialize all the pins to 
outputs//////////////////////////
		enableState = false;
		pinMode(pwmPin, OUTPUT);
		pinMode(dirPin1, OUTPUT);
		pinMode(dirPin2, OUTPUT);
		pinMode(enablePin, OUTPUT);

		state = disabled;
	}
	void DCMOTOR::attach(uint8_t pwmPin, uint8_t dirPin1, uint8_t dirPin2){ 
//method to set up the object
		/////////////////////////set driver pins to the ones 
sepecified////////////////////////
		this->dirPin1 = dirPin1;
		this->dirPin2 = dirPin2;
		this->enablePin = enablePin;
		///////////////////////////Initialize all the pins to 
outputs//////////////////////////
		enableState = false;
		pinMode(dirPin1, OUTPUT);
		pinMode(dirPin2, OUTPUT);
		pinMode(enablePin, OUTPUT);

		state = disabled;
	}

	void DCMOTOR::motorEnable(void) {//This method allows the motors to move
		enableState = true;
		digitalWrite(enablePin, enableState);
		return;
	}

	void DCMOTOR::motorDisable(void) {//This method forces the motors to stop
		enableState = false;
		digitalWrite(enablePin, enableState);
		return;
	}

	void DCMOTOR::motorBrake(void) {//Forces the motors to stop without disabling 
them
		dir1State = false;
		dir2State = false;
		digitalWrite(dirPin1, dir1State);
		digitalWrite(dirPin2, dir2State);
		return;
	}
```

```
	void DCMOTOR::motorRunCW(uint8_t pwmIn) {//Run the motor Clockwise (nominally
backwards)
		dir1State = true;
		dir2State = false;
		digitalWrite(dirPin1, dir1State);
		digitalWrite(dirPin2, dir2State);
		analogWrite(pwmPin, pwmIn);
		return;
	}

	void DCMOTOR::motorRunCCW(uint8_t pwmIn) { //Run the motor Counter-Clockwise
(nominally forwards)
		dir1State = false;
		dir2State = true;
		digitalWrite(dirPin1, dir1State);
		digitalWrite(dirPin2, dir2State);
		analogWrite(pwmPin, pwmIn);
		return;
	}

	DCMOTOR::MotorState DCMOTOR::getState(void){//this returns the current state of
the motor
		return state;
	}

	; //This semicolon makes everything else work. Don't ask why


////////////////////////////////////////////////////////////////////////////////////////
//////
/*
*This library was written by Nathan Beeten on October 28, 2016
*It was last updated on October 31, 2016
*This library was created for the Harry Fultz Institute's Robotics Club
*/
////////////////////////////////////////////////////////////////////////////////////////
//////
#include "DCMOTOR.h"

	DCMOTOR::DCMOTOR () {} //default Cunstructor to create the object

	void DCMOTOR::attach(uint8_t pwmPin, uint8_t dirPin1, uint8_t dirPin2, uint8_t
enablePin){ //method to set up the object
		/////////////////////////set driver pins to the ones
sepecified////////////////////////
		this->pwmPin = pwmPin;
		this->dirPin1 = dirPin1;
		this->dirPin2 = dirPin2;
		this->enablePin = enablePin;
		///////////////////////////Initialize all the pins to
outputs//////////////////////////
		enableState = false;
		pinMode(pwmPin, OUTPUT);
		pinMode(dirPin1, OUTPUT);
		pinMode(dirPin2, OUTPUT);
		pinMode(enablePin, OUTPUT);

		state = disabled;
```

```
	}
	void DCMOTOR::attach(uint8_t pwmPin, uint8_t dirPin1, uint8_t dirPin2){
//method to set up the object
		//////////////////////////set driver pins to the ones
sepecified////////////////////////
		this->dirPin1 = dirPin1;
		this->dirPin2 = dirPin2;
		this->enablePin = enablePin;
		///////////////////////////Initialize all the pins to
outputs///////////////////////////
		enableState = false;
		pinMode(dirPin1, OUTPUT);
		pinMode(dirPin2, OUTPUT);
		pinMode(enablePin, OUTPUT);

		state = disabled;
	}

	void DCMOTOR::motorEnable(void) {//This method allows the motors to move
		enableState = true;
		digitalWrite(enablePin, enableState);
		return;
	}

	void DCMOTOR::motorDisable(void) {//This method forces the motors to stop
		enableState = false;
		digitalWrite(enablePin, enableState);
		return;
	}

	void DCMOTOR::motorBrake(void) {//Forces the motors to stop without disabling
them
		dir1State = false;
		dir2State = false;
		digitalWrite(dirPin1, dir1State);
		digitalWrite(dirPin2, dir2State);
		return;
	}

	void DCMOTOR::motorRunCW(uint8_t pwmIn) {//Run the motor Clockwise (nominally
backwards)
		dir1State = true;
		dir2State = false;
		digitalWrite(dirPin1, dir1State);
		digitalWrite(dirPin2, dir2State);
		analogWrite(pwmPin, pwmIn);
		return;
	}

	void DCMOTOR::motorRunCCW(uint8_t pwmIn) { //Run the motor Counter-Clockwise
(nominally forwards)
		dir1State = false;
		dir2State = true;
		digitalWrite(dirPin1, dir1State);
		digitalWrite(dirPin2, dir2State);
```

```
        analogWrite(pwmPin, pwmIn);
        return;
    }

    DCMOTOR::MotorState DCMOTOR::getState(void){//this returns the current state of
the motor
        return state;
    }

    ;
```

STEPPER.H

```
#ifndef STEPPER_H
#define STEPPER_H

#include <Arduino.h>

class STEPPER {
   public:
       STEPPER(); //default constructor
       void attach(uint8_t dirPin, uint8_t stepPin); //explicit constructor
       void step(); //take one step
       void step(bool dir); //take one step
       void stepSpd(uint16_t freq, bool dir); //takes steps at a certain speed
       void stepSpd(uint16_t freq); //takes steps at a certain speed
       void changeDir(bool dir); //changes rotation direction

   private:
       bool dir; //rotation direction
       uint8_t dirPin; //controls rotation direction
       uint8_t stepPin; //tells motor to take a step
};

#endif
```

STEPPER.CPP

```
#include "STEPPER.h"

/** Default constructor
*/
STEPPER::STEPPER() {
}

/** Initialize the pins for the stepper motor
   @param dirPin Pin for controlling direction
   @param stepPin Pin for taking steps
*/
void STEPPER::attach(uint8_t dirPin, uint8_t stepPin) {
   this->dirPin = dirPin;
   this->stepPin = stepPin;
   pinMode(dirPin, OUTPUT);
   pinMode(stepPin, OUTPUT);
   dir = 0;
}

/** Takes a single step
*/
void STEPPER::step() {
   //Ensure the output is low
```

```
   digitalWrite(stepPin, LOW);
   //set direction to correct direction
   digitalWrite(dirPin, dir);
   //Toggle output
   digitalWrite(stepPin, HIGH);
   //
   digitalWrite(stepPin, LOW);
}

/** Takes a single step
   @param dir New direction value
*/
void STEPPER::step(bool dir) {
   digitalWrite(stepPin, LOW);

   changeDir(dir);

   digitalWrite(dirPin, dir);

   digitalWrite(stepPin, HIGH);

   digitalWrite(stepPin, LOW);
}

/** Drives the stepPin output at the desired frequency in a new direction
   @param freq Frequency from 31-65535Hz
   @param dir New direction value
*/
void STEPPER::stepSpd(uint16_t freq, bool dir) {

   changeDir(dir);

   digitalWrite(dirPin, dir);

   tone(stepPin,freq);
}

/** Drives the stepPin output at the desired frequency
   @param freq Frequency from 31-65535Hz
*/
void STEPPER::stepSpd(uint16_t freq) {
   //set direction
   digitalWrite(dirPin, dir);
   //output a square wave at the desired frequency
   tone(stepPin, freq);
}

/** Changes the direction variable
   @param dir New direction value
*/
void STEPPER::changeDir(bool dir) {
   this->dir = dir;
}
```

APPENDIX G: KIT OF PARTS

LIST OF ITEMS IN KIT OF PARTS

4x wheels

2x large 19:1 geared motors

1x 27:1 geared stepper motor

1x large breadboard

1x 7.2V 3000mAh battery

1x USB cable

1x USB Xbox 360 controller receiver

1x Xbox 360 controller

1x USB host Arduino shield

1x Arduino Uno

1x 9g micro-servo with attachments

1x Infrared light sensor

1x Infrared light emitter

1x Grayscale sensor

1x LED module

1x Multi-turn potentiometer

1x Pushbutton

2x Motor to wheel adaptors

APPENDIX H: SEMI STRUCTURED INTERVIEW RESULTS

We administered a series of semiformal interviews with students who volunteered to talk to us about their experience with the club. We interviewed 16 of the 24 students involved with the club, and while most of the interviews were done with individual students, 3 of them had a friend that helped them translate their thoughts. Going into the interviews we didn't have a strict list of questions to ask, but we went into the interviews trying to determine the following:

- Determine student feelings towards various topics including:
  - The progress on their project
  - Competing against their classmates
  - Working as a team
- Compare and contrast between their classes at school and the club
- Determine the process they went through to design their robots
- Determine student perceptions about the lessons

REPEATED THEMES AND KEY POINTS:

STUDENT FEELINGS REGARDING THEIR PROJECT:

Students reacted almost universally positively regarding their progress so far. Most students reflected that they were learning a lot from their work and that they were finding it fun and challenging. The only negative comments came from a few students who remarked that they wished that work on their projects started earlier.

COMPETING AGAINST CLASSMATES:

All of the students interviewed stated that they enjoyed having a competition to work towards. None of the students stated that they were solely motivated by winning, other motivations cited were desires to learn, push themselves, and to make friends. We also tried to determine how they were interacting with other teams. A majority of students reported some level of communication with other teams, with a large number of them stating that they had both given and received help from other teams. A couple students stated that they didn't communicate with other teams out of fear that the other teams would steal their ideas. This was particularly interesting because other students from the same team reported sharing details of their design with the other teams.

WORKING AS A TEAM:

Each student we talked to said that they were enjoying working as a team. Some students said that this was their first experience working as a team on a project, and that they were enjoying not being solely responsible for working on the project. All teams interviewed except for one stated that they worked together to ensure that each member had an understanding of each part of the project with that topic's specialist working to teach the other members about their specialty and how it related to their robot. The team that reported not teaching their other team members cited it taking too long to explain the work to their team mates, and that they would rather spend their time working on the project. Many of the students stated that they felt very close to their team mates, and that working together as a team made them better friends.

COMPARING CLASSES TO THE CLUB:

Students stated that the main difference between the club and that classes was a lack of hands on work in classes. When asked which they preferred they responded that they vastly preferred being able to build things to the pure theory they learn in class. Students stated that almost none of their classes allowed them to work on something that they came up with and instead required them to repeat what they had learned during lectures.

DETERMINING THE STUDENT DESIGN PROCESS:

Students had a variety of responses when asked how they came up with their robot designs. Some students came up with multiple designs and then discussed pros and cons with their teams, and each team had a different criteria to decide what made a design good or bad. The primary factors in robot design included: speed, efficient ball collection, design simplicity, and having a compact design.

DETERMINING STUDENT PERCEPTIONS OF LESSONS:

We asked the students how they felt about the lessons that we gave. Most students said that they found them useful, but there was a range of how much they gained from them. Most of the first year students said that they found the lessons very useful, and would have liked to have received more lessons on advanced topics such as programming. Some of the first year students however said that they didn't need the lessons and would have rather gone straight into working on the robot. The students who had been in the club the previous year stated that the lessons weren't as useful for them, but found them necessary for the new students to get acquainted.

STUDENT QUOTES:

"With this competition I have been more close to other students, just because of this competition I have made new friends, I really like that"
"You are more free to speak and do things that you cannot do in class, you are free to bring new ideas. You are free to get any idea you want and build anything you want"
"I have a dream to build the Iron Man suit"
"We help each other, what they don't know I teach them, and what I don't know they teach me"
About teamwork:
"If any team comes to my team to ask for help I will be pleased to give them help"
"We learn a lot in the robotics club, more than we would in school"
About lessons:
"Even if you don't know anything about robotics, you can progress your skills"
"I wanted to learn it and I learned it, that's what makes it great I think."
About changing the club:
"There's a saying in Albania, good things never finish"

APPENDIX I: INFORMED CONSENT FORM

Informed Consent Agreement

Harry Fultz Institute Robotics Program WPI IQP

Created by: Nathan Beeten, Jacob St. Germain, Josie Leingang, Ben Titus

Purpose: The goal of the WPI Robotics student project is to create an effective robotics competition at the Harry Fultz Institute by teaching robotics topics to students, providing and creating a support system for the competition, and introducing cooperation and an element of competition into a learning environment.

Harry Fultz Institute student involvement: As a part of the WPI student project, the team will be analyzing the effects of competition on teamwork and student learning, through inviting the Harry Fultz Institute students to voluntarily participate in surveys, interviews and WPI students' observations. The WPI students will only use the data collected for academic purposes and will not share information gathered with any sources outside of the Harry Fultz Institute and WPI.

Confidentiality: Students' names will not be used when reporting information gathered from surveys, interviews or observations. All data will remain anonymous unless consent is given by the student.

Photography: The WPI Robotics project team may use photographs of the Harry Fultz Institute students and their work to be included in a final report. These photos will not be distributed outside of the report unless given consent by the students involved.

Voluntary participation: Your participation in this project is completely voluntary. There is no penalty if you decide not to participate.

If you have any questions you may contact the WPI student group (a16robotics@wpi.edu) or the WPI academic advisors Peter Christopher (peterrc@wpi.edu), and Robert Hersh (hersh@wpi.edu).

Agreement: I agree to participate in the WPI Robotics project as described above.

Your Name [printed]: ____

Your Signature: ____

Date: ____

APPENDIX J: FREE LISTING TOPICS AND PROCEDURE

IN CLASS PROCEDURE:

- Ensure that everyone in the sample group has a writing utensil and something to write on.
- Inform the sample group that the following exercise has no right answers and that after a topic is presented, each individual in the sample should write down any and all words that come to mind based on the question presented to them.
- Ensure they realize they don't need to put their name on it.
- Read one of the questions out loud to the sample. Allow 5-7 minutes for them to write down any that they associate with the prompt.
- During this process try not to speak or suggest any answer as this can skew the results.
- Once the 5-7 minutes are up, have them turn in their papers and either repeat the process with a different prompt or thank them for participating and end the exercise.

ONLINE PROCEDURE:

- Ensure directions are clear on the survey being sent to students.
- Send the survey to students with instructions on how to complete it along with a deadline.

TOPICS FOR THE FREE LISTING EXERCISE WERE AS FOLLOWS:

- What words describe a good team partner?
- What qualities describe a good teacher?
- What words describe your experiences with robotics?
- What words or phrases describe what happens at a competition?
- What attributes describe a good opponent in a competition?