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Introducing a Robotics Club in Albania

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Introducing a Robotics Club in Albania

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Abstract

This project established a robotics club at the Harry Fultz Institute Technical High School in Tirana, Albania. We worked with a group of 24 enthusiastic students, divided into six teams, each directed by a student mentor. Employing a strategy of self-directed learning, we helped the teams design and build low-cost robots, culminating in an official presentation to the school. We assessed outcomes by documenting participant perceptions of the educational activities. Student participants reported that they valued the experience and that they would continue to engage in robotics activities after we left the country. We recommend that the Harry Fultz Institute continue the robotics club, and that other Albanian schools begin their own robotics programs.

Acknowledgements

We express our sincere gratitude to the staff, faculty and students of the Harry Fultz Institute, especially Professor Enxhi Jaupi, whose direct involvement and support made this project a reality.

We give special thanks to the students who participated in our robotics program. These students dedicated countless hours to their projects, and their efforts built the foundation for a robust robotics program at their school. In addition, we thank the research staff of the WPI Gordon Library for the help they provided as this project got off the ground.

Finally, we thank our project site advisor, Professor Peter Christopher, and our research instructor Professor Robert Hersh, for their great support and guidance throughout the research and execution phases of this project.

Authorship

We, the authors listed on the cover of this document, made equal contributions to this project and this report.

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Executive Summary

Robotics projects are a popular approach to teaching STEM (science, technology, engineering and mathematics) topics in high schools in many parts of the world. The goal of this project was the development of a robotics program to provide the students of the Harry Fultz Institute Technical High School in Tirana, Albania with experience in the field of robotics and a greater appreciation for engineering design, science and teamwork. We organized the project around three main objectives:

- Help students at Harry Fultz Institute Technical High School design hands-on technical robotics projects tailored to their interests.
- Start the Harry Fultz Institute Technical High School robotics club and help it convene in its first few weeks of meetings; help the students become self-directed and move the group through early challenges.
- Identify strategies to enable Harry Fultz Institute Technical High School to maintain and grow its robotics program in the future.

Existing literature supports robotics as a STEM teaching tool in schools. Robotics projects help students relate what can be unfriendly math and science concepts to something clearly useful and applicable in the real world (Nugent et al. 2010, p. 392). This can increase the rates at which students consider working professionally on STEM-related projects: in one study, students who participated in the FIRST Robotics Competition (FRC, an international educational non-combat robotics competition) were ten times more likely to hold an "internship, apprenticeship, [or] co-op job freshman year" than students in a comparable group who did not participate in FIRST (Melchior et al. 2005 p. 38). Even relatively small countries with new robotics industries have become involved in educational robotics. For example, in Israel, a large number of schools participate in the FRC (FIRST Israel n.d. *Groups*). The country's involvement in the program is growing; the number of student participants in Israel's national FRC event approximately quintupled between 2005 and 2009 (Boudreaux 2009). Israeli schools also incorporate FIRST Lego League, which serves younger grade-school students, into robotics education efforts (FIRST Israel n.d. *FLL*).

Robotics projects are also beneficial because they can be designed directly by students. Motivation to learn is greater in students who are pursuing their own interests (Denofrio et al. 2007). Thus, it is favorable to tailor educational activities toward the interests of the students involved. Students may express their interests in the questions that they ask, and teachers may design curricula around these questions (Hagay et al. 2013). Given the chance, students may express direct interest in particular projects, genres of projects or activities. By allowing students to design their own robots, educators place learning where it belongs: in the hands of students.

Robotics programs can be hard to adopt in some environments. The Harry Fultz Institute Technical High School is an example of such an environment. At this time, the school's yearly budget for a robotics club is approximately $300 US, and only one teacher is available to mentor the club. In addition, specialty robotics parts can take weeks to arrive at the school when ordered from overseas. To start the robotics club at Harry Fultz Institute Technical High School, we had to work within these constraints.

When we arrived at the Harry Fultz Institute in Tirana, we first took an inventory of one of the high school's electronics laboratories. Included in this inventory was a selection of components that we brought with us from the United States and gave to the school. The project liaison and assigned robotics club teacher, Professor Enxhi Jaupi, selected 24 club members from a population of very interested and enthusiastic electronics students at the school. He divided these students into six groups, each containing four members, and assigned one member of each group as the group leader, per our recommendation. The group leader system was motivated by the high student-teacher ratio in the club. We expected that the group leaders would act as peer mentors, reducing the load on Professor Jaupi.

For a week, we taught the student group leaders some of the basic programming techniques for Arduino, a popular open-source microcontroller board. During this time, we also asked the student leaders to propose Arduino-based robot designs. Harry Fultz Institute administration requested that we keep the budget close to $300 US, so we imposed a rough cost limit of $50 US for each robot, excluding the cost of the Arduino microcontroller boards and other components already available at the school. We helped the students find sources for inexpensive components, but we learned that most of the parts the students requested could not be purchased within Albania. Ultimately, we organized a single order from RobotShop, a Canadian supplier, and expedited the shipping of the components.

While we waited for components to arrive, we worked with the student teams to refine their designs. The students produced computer diagrams and 3D models of their physical robots, as well as electronic circuit diagrams and schematics. Some of the students started writing programs for their robots while waiting for the parts to arrive.

Because of delays in credit card processing, and part substitutions to avoid backorders, we did not receive our order of components until the end of the fifth week of the project. The students constructed their robots shortly after this time, by referencing the 3D models and schematics they had created previously. The robots were diverse, exhibiting a wide range of interesting functionality. Some robots avoided obstacles; another followed a black line marked out on the floor. One robot even balanced on two wheels using sensor feedback. The students exhibited their robots to Fultz Institute staff, faculty and parents in an official presentation at the school. The students continued to refine their projects after this time. Some students planned to start working on more advanced projects, including a pre-built six-axis robotic arm owned by Professor Jaupi.

We concluded that the Harry Fultz Institute was well suited to robotics education activities, and recommended that the school continue its robotics program. We now know that robotics education activities are possible even at low costs, and that the students of the Harry Fultz Institute Technical High School have a strong interest in hands-on project work. Professor Jaupi has ties to the Polytechnic University of Tirana; we recommended that he recruit students and faculty from the university to mentor club members in the future. This may allow a larger number of students to participate in the club. We also recommended that the school perform community outreach to create a platform of outside support for the club, and consider joining an international robotics league such as FIRST, because such leagues provide many opportunities for fundraising and corporate sponsorship. Finally, we recommended that other Albanian schools take action to start their own robotics programs, and consider international competitions such as FIRST.

1 Introduction

As schools attempt to incorporate STEM (Science, Technology, Engineering and Mathematics) topics into their curricula, robotics activities offer great potential as teaching tools, even in subjects that are not directly robotics-related (Benitti 2012; Norton 2007; Melchior et al. 2005). Many schools already have thriving robotics programs through international competitions such as FIRST (For Inspiration and Recognition of Science and Technology). These programs promote student interest in STEM topics, leading to improved uptake of science and engineering fields in college, and to increased school attendance and student confidence (Melchior et al. 2005; FIRST Robotics Competition 2013; Atmatzidou & Demetriadis 2014). Robotics career opportunities are also growing: in the United States, opportunities for jobs requiring robotics knowledge increased by 29% in 2012 (Robotics Business Review 2012).

Notwithstanding the success of past programs, robotics activities can be difficult for schools with limited resources, due in part to the cost of the materials required and further to the requirements for teacher involvement and availability of equipment.

Commercial educational robotics kits exist, but versatile options tend to be expensive. For schools with limited budgets, the investment may not be justifiable. The necessary parts may also be hard to obtain, especially in small or less developed countries. Another major challenge is that of teacher availability and expertise. Some schools find it impossible to devote a large number of experienced teachers to a robotics group.

Some work has been done to reduce the cost of robots in the classroom. The African Robotics Network (AFRON) ran a contest in 2012, challenging competitors to develop extremely low cost educational robots with a $10 US price point (AFRON 2013 *$10 Robot Design Challenge*; Bishop 2012). Mark Tilden's BEAM (Biology Engineering Aesthetics Mechanics) approach, a philosophy which focuses on "minimalist electronics" (limited microcontroller usage) and scavenging for components in "technoscrap" (Seale 2003), provides the basis for a solution to the problem of parts availability. Neither of these topics directly addresses the third major challenge, that of qualified teacher availability. One solution, employed by the FRC (FIRST Robotics Competition)[1], is to pull in volunteer expert mentors from industry, to work with students. Another technique is peer mentoring or group tutoring; researchers have shown that this type of guidance can improve learning (Greenwood et al. 1988; Greenwood et al. 1989; Topping 1996).

The sponsor of this project is the Harry Fultz Institute, a technical high school and community college in Tirana, Albania. The Harry Fultz Institute wishes to host a robotics club for its high school students. Students and faculty at the school have expressed fervent interest in robotics activities, but the aforementioned challenges have limited the school's involvement in such activities: the school's robotics club budget is approximately $300 US per year, and busy teacher schedules force a high student-teacher ratio in the club (E. Jaupi, personal communications, Sept. 2014). In this project, we spent seven weeks working with the school to start the robotics club under these constraints and to mitigate early challenges. The school may wish to expand its robotics program to allow more students to participate in the future; thus, we also built recommendations to ensure the long-term viability of the club.

In pursuit of the goal established by the Harry Fultz Institute, we first assessed the school's available resources. This included the availability of physical components, the school's budget and the student-teacher ratio within the club. After collecting this data, we developed project liaison Professor Enxhi Jaupi's electronics lab at the school into a robotics laboratory. This lab provided a space in which six teams of four enthusiastic students, each containing a specially selected student peer mentor, created robotics projects of their own design, with our assistance and the assistance of Professor Jaupi. We focused on small, mobile, Arduino-based robots, due to the universal adoption of the Arduino microcontroller and its ease of procurement and integration. We also helped

[1] FIRST is an international organization that promotes robotics in schools and organizes various educational robotics competitions. The FRC (FIRST Robotics Competition) addressed here is the top tier of the FIRST competition; high school students in the FRC work for six weeks to build a 120 pound industrially-controlled robot and compete in a complex team challenge. The challenge changes each year, so students commonly participate for multiple years.

Professor Jaupi repair an existing robotic arm in the laboratory and integrate it with an Arduino controller, to provide a platform for more advanced projects in the future. As the research period closed, we reduced our involvement in day-to-day operations, to help the club function on its own. We also assessed the club's progress by holding a focus group with the subjects involved.

This report documents the club development process, and the lessons learned during the project. The contents may be useful to people starting other robotics clubs in Albania, or in other settings around the world in which resource limitations or rapidly-developing technology sectors motivate new forms of education.

2 Background

2.1 Background Introduction and Project Motivation

This chapter describes the project sponsor, the motivation for the project and existing literature pertaining to the project. The contents of this chapter document research that we conducted to bolster the inquiries we made during the project. We resolved uncertainties that were not documented in existing literature when we arrived in Albania, through the techniques detailed in the Methodology chapter.

This project's sponsor, the Harry Fultz Institute, is a private technical school and community college in Tirana, Albania. Its mission "is to instruct and educate its students, so they can achieve their academic and career goals as responsible citizens and qualified professionals, who contribute with integrity to improve the quality of life in their communities, country and region" (Harry Fultz Institute n.d.). Formally, the sponsor of this project is the high school component of the Harry Fultz Institute. The students of the high school can pick a discipline to study, similar to a major at a university, during their time at the school. The available disciplines are electronics, business, and auto-mechanics. All students follow a required core curriculum along with the courses within their respective disciplines. As of 2014, with the introduction of a general high school, students may now choose to attend Harry Fultz without specifying a discipline. This and more information about the school's operation is available at the Harry Fultz Institute English language website, http://ww.harryfultz.edu.al/en/.

Harry Fultz Institute wishes to start a robotics club. We interviewed Enxhi Jaupi, a teacher in the Electronics Department at Fultz and the liaison for this project, on 26 September 2014 to establish the formal goals of the project and the club. This interview revealed that a typical class size for Professor Jaupi's courses is approximately 30 students (E. Jaupi, personal communication, 2014). Based on this number, we started work under the assumption that the club would exhibit a high student-teacher ratio. The water education group (a WPI Interactive Qualifying Project team that worked with Harry Fultz Institute in 2013) found that "students often watch teachers perform demonstrations in front of the class instead of conducting experiments on their own" (Miralda, et al. 2013, pg. iii). Enxhi Jaupi also indicated that it could take upwards of two months for ordered parts to arrive in Albania (E. Jaupi, personal communication, 2014). This parts availability constraint was another driving factor in the project.

Since Harry Fultz is a private technical school, it has some underlying benefits that were advantageous to this project. In initial discussions, Enxhi Jaupi indicated that there was at least one more teacher who was interested in assisting the club. Professor Jaupi also indicated that the club had widespread interest from students at Harry Fultz. We considered these factors when researching possible club organization strategies.

The Harry Fultz Institute has labs for electronics, but prior to this project, the school's component resources for robotics-related projects were not well defined and seemed to be lacking, especially in stocks of actuators and microcontrollers. We learned early-on that the club would have a starting budget provided by the school of approximately $300 US per year. Thus, the research basis for this project was to find ways to execute relatively inexpensive robotics projects at Fultz, leveraging the school's existing (or easily obtained) resources, and maintaining a hands-on, enjoyable and educational environment for the students (E. Jaupi, personal communication, 2014).

2.2 STEM Education and Robotics

Students can tell when a learning activity is "useful and effective" (Jenkins 2008, p. 57). In addition, students are aware when an educational environment is not tailored to their interests. An Israeli student wrote:

> *"When you are under 18, it doesn't really matter what you want. Someone else will tell you what you need, and if you don't agree with him it only shows that you are not qualified to decide for yourself … Someone else tells you when to learn, what to learn and how to learn, but your own interests are called 'a waste of time'" (Denofrio et al. 2007, p. 1872 citing Idan 2009, p. 6 [in Hebrew]).*

Motivation to learn is greater in students who are pursuing their own interests (Denofrio et al. 2007). Thus, it is favorable to tailor educational activities toward the interests of the students involved. Many methods may be used to develop these activities; for example, student questions are usually motivated by "a desire to learn something relevant to their personal lives" (Hagay et al. 2013, p. 117 citing Chin 2004). Therefore, students may express their interests in the questions that they ask, and teachers may design curricula around these questions (Hagay et al. 2013). Given the chance, students may express direct interest in particular projects, genres of projects or activities.

Giving students a voice in the design of their science education is shown to increase motivation (Jenkins 2006, p. 78). If students are to guide their own educational experiences, they must be given a significant amount of freedom in the process. Creating a student voice in education requires “a willingness to engage students as genuine partners in the teaching-learning process” (Jenkins 2006, p. 78). One key criterion for effective learning, then, is a communication partnership between students and teachers, going in *both* directions.

Some discussion is necessary to put this point in the context of the project at hand. The focus of this project is robotics education; while some may argue that robotics is not of interest to all students, concerns about student interest in robotics are no driver in this project: Enxhi Jaupi reported early-on that his students at Harry Fultz Institute had expressed universal interest in robotics activities (E. Jaupi, personal communication, 2014). Due to this widespread interest, this project provided an opportunity to investigate a more radical education strategy, where *interest-driven learning* referred to activities planned at the hands of the students, with the partnership (as described above) of teachers. In this sense, the concept of interest-driven learning in this project goes beyond simply planning activities within a topic area suggested by students.

Students who engage in robotics-based programs experience an increase in their level of understanding of STEM topics. A review of educational literature showed that past research supported robotics education as a technique to amplify learning “in specific STEM … concept areas” (Benitti 2012 p. 986; Heslinga & Giovacchini 2011). Another quotation indicates that robotics education also leads to improvements in so-called *soft skills*: robotics “can promote development of systems thinking, problem solving, self-study and teamwork skills” (Verner & Hershko 2003).

Robots help students relate what can be unfriendly math and science concepts to something clearly useful and applicable in the real world (Nugent et al. 2010, p. 392). This can increase the rates at which students consider working professionally on STEM-related projects: in one study, students who participated in the FIRST Robotics Competition (FRC) were ten times more likely to hold an "internship, apprenticeship, [or] co-op job freshman year" than students in a comparable group who did not participate in FIRST (Melchior et al. 2005 p. 38). Students who participated were also "more than three times as likely to have majored specifically in engineering" (Melchior et al. 2005 p. 37). In one case study, a technical high school in Cleveland, OH saw a jump in attendance from 60% to 82% when it implemented a FIRST team (FIRST Robotics Competition 2013).

An experiment by Professors Soumela Atmatzidou and Stavros Demetriadis of Aristotle University in Greece explored a hands-on approach to introducing high school students to robotics and assessing the students' computational thinking skills. In this experiment, the researchers split 35 students into three-member groups. Over 11 two-hour sessions, the students programmed robots to perform a variety of tasks. For their final session, students combined the concepts they had learned to complete a single challenge. The researchers found that students enjoyed working in groups, thought the activities very interesting and said that they would like to continue engaging in robotics after the sessions were over (Atmatzidou & Demetriadis 2014). It is possible that the challenge-based structure of the Atmatzidou and Demetriadis program was also beneficial: when students can successfully complete a goal, they feel empowered and their self-esteem is boosted (Salomon & Globerson 2014). Career implications are also significant. One student participant stated: "I'd like to keep working on robotics because it is the job of the future" (Atmatzidou & Demetriadis 2014 p. 49). We consider this an important motivational factor for the students of the Fultz robotics club.

Students who pursue robotics-related careers experience the economic and competitive advantages of entering a growing economy. The field of robotics is on the rise and in high demand. In 2012, US robotics job opportunities rose by 29%; this statistic covered any job requiring a robotics skill set (Robotics Business Review 2012). Israel provides an example of a country closer to Albania in size that has experienced great technological growth in robotics and related fields. As of 2008, Israel had 3000 start-up companies in research and development; 80% were less than 10 years old. This shows that much of Israel's technological development was relatively recent, in the last

10 to 15 years (Machine Design 2008). Israeli robotics start-ups include ReWalk (www.rewalk.com) and Mazor Robotics (mazorrobotics.com), and the Israeli Robotics Association (IROB) exists to promote robotics research, robotics education, and the use of robotics in traditional industries, such as agriculture and medical applications. IROB hosts events throughout the year, including an annual national robotics conference in Israel (The Israeli Robotics Association n.d.).

Growth in Israeli technology has been accompanied by increased adoption of intensive robotics activities in education. As noted previously, FIRST Robotics activities are collaborative, fast-paced and hands-on; they provide students with extensive real-world experience in robotics research environments. Israel has 52 FIRST Robotics Competition teams (FIRST Israel n.d. *Groups*), and the number of student participants in Israel's national FRC event approximately quintupled between 2005 and 2009 (Boudreaux 2009). This reflects a clear increase in robotics education activity in recent years. FRC groups serve high school students, but Israel also participates in FIRST Lego League (FLL) competitions, which serve younger, grade school students (FIRST Israel n.d. *FLL*). Closer to Albania, one team from United World College in Mostar (Bosnia and Herzegovina) has participated in an Israeli FRC competition. This team is the first (and to our knowledge the only) FRC team in the Balkans (United World College in Mostar 2011).

The conclusion is that, with appropriate effort, countries with relatively small populations can still adopt robotics-based education strategies, even such intense and paradigm-altering programs as FRC. Taking Israel as an example, it appears that competition-based programs such as FIRST provide an especially powerful avenue for these types of activities.

The previously-cited article from Boudreaux notes another interesting point about FRC in Israel: while some students at wealthy institutions are involved in robotics competitions, other student participants come from disadvantaged backgrounds. Their teams are funded by corporate sponsors eager to inspire future engineers and scientists (Boudreaux 2009). While robotics teams are funded by corporations in various settings around the world, the example in Israel shows that this scheme may translate well to Albania, where sufficient funding may not be available from schools.

2.3 Robotics with Limited Resources

Unfortunately, robotics is expensive. When purchasing enough kits for a class of students, the number of robots required increases with class size. For all students to remain involved, it is optimal that they work in small group sizes. A 2006 guide by the Carnegie Mellon Robotics Academy states that students should be formed into teams of 2 or 4 (Carnegie Mellon Robotics Academy 2006, p. 3). Another resource, published in the Stanford University Newsletter on Teaching, provides a slightly different recommendation for group size: "Most faculty … agree that groups of between 4 and 6 students seem to work best, though depending on the task, larger groups can function successfully". In either case, costs can be prohibitively high as more students join the class.

Some popular examples of educational robotic kits include those produced by LEGO, VEX, Pitsco TETRIX and Parallax. The costs of various kits from these suppliers are summarized in Table 1, below.

Producer	Robot	Kit Cost	Reference Citation
LEGO	MINDSTORMS EV3	$349.99 US	LEGO 2014 *LEGO Mindstorms EV3*
VEX	Classroom and Competition Programming Kit	$799.99 US	VEX 2014 *Classroom and Competition Robotics Kits*
VEX	Programming Control Starter Kit	$399.99 US	VEX 2014 *Robot Starter Kits*
Pitsco (TETRIX)	MAX Starter Set	$595.00 US	Pitsco, Inc. 2014 *TETRIX MAX Starter Set*
Pitsco (TETRIX)	PRIME Starter Set	$329.00 US	Pitsco, Inc. 2014 *TETRIX PRIME Starter Set*
Parallax	Boe-Bot Serial	$159.99 US	Parallax 2014 *Boe-Bot Robot Kit - Serial*
Parallax	Scribbler 2	$129.99 US	Parallax 2014 *Scribbler 2 (S2) Robot*
Parallax	SumoBot	$129.99 US	Parallax 2014 *SumoBot Robot*

Table 1: Costs of Robotics Kits

The lowest price of all the kits in Table 1 is $129.99 US. Note the cost implication: if one kit can be used to teach three to four students, the cost of kits for a class of thirty students starts at approximately $975 US. Recall the Stanford article's point: larger groups can be beneficial in some circumstances. Larger groups commonly occur when students work on subsystems of one larger robot instead of many smaller ones. Examples of this are FRC and FTC[2] (FIRST Robotics Competition n.d. *FIRST Progression*). When students must work together on different systems to achieve one goal, they are forced to cooperate. This fosters a better understanding of team dynamics and leadership roles (Heslinga & Giovacchini 2011; Melchior 2005).

Unfortunately, large robots with complexity sufficient for this model tend to be even more expensive. For example, registration costs alone for FIRST Robotics Competition (FRC) Districts (two competitions covered) are $6,000 US for a rookie team and $5,000 US for a veteran team, with the District Championship (if the team becomes eligible) costing another $4,000 US (FIRST Robotics Competition 2014 *FRC Payment Terms*). FTC costs are lower. Robots are constructed from the TETRIX Kit of Parts, priced at $525 US (FIRST Tech Challenge 2014 *TETRIX Kit of Parts*), and the LEGO MINDSTORMS EV3 Brick, at $159.99 US (LEGO 2014 *EV3 Intelligent Brick*). Registration through FTC is $275 US (FIRST Tech Challenge 2014 *FTC Payment Terms*).

There have been some attempts to make cheap robots for classroom use. One example is from AFRON, the African Robotics Network in Ghana. AFRON held a "10 Dollar Robot Design Challenge" in 2012. The goal of the challenge was "to design a new class of affordable robots for learning (especially in primary and secondary schools)" (AFRON 2013 *$10 Robot Design Challenge*). Robots were divided into three classes: devices tethered to a computer, stand-alone devices programmed by a computer (traditional), and complete platforms where programming and processing are performed onboard (all-in-one) (Bishop 2012).

[2] The First Tech Challenge is a lower-level version of FRC, in which students compete using TETRIX robotics kits, building relatively small robots.

The winning robots in the 2012 AFRON challenge were diverse, and they provide a good view of the different types of low cost robots (AFRON 2013 *$10 Robot Design Challenge*). An outstanding example is the winner of the tethered category, called “Lollybot”. This design is built using common components; its main body and drive system are constructed from a scavenged PlayStation controller. Most of the other components in the design could also be scavenged, making this a very accessible robot. The actual cost to build the robot is quoted at $8.96 US. The robot’s motion controls and sensors (line following, bump sensing and other experimental sensors) are accessible through the PlayStation controller’s built-in USB HID interface, so the robot is fully programmable as long as it remains tethered to a computer (Tilley 2012).

Another outstanding example robot is called “Swarmbot”, from the traditional category. This design is more versatile, as it can be operated when it is not tethered to a computer. The sensor loadout is divided into categories; “shield” circuit boards are used to carry optional sensors such as IR object detectors and mechanical bump sensors. The cost of the complete robot with IR sensors, constructed from through-hole components, is quoted at $9.51 US. An unfortunate downside to this design is that it requires a custom circuit board for component mounting, unless the builder is skilled enough to work with prototyping boards or loose components (XinCheJian Hackerspace 2012).

In 2014, AFRON held another challenge, focused on refining the designs from the 2012 challenge. Here, the first place winner, the MIT SEG, stood out as a highly accessible design (AFRON 2014 *2014 Design Challenge*). The robot is built from plastic sheet cut and folded into a patterned shape. An Arduino Pro Mini processor provides a cheap computing solution, and the sensors are attached via a daughterboard (a custom component). The robot is quoted at $20.27 US, assuming a build quantity of four robots, for a total cost of $81.08 US, plus the cost of a programmer and battery charger, totaling $18.20 US (the programmer and charger can be used with multiple robots). The robot is programmable, and contains sensors sufficient to follow a line. Unfortunately, while this design uses the commercially available Arduino as its processor, it still requires some custom circuits or the expertise necessary to prototype these circuits without a printed circuit board. Finally, this design requires a programmer device to upload code to the robot, so students will be limited by the number of programmers in the classroom (Mehta et al. n.d.).

Another popular tool in low-cost robotics is the aforementioned Arduino microcontroller board. Arduino is a family of open-source computing products that incorporate microcontrollers (mostly from ATMEL), easy-to-connect breakout pins, and simple, beginner-friendly computer interfaces (typically USB). Some popular Arduino boards are widely available for less than $30 US (Sparkfun Electronics n.d.) and can be used to control a vast array of hobby- and education-level robotics projects. One of the most valuable aspects of the Arduino board is its USB boot loader interface. This system allows students to write programs for the Arduino, controlling its output pins (which may be connected to peripherals such as motors) and responding to sensor input, without the need for a separate programming module. The simple, easy-to-use programming system means the Arduino board is ideal for beginners and educational applications.

In environments and situations where parts are scarce, the BEAM robotics philosophy can be a cost-effective option. BEAM stands for Biology, Electronics, Aesthetics, and Mechanics (Seale 2003). BEAM was created by Mark Tilden, a robotics physicist who felt the need to create easy, biology-inspired, cost-effective robotics projects that would inspire children (Marsh 2010). The basic principle of BEAM robotics is to construct robots that are inspired by nature, controlled by electronics, visually pleasing or “clean”, and mechanically clever (Seale 2003). These robots use minimalist electronics, recycled components, and solar power if possible. BEAM robots can often be made entirely out of recycled materials, including scavenged electronics. “Virtually all the parts required to make a BEAM robot can be found in broken electronics (ovens, Walkmans, CD players, VCRs, pagers)” (Seale 2003). BEAM robots are only limited by what can be found (Solarbotics, Ltd 2006).

A classic, relatively advanced BEAM scavenged design is “Mousey the Junkbot”, created by Gareth Branwyn. The robot is a photovore, designed to follow light sources; it performs this task using simple sensors and fixed (non-programmable) circuitry. The Mousey design is noteworthy because of its highly scavengable bill of materials; the robot uses sensors and a body pulled directly from an old-style ball mouse (Branwyn

2005). Note that all BEAM designs use simple electronics, with no programmable microcontroller component. This is a limitation of the BEAM architecture; microprocessors are difficult to scavenge because most require a programmer. This is what makes the Lollybot design, discussed above, so attractive: it uses the discrete components and the processor interface hardware from a consumer product that can be obtained easily.

Neither BEAM nor the AFRON projects directly address the problem of student-teacher ratio. Peer learning provides a means to effectively reduce this ratio (Topping 1996). This method can be described as follows: "People from similar social groupings who are not professional teachers helping each other to learn and learning themselves by teaching" (Topping 1996). This description refers to a tertiary setting, but it is directly applicable to secondary and primary schools.

Peer tutors can be students of the same class, or students from a higher grade level (Greenwood, et al. 1989). One study showed that students who were tutored by peers engaged in higher overall levels of academic behavior (Greenwood, et al. 1989). As aspiring engineers, we (the project team members) all participated in FIRST competitions during high school; we attest from personal experience that peer mentoring is intrinsic in the FIRST competitions. In the FRC, student teams also recruit adult volunteer mentors from industry, to provide expert insight into the project. The industrial mentor approach is closer to a traditional teacher-student relationship, but the peer mentoring approach is noteworthy because it blurs the line between learners and educators.

When these topics and ideas are combined, an alternative vision for a robotics education classroom takes shape. The literature discussed in this chapter suggests that, if robots can be built for a low enough cost, a large class of students with few teachers can work on the robots in small groups. Each group can be led by a student peer mentor or group of mentors, to limit the amount of teacher involvement required. The peer mentoring approach can also improve the quality of the learning taking place, for both the mentors and the students. Students understand the material better through additional tutelage, and the mentors gain valuable teaching experience.

3 Methodology

3.1 Methodology Introduction

This project's goal was the development of a robotics program to provide the students of the Harry Fultz Institute Technical High School with experience in the field of robotics and a greater appreciation for engineering design, science and teamwork. We organized the project around three main objectives:

- Help students at Harry Fultz Institute Technical High School design hands-on technical robotics projects tailored to their interests.
- Start the Harry Fultz Institute Technical High School robotics club and help it convene in its first few weeks of meetings; help the students become self-directed and move the group through early challenges.
- Identify strategies to enable Harry Fultz Institute Technical High School to maintain and grow its robotics program in the future.

This chapter describes the methods that we used in pursuit of these objectives.

3.2 Designing a Hands-On, Interest-Driven Robotics Program

To design a hands-on robotics program, we determined the types of robotics activities the Harry Fultz Institute could support with its existing resources: equipment, labs, classroom space, and budget. To gather data about the existing resources of the school, we conducted an inventory of available technology resources. The resulting data detailed the school's available computing devices, and all potentially useful tools, parts and equipment for the physical aspects of robot building. The process for the inventory is described in Appendix A. We kept the parts documented during the inventory in mind as we developed activities with students at the school. We attempted to use existing resources when possible, to minimize cost and procurement time.

The Harry Fultz Institute assigned Professor Enxhi Jaupi, an electronics teacher, as the leader of the robotics club. In the initial sponsor liaison interview, Professor Jaupi indicated that Fultz had teachers (including himself) with experience in robotics-related fields (E. Jaupi, personal communication, 2014). We originally intended to host a focus group with any teachers interested in mentoring, but there were no teachers other than

Professor Jaupi whose schedules could accommodate the club. Our primary assessment of teacher experience then came, necessarily, from discussion with Professor Jaupi throughout the course of the project.

Professor Jaupi hand-picked the students and student leaders for the robotics club from his classes. He selected some students before we arrived in Albania, and added a few more students after this time. To learn more about student perspectives and interests, we attempted to conduct a focus group with the students selected by Professor Jaupi to lead the club. The focus group was to be driven by the questions detailed in Appendix B. By conducting this focus group, we had hoped to determine the types of projects (and organizational strategies) best suited to the Fultz Institute. When the focus group convened, we found that the students were still quite reserved (they had only just met us). As a result, the focus group turned into an informal discussion, during which we became better acquainted with the students. Note, however, that this discussion was still driven by the original questions in Appendix B, although we adapted them to the situation.

During the initial discussion, we learned the majority of the students had little or no experience with the Arduino microcontroller. As a result, we decided that the students would need to have detailed lessons introducing them to the Arduino microcontroller and the Arduino programming environment. We researched Arduino resources that could introduce Arduino to the students at a low level, and came across a free version of an online Arduino course for absolute beginners that consisted of 12 tutorial videos. The course itself and all information pertaining to it can be found at www.opensourcehardwaregroup.com. We provided digital copies of (and links to) these videos to the student leaders during the first week of meetings, to supplement the in-class activities discussed in section 3.4.

In selecting robotics projects for the Fultz club to undertake, we allowed the students as much control as possible. We provided Professor Jaupi's assigned student group leaders with a basic requirement that Arduinos be used, along with a cost target of $50 US. We also asked the students to look at the types of past work discussed in the Background chapter for inspiration. We then asked the students to create their own design ideas and project goals. Our expertise played a role in this step of the project; we all had robotics exposure before this project, and we all provided insight into the best solutions to problems in students' proposed designs. Some of us had resources we brought from the United States and contributed to the club; these resources also affected the types of projects that the students selected. Because it is unlikely that team members will supply components in future years, we ensured that any components we brought to the school would be reusable in future years (our primary contributions were a set of Arduino boards and a pre-built robot chassis). All of the students selected their own projects; our input only served to steer the students toward diverse projects with realistic goals. Professor Jaupi asked a few of the students to alter their selections because other groups were already pursuing similar projects. These students, however, went on to select their own unique projects.

We deemed two of the Harry Fultz Institute's robotics resources significant and complete enough to incorporate directly into the development process for the club. The first was a five-axis robotic arm, owned by Enxhi Jaupi, which WPI team member Bill Hunt spent the first few weeks of the project modifying for use with an Arduino Mega 2560 control board. The second was an assembled, small, kit robot called "Blu" that WPI team member Bill Hunt brought from the United States and gave to the Fultz Institute. Since these robots were already assembled and included many useful components, we decided to keep them assembled and use them as educational aids for the robotics club. Note that, because the development of robotics activities fell within the scope of this project, more discussion of the robots used and their technical parameters can be found in the Results chapter of this document.

3.3 Maintaining and Growing the Robotics Program

The Harry Fultz Institute initially agreed to fund the robotics club with approximately $300 US per year. We were originally concerned that this amount might not be sufficient, as the school needed to acquire the equipment and components necessary for a large number of students to work on robots. Professor Jaupi assured us a slight increase could be approved by the Fultz Institute's administration. We discussed possible reimbursement through WPI, but to simplify the matter, we decided to work within the funds available from the Harry Fultz Institute.

As noted above, Professor Jaupi was the only non-student mentor for the club. To assist Professor Jaupi we focused on student training, directing the students to work successfully without additional mentors. We accomplished this by training the six student leaders first, so they could help their teammates learn material later on. This application of peer mentoring continued throughout the club's activities.

Although additional funding for components, tools, and software may be required in future years of the robotics club's operation, we decided not to pursue external funding as it is outside the scope of the club at this time. If the club does decide to pursue external funding in future years, they may choose to organize traditional fundraisers such as dinners, car washes, and raffles. They may also pursue corporate sponsorship.

3.4 Club Development Process and Schedule Overview

Because they were inexperienced with robotics, the students in the robotics club required guidance. We determined that Professor Jaupi should be assisted by six of the student members, acting as group leaders. Based upon discussions with Professor Jaupi, we elected in advance to limit club membership to 24 students: 22 seniors (grade 13), plus 2 juniors (grade 12). The resulting group was slightly smaller than Professor Jaupi's standard electronics classes; this ensured enough equipment was available in the laboratory, and that each group of four students contained a student leader. Professor Jaupi selected the six student leaders based upon his own assessment of their abilities in programming, electronics and (most importantly) teaching. Note that the structure of the club explained here is described visually by the flow chart in Figure 1.

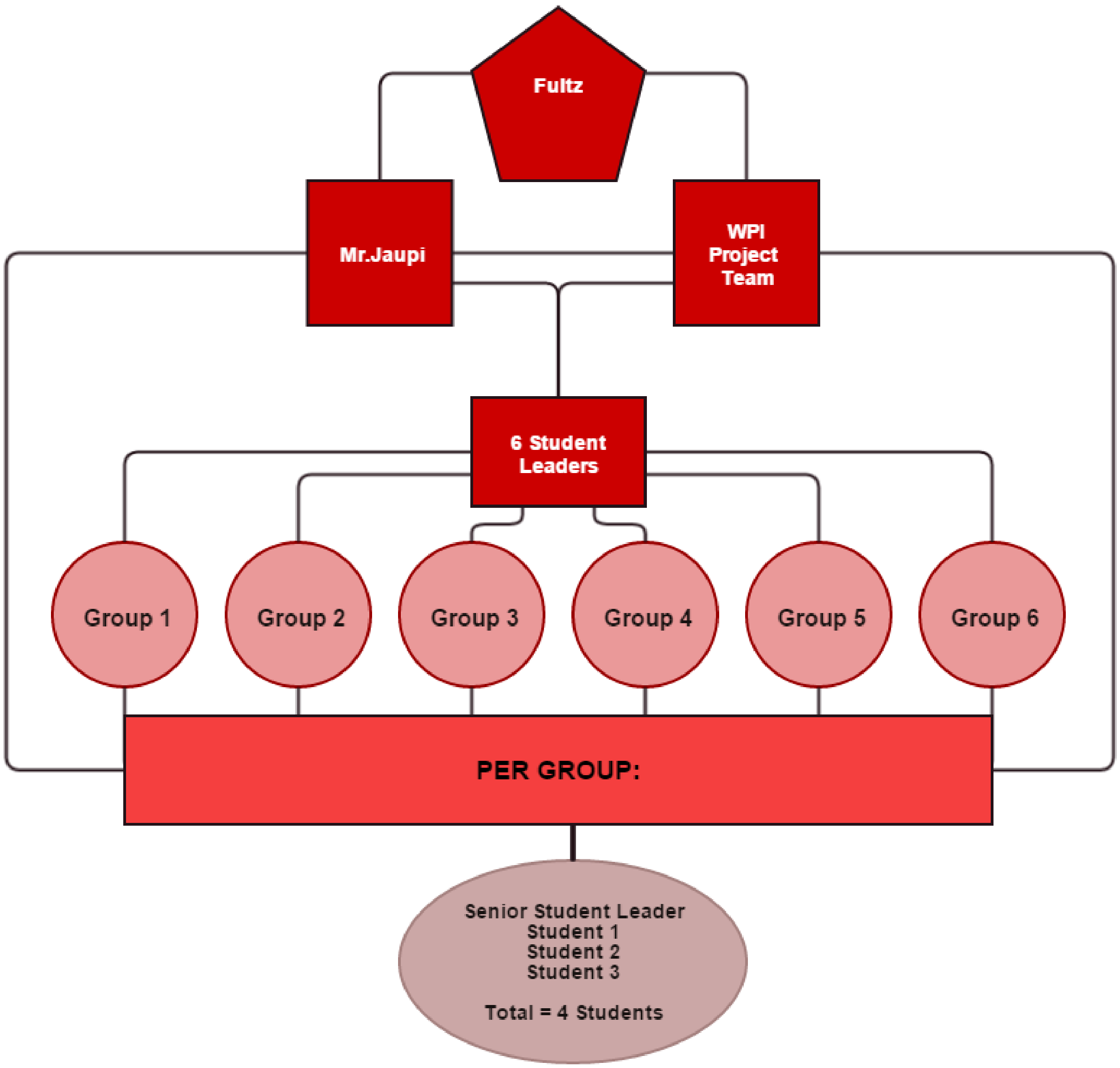

Figure 1: Fultz Robotics Club Flow Chart

After establishing the division of students into teams with Professor Jaupi, we facilitated the first few weeks of robotics club meetings at the Harry Fultz Institute. The remainder of this section describes the process and schedule for these meetings, along with the research tasks we performed on-site in Albania. The project's schedule was dictated in part by the availability of resources at the school, ordering schedules, and project activities outside of the team's control; as such, the schedule was altered several times over the course of the project.

We spent approximately one week conducting initial inventory and preparatory discussions involving Professor Jaupi and the students. We then spent one week training student team leaders in the laboratory on Arduino programming, through in-class activities supplemented by Arduino instructional videos from the aforementioned www.opensourcehardwaregroup.com video series. Our motivation for these lessons was to help the student leaders establish a basic understanding of Arduino, so the full group meetings would run more smoothly.

During the second week, the student leaders also proposed small robot designs. Each student design fulfilled the assigned criteria of being Arduino-based and as inexpensive as possible. We gave the students real budget numbers ($300 US, divided to $50 US per group) to motivate low-cost designs. Leaders who already knew their group members sought group input. We then spent time with each leader, reviewing the design and suggesting modifications to reduce cost and improve performance and feasibility. We also asked each leader to submit a drawing or other graphical depiction of their robot concept. After consulting with the student leaders multiple times, we established a formal description for each student team's robotics project. As the second week ended, we prepared a detailed order list, and sourced the components required for each student team's robot design from an online vendor. We chose to order components from a single, highly versatile supplier (Canada's RobotShop) with expedited shipping, so that students would not be overly limited by part availability. While this decision increased cost slightly, it greatly increased the range of projects available to the Fultz students.

During the third week of the project, we met with all 24 students in the laboratory, giving additional instruction on Arduino programming with the help of the previously trained student leaders. The activities during the third week were more student-guided, as we tried to reduce our involvement slightly. One activity even directly incorporated code debugging as a student challenge. In addition to programming activities, we asked students to present their team robotics projects during the third week. We took this opportunity to provide final recommendations to the students, and to clarify the technical challenges that each student team would face.

Note that we planned out any Arduino training activities each day before the laboratory meetings up until the end of week three. For the remainder of this document, these pre-planned activities will be called "training activities". While we purposefully reduced the rigidity of training activities as the club progressed, all these activities used relatively strict guidelines or pre-set goals to keep the students on track. More detailed descriptions of the training activities can be found in Appendix C. Note additionally that, during the first three weeks of student meetings, Professor Jaupi filled an observational role, keeping track of the events in the laboratory for his own notes, and helping students who came to him with questions outside of the laboratory sessions. As the project progressed, we asked Professor Jaupi to attempt to spend more time in the laboratory going from group-to-group, answering questions about the robotics projects. The goal of this action was to prepare Professor Jaupi for his eventual role as the club's only non-student mentor and advisor.

Due to delays associated with backorder and credit card verification, the final order of parts for the team robotics projects was not shipped until near the end of the third week. We originally had planned to spend the fourth week working with students on their team robotics projects, but instead had to rearrange the club schedule slightly. During the fourth week and most of the fifth week, we worked with students on more detailed designs for their robots, pointing out aspects that needed to be corrected or improved. We also helped the students think about the mathematics behind their robots whenever possible. For example, we encouraged a group that built a balancing robot to consider their design's rotational inertia. We gave the students multiple deliverable assignments, including creating three-view diagrams of their robots, developing block schematic diagrams of their robots, and drawing circuit schematics for their robots. We provided these goals to compel the students to think about their projects from an engineering design perspective, and to ensure that the students fixed major design errors before constructing anything physical.

Near the end of week five, the parts shipment arrived. We provided the students with their ordered parts, and asked the students to start building and programming their team robotics projects. We documented these activities through the end of week six, but the students kept working on their projects after this time. We purchased some extra parts (such as chassis materials) on our own budget during this phase. We continued, as time passed, to reduce our involvement with the students, so that the club could begin to function independently with the help of Professor Jaupi alone. Note that we remained available to the students during all meetings and answered any questions submitted by students via email for the duration of the project. As time passed, the students started to work on their robots at home some nights, emailing us for help when needed. Note additionally that the events of the build period (weeks five and six) are documented in more detail in the Results chapter of this report.

At the end of week six, we organized a focus group, comprised of a selection of eleven students from the robotics club. This focus group discussion was guided by the questions in Appendix D. The outcomes of the closing focus group discussion motivated future recommendations for the club. We spent the remainder of the project (week seven) helping students fine-tune their projects, and working with Professor Jaupi to prepare his robotic arm for use by the students (and for his own personal projects). We also asked the students to prepare reports, for their own documentation experience, and presentations for school faculty, staff and parents. We scheduled the presentations for 12 December 2014. On this date, the students gathered in front of presentation guests. Each of the six student groups presented for approximately five minutes, then all the groups demonstrated their robots up-close as guests traversed the room.

For a graphical view of this project's scheduled process, see Appendix E. For information on the outcomes at each step of the project, see the Results chapter.

4 Results

4.1 Results Introduction

This chapter documents the concrete outcomes of the project, including the resources we inventoried at the Harry Fultz Institute, the students' responses to Arduino training activities, the processes the students followed while developing their own robotics projects, and the discussions that took place with the students at the end of the project. While we have included some discussion of the results of the project at the end of this chapter, our conclusions can be found in the Conclusions and Recommendations chapter.

4.2 Inventory of Fultz Resources

During our first week at Harry Fultz Institute, we took inventory of one of the high school's electronics laboratories, where the robotics club would meet. This inventory included tools, components and equipment found in the lab. We also included components we brought from the United States.

Table 2 lists tools and equipment in the laboratory. The students used resources such as multimeters, oscilloscopes, function generators, and power supplies to test circuitry and robotic components. These resources allowed easy troubleshooting, which helped students quickly locate problems in their projects.

Item	Quantity	Why is this item useful?
Multimeters	~10-20 (According to liaison)	Measure Voltage, Resistance, or Current of circuits
Voltcraft Oscilloscope 630-2 30 MHz	9	Analog Oscilloscope; used for testing
Voltcraft Universal System MS-9160	6	Frequency Counter, Function Generator, Digital Multimeter, and Power Supply
Function Generator: GW Instek: GFG-8016G	2	Used for testing circuitry
Power Supply: Instek, Dual tracking w/ 5V fixed, PC-3030	3	Used for testing robot and other components

Item	Quantity	Why is this item useful?
Soldering Irons	23	Used to attach components to copper plated circuit boards, and for general electrical wiring jobs.
Magnifying Glass for Soldering	3	Used for precise soldering
De-soldering Irons	9	Used to remove solder from circuit board
Heat Gun**	1	Shrinking heat shrink, if heat shrink is available to use
Wire Cutters	15	For cutting wire to use on soldered breadboard
Needle Nose Pliers	3	Detailed soldering work
Various Screwdrivers	9	7 Flatheads, 2 Philips
File	1	Smoothing out sharp edges on different pieces
Tweezers	2	For manipulating small parts
Gordak 850, SMD Rework Soldering Station	1	Soldering surface mount devices

Table 2: Laboratory Equipment Inventory

Students used many of these resources when constructing their robots; most had previous experience with electronics equipment in Professor Jaupi's classes. We feel the equipment in the laboratory was sufficient for robotics activities involving small, tabletop robots made from light-duty materials requiring minimal machining or drilling. Because the electronics lab did not contain any tools for mechanical manufacturing, the club may have to seek the involvement of other, more mechanically-oriented laboratories on the Fultz Institute campus if it ever needs to fabricate complex, custom mechanical robot components.

Table 3 contains component resources we discovered during our inventory, including items such as wire, solder, flux, timers (and other integrated circuits), diodes, potentiometers, and circuit boards. Students used many of these items when they constructed their robots.

Item	Quantity	Reusable	Why is this item useful?
CS-113 Robot	1	Reusable	It is likely possible to interface this arm to

Item	Quantity	Reusable	Why is this item useful?
Arm			an Arduino; thus, working with the arm may constitute a full student project.
Assorted Potentiometer s	~30	Limited Reusable	It may be used to provide inexpensive motion feedback to an arm, or as an adjustable resistance in a demonstration project.
Assorted XLR and MIDI connectors	~10	Limited Reusable	These may be useful in a project that interfaces with existing audio devices.
Extensive collection of 7400 series ICs	~40 each type	Limited Reusable	These can be used to implement digital logic directly; they are especially useful for BEAM robotics projects.
7805 and 7812 Regulators	50+ 7805, ~50 7812	Limited Reusable	Linear voltage regulators at 5 and 12 volts; may be useful in Arduino interface.
LM 348 Amplifiers	17	Limited Reusable	Quad 741 Op-amp, may be used for simple analog designs (BEAM robots) or comparison circuits (line/light following)
ADC0804 Analog-Digital Converter	17	Limited Reusable	8-bit analog-digital converter; may be useful in a project that uses many analog sensors; or a chip-to-chip 7400 series design.
Copper Protoboards	>8	Non-reusable	Good for circuit prototyping in any electronics project.
Standard-size Solderless breadboard	>6	Reusable	Useful for general prototyping in any electronics project.
555 Timers	~20	Limited Reusable	Useful for BEAM robots, simple timer and audio designs, sensor interfaces.
Assorted Resistors	Variable	Limited Reusable	Various quantities of standard resistor values, poorly organized; some resistors in short supply, some in large bags.
Diodes	~50	Limited Reusable	Drawer of small diodes; good for electronics prototyping; symmetric switch debounce.
Assorted Other Electronic Components	Large quantity	Limited Reusable	Very poorly organized (mixed) drawers of resistors, capacitors, diodes,
Arduino Duemilanove	3	Reusable	Brought by team to Albania, useful for control of a wide variety of robot designs.
Arduino Mega	1	Reusable	Prof. Jaupi's personal board; for use with

Item	Quantity	Reusable	Why is this item useful?
2650			CS-113 arm. BROKE DURING USE; REPLACEMENT ORDERED IN WEEK FOUR.
Arduino Uno	3	Reusable	Brought by team to Albania, useful to control a wide variety of robot designs.
Blu Robot Chassis	1	Reusable	Brought by team to Albania. Robot with two wheels (continuous rotation servo motor drive), mini breadboard and AA battery pack. Needs 9V battery connector to operate.
Assorted circuit boards and past kit projects	Large quantity	Limited Reusable	Large number of surplus boards and devices may be useful to source sockets and discrete components.
Multi-wire cable	Several feet	Limited Reusable	Length of cable with a large number of discrete insulated wires inside. A good source for breadboard prototyping wire.
Test cables	Large quantity	Reusable	Various test cables (alligator, banana terminal, etc.). Good for prototyping and testing with lab equipment.
Two axis servo gimbal	1	Reusable	Gimbal with two mini-servos, mounted to control pitch and yaw. Useful for robotics demonstration, camera aiming, and project parts.
Solder and flux	Large quantity	Non-reusable	Supply of solder and flux sufficient for electronics prototyping of many (more than 10) small robots.
USB A-B Cable	2 or 3 (MORE TURNED UP POST-INVENTORY)	Reusable	Required for USB Interface to Arduino
7-segment Display	~15	Limited Reusable	Useful for debugging discrete TTL digital circuits.

Table 3: Component Resources

Note that we brought a total of four Arduino Uno microcontroller boards to Albania, but only left three behind at the school.

We noted two complete robots during the inventory, the first a robotic arm owned by Professor Jaupi, the second a simple robot (called *Blu*) given to the school by WPI team member Bill Hunt. As noted in the Methodology chapter, we decided soon after taking inventory that these robots should be kept in operating condition and not dismantled for parts. The Blu robot was small and simple: it consisted of a pair of ABS plastic plates, carrying two Parallax continuous rotation servo motors with direct-mounted wheels, a four-AA battery pack for motor power and a solderless breadboard for circuit prototyping. We chose, under Professor Jaupi's suggestion, to provide the Blu robot to one of the less experienced teams as a starting point for their robot. Since the robot was mostly complete upon arrival in Albania, it provided a convenient example for students who had never seen a small, dual motor platform.

Professor Jaupi's robotic arm was small (tabletop) and stepper-motor driven. It provided stepping control over six axes, including a single axis, parallel-jaw gripper with a closure-detecting limit switch. When we first took inventory, the arm had no means for easy connection to a control computer, save a parallel port of questionable functionality. To connect the arm to an Arduino board, we removed a set of latch integrated circuits from its control board in a location that provided direct access to the motor drivers (a series of Darlington-pair sink driver integrated circuits). After some experimentation with Arduino stepper-motor control libraries available online, we gained control over the arm's movement using the Arduino Mega 2560. Because the focus of this project was social, not technical, we have omitted further detail about the interfacing electronics for the arm from this report. The connections involved are simple, and the arm is accompanied by a user manual in Italian that provides information about the arm's operation. Note that some of the pinout numbers in the control board schematic provided by the user manual for the arm are erroneous; to avoid future errors in connection, we made simple wire harnesses with Professor Jaupi that could be left mounted on the robot's control board, and included pinout notes in the example code for the arm.

Professor Jaupi's robotic arm has vast educational uses, as it can be programmed to do many tasks. It is possible to pick up items and place them elsewhere, or integrate additional sensing capabilities into the arm for more complicated action planning. The arm holds promise as a platform for more advanced, ongoing projects in future years of club operation. Note that the Arduino Mega 2560 microcontroller we used to drive the arm stopped functioning at the beginning of week four. We ordered a replacement at Professor Jaupi's request, but this failure prevented us from introducing the arm to the students early-on, which we had originally hoped to do. We believe the failure occurred because the board was not manufactured by the official Arduino manufacturer. The club may wish to avoid these clone boards in the future.

Table 4 displays the computing resources available to the students in the lab. Professor Jaupi's desktop computer had many software programs installed, as well as internet access, so the students were allowed to use this computer (under supervision) as necessary. The students also brought their own laptops. Most groups already possessed or downloaded some form of CAD software and electrical schematic modeling software. This allowed the students to create digital models of their robotic designs. The electrical design software enabled them to design circuits before physically constructing them, which enabled electrical design activities before parts had physically arrived.

Note that, while many groups worked with legal, free or educational versions of design software such as Sketchup and Fritzing, some students admitted to pirating illegal copies of more advanced, expensive software. We did not condone these actions, and we advised students against illegal software use. For anonymity, the names of the students who took these actions are omitted from this report. Future project teams should be aware of the students' tendency to download software without proper licensing.

Model/Description	Quantity	Relevant Software
Prof. Jaupi's Desktop	1	Multisim, Eagle, Arduino IDE, Microsoft Office Suite
Student Laptops	>1 Per Team	Microsoft Office Suite, Fritzing, Arduino IDE, CAD

Table 4: Computer Resources

4.3 Arduino Lessons and Workshops

During our second week at the school, we met with the student leaders to train them and introduce them to Arduino programming. The Arduino lessons combined lecturestyle teaching with small, hands-on challenges. The goal of the activities was to provide the student leaders with a solid introduction to Arduino so they would be able to teach their team members during the following week. A more in-depth explanation of the training activities can be found in Appendix C.

The lessons with the group leaders took place over two days, which we determined was enough time to introduce the students to Arduino; the rest of the activities during week two focused on student project design. From our perspective, the student leader training activities were successful. The student leaders seemed to pick up the basics of Arduino quickly; while some of the material went beyond their prior knowledge of programming, they did not become flustered by the new information. In fact, they seemed to enjoy it even more as a result, especially the hands-on challenges. With these activities, the students went above and beyond the initial programs we asked them to test so they could learn more about the operation of the Arduino boards. Note that the sixth group of students was not formed until the end of the second week; as a result, the new group leader did not get the same introduction as the other group leaders. We worked directly with the sixth team during the lessons of the following week to bring them up to speed alongside the other groups.

In the third week, we started meeting with all of the students in the club, with the goal of introducing the rest of the students to Arduino. Again, see Appendix C for more information on the activities that took place during this period. The third week activities proved successful; the groups were able to complete all the assignments and understand the concepts with limited intervention from Professor Jaupi and ourselves. Some of the teams needed more help than others, but they all completed the assignments successfully within an hour or two. These lessons took place over three days and got progressively more difficult, with each new topic building on the topics taught the previous day. We felt these lessons gave the students a solid introduction to Arduino so they would be prepared when they started programming their own robots.

4.4 Cost Breakdown

This section documents the costs of the student robotics projects. The Harry Fultz Institute supplied the robotics club with a budget of approximately $300 US, with some room for expansion. While we were originally concerned about finding the parts for student projects locally, we soon determined that it would be possible to order the components overseas and get them delivered by expedited post. The Bill of Materials (BOM) for all student projects is shown in Table 5, below.

Component Requirements	Supplier	Item ID	Qty	Unit Price	Total Price
Ultrasonic Range Finder	Robotshop	RB-Ite-54	8	$3.61	$28.88
Bluetooth Serial Module	Robotshop	RB-Ite-77	4	$12.60	$50.40
Motor	Robotshop	RB-Sbo-02	8	$5.75	$46.00
Wheel	Robotshop	RB-Sbo-59	6	$3.25	$19.50
Dual Motor Controller	Robotshop	RB-Pol-189	5	$4.25	$21.25
Ball Caster	Robotshop	RB-pol-91	4	$1.99	$7.96
Logic Level Converter	Robotshop	RB-Spa-879	4	$2.95	$11.80
Motor Mount	Robotshop	RB-Sbo-45	12	$1.35	$16.20
Light Sensor (photoresistor)	Robotshop	RB-Spa-350	5	$1.50	$7.50
Microphones	Robotshop	RB-Spa-200	4	$0.95	$3.80
Bright LEDs	Robotshop	RB-Spa-209	2	$1.50	$3.00
Analog Line Sensor (2pk)	Robotshop	RB-Pol-49	2	$4.25	$8.50
Accelerometer module	Robotshop	RB-Ite-11	1	$3.60	$3.60
High Speed Motor	Robotshop	RB-Sbo-07	2	$5.75	$11.50
Steering Servo	Robotshop	RB-Hit-27	1	$9.99	$9.99
Motor wheel mounting plate	Robotshop	RB-Sbo-08	4	$1.00	$4.00
Omni Wheel	Robotshop	RB-Dag-17	4	$3.43	$13.72
Propeller (fan)	Robotshop	RB-Gem-10	2	$3.60	$7.20
				Total	$274.80

Table 5: Bill of Materials for Student Projects (USD)

Table 6 shows the group-by-group cost breakdown for the project, along with the cost for expedited shipping of the components from Robotshop in Canada. To keep expedited shipping costs low, we had to order all the components from a single supplier. In future years, when the schedule of an external project team does not limit the club's timeline, the club may avoid such constraints by selecting non-expedited shipping.

Group	Cost Achieved (USD)	Notes
Group One	$46.10	N/A
Group Two	$38.85	N/A
Group Three	$47.71	N/A
Group Four	$43.43	N/A
Group Five	$84.61	N/A

Group Six	$14.10	Using existing Blu robot chassis
Shipping Estimate:	$65.86	Robotshop Canada Parcel Air - 7 to 12 days
Total Order	$340.66	

Table 6: Group-by-Group Cost Breakdown and Shipping Cost

Note that some of the parts on the original order list had to be substituted for equivalent parts to prevent backorders; we also removed a few non-critical parts from the order for the same reason. After these modifications and a small increase in the shipping cost, the final order cost (including shipping) was $344.30 US, a value slightly above the original quote shown in Table 6. As noted in the Methodology chapter, the parts did not arrive until relatively late in the project period because of delays before the order shipped. At this time, however, the students had detailed designs for their robots, and were ready to begin construction.

Note also that, in addition to the parts we ordered for student projects, we also ordered an Arduino Mega 2560 for 46.74 Euro (approximately $60 US), to replace a broken board that Professor Jaupi had been using for his robotic arm. On top of this, we personally purchased a few minor components for the group, including chassis materials, battery holders and batteries, at total cost under $100 US.

4.5 Student Robot Designs

This section describes the robots designed and constructed by each group, adjustments we suggested, the parts required, the successes and challenges in each team's project, and the robots the students ultimately produced. Because only six teams of students participated in the project, we have elected to document each team's process individually in this section.

Note that, to maintain courteous anonymity, this section does not contain name or gender disclosures. As a result, gender pronouns in this section are replaced by the "her/he" construct. Note also that these student projects continued after we stopped formally documenting their progress. The contents of this chapter describe group progress up until 5 December 2014. After this time, we continued to help students with their designs on a casual basis.

4.5.1 Group One

Group One proposed a robot that could move autonomously, avoiding obstacles using an ultrasonic rangefinder, but also be controlled remotely by a Bluetooth-connected Android phone. We did not propose any major changes to Group One's original design. See Figure 2 for a 3D graphic produced by the team of their robot design.

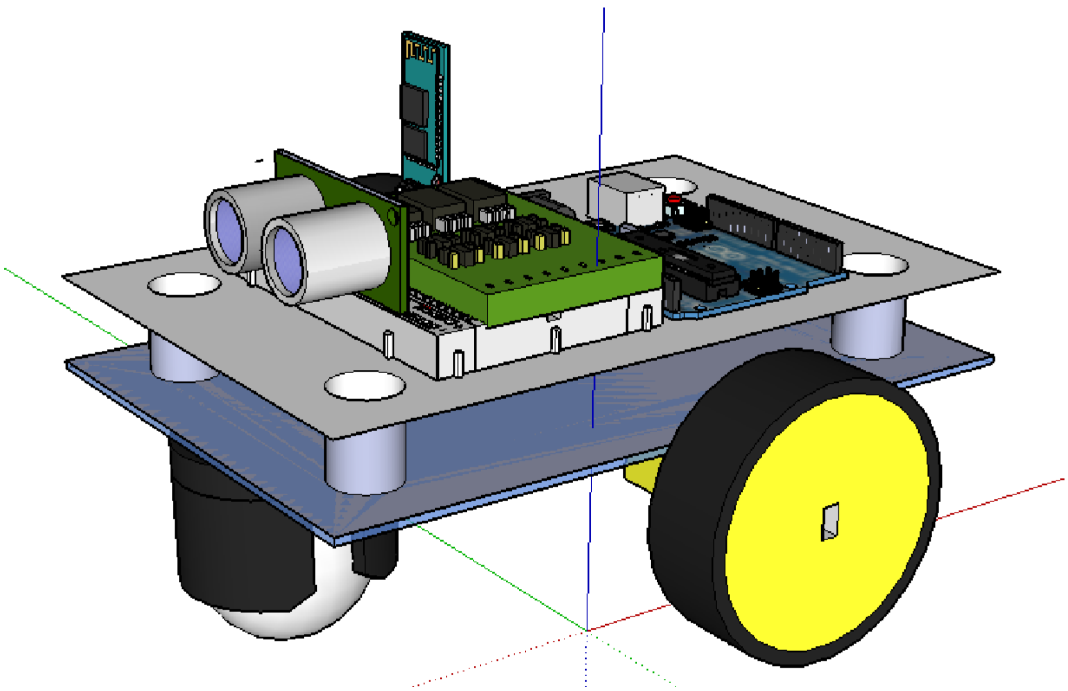

Figure 2: Ultrasonic-Sensing Bluetooth Controlled Robot Design

As of 5 December 2014, Group One had their robot driving around and avoiding obstacles. The group was starting work on a program for Bluetooth control, and an algorithm that would allow the robot to follow a human being. See Figure 3 for a photograph of Group One's robot.

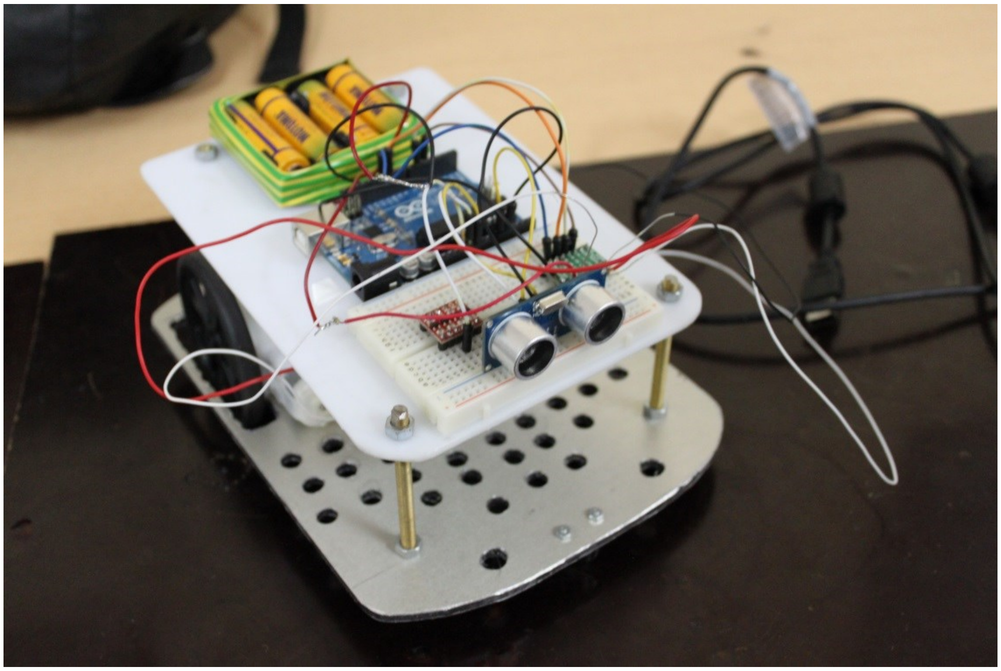

Figure 3: Group One's Obstacle Avoiding Robot

4.5.2 Group Two

Group Two proposed a robot that could seek out a person making sound in a darkened room, bringing that person a source of light. The leader of Group Two stated that this project proposal was motivated by frequent blackouts, a problem she/he observed in Albania.

We approved Group Two's design because of its heavy reliance on sensors. The robot would need to be able to avoid obstacles, seek sound sources, and measure light levels. Group Two spent most of the development process perfecting the amplifier circuit for their microphones. This circuit went through several revisions; as of 5 December 2014, the group was finishing with the final amplifier circuit design, and demonstrated the robot's light sensing and obstacle avoidance capabilities. The group was not observing measureable differences between the sensing microphones, and was starting to work on a physical sound wave guide to increase the directionality of the sensors. See Figure 4 for a photograph of Group Two's robot.

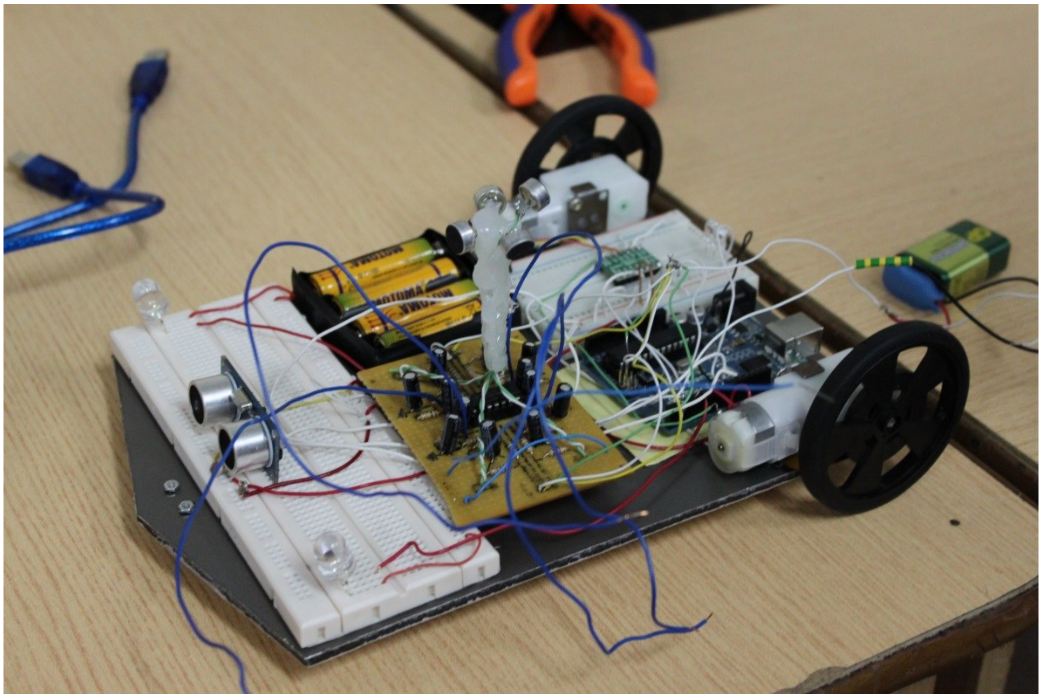

Figure 4: Group Two's Sound Seeking Robot

4.5.3 Group Three

Group Three proposed a robot that could balance on two wheels (an idea originally suggested by Professor Jaupi), while avoiding obstacles and taking movement commands from a Bluetooth-connected Android phone. We approved this project, as it presented an opportunity to teach Group Three about Proportional-Integral-Derivative (PID) control systems, and inertial sensing. We stressed to Group Three the importance of designing this robot with a balanced center-of-mass, to avoid an awkward or impossible pose in the balanced state. We also asked Group Three to think about rotational inertia, and its effects on the robot's settling time and maximum travel speed.

Group Three built their robot with relative ease, but encountered a number of challenges when writing the robot's software. The group attempted to balance using an accelerometer, but found that the robot was prone to oscillations. The use of a downward-facing ultrasonic rangefinder for balancing measurements was then suggested to the group.

After several mechanical and software revisions, Group Three managed to make the robot balance for several seconds under its own power, using the ultrasonic sensor, but was still working to perfect the balancing algorithm as of 5 December 2014. Group Three expressed interest in adding a gyroscopic sensor to the robot to improve its balance sensitivity. The group did get its Bluetooth module working, but still needed to incorporate it into the robot. See Figure 5 for a photograph of Group Three's robot balancing on its own.

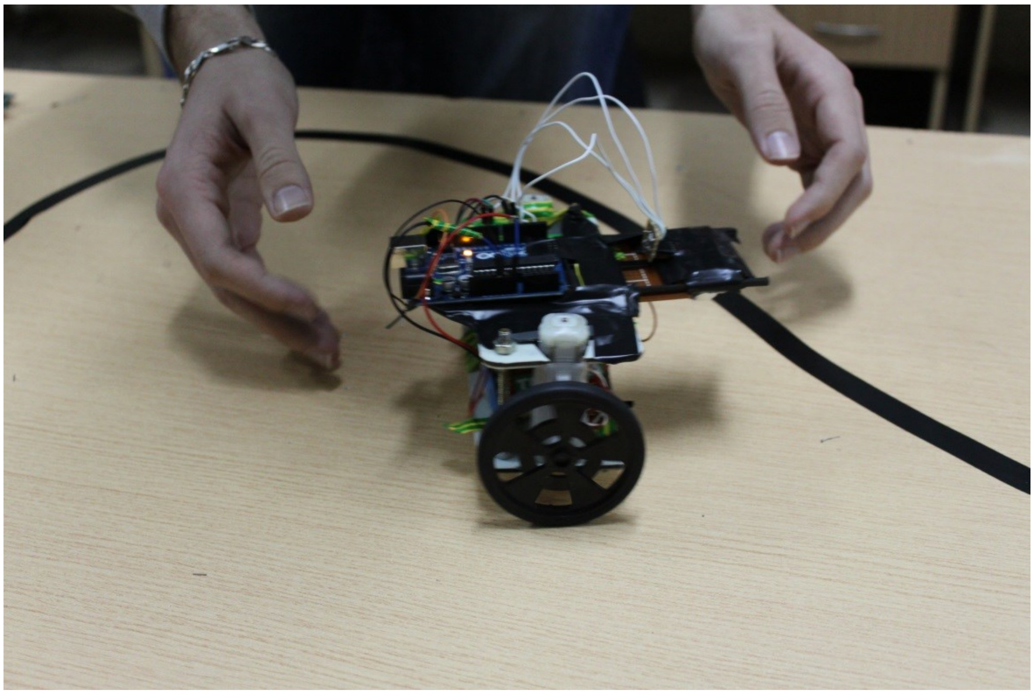

Figure 5: Group Three's Balancing Robot

4.5.4 Group Four

Group Four proposed a robot driven by a motorized, air-blowing fan, and steered like a car with pivoting front wheels. Originally, the group only planned to include remote control functionality for their robot (via a Bluetooth system similar to the other designs). We approved this design, but asked the group to include some sensors in their project. They elected to use light sensors to follow a light source in a dark room. For images of Group Four's robot design and circuit schematic, see Figure 6 and Figure 7 (below, respectively). During design discussions with Group Four, we suggested the group use turbine equations to estimate their robot's thrust capability. The group obliged, and did some of these calculations while waiting for parts to arrive.

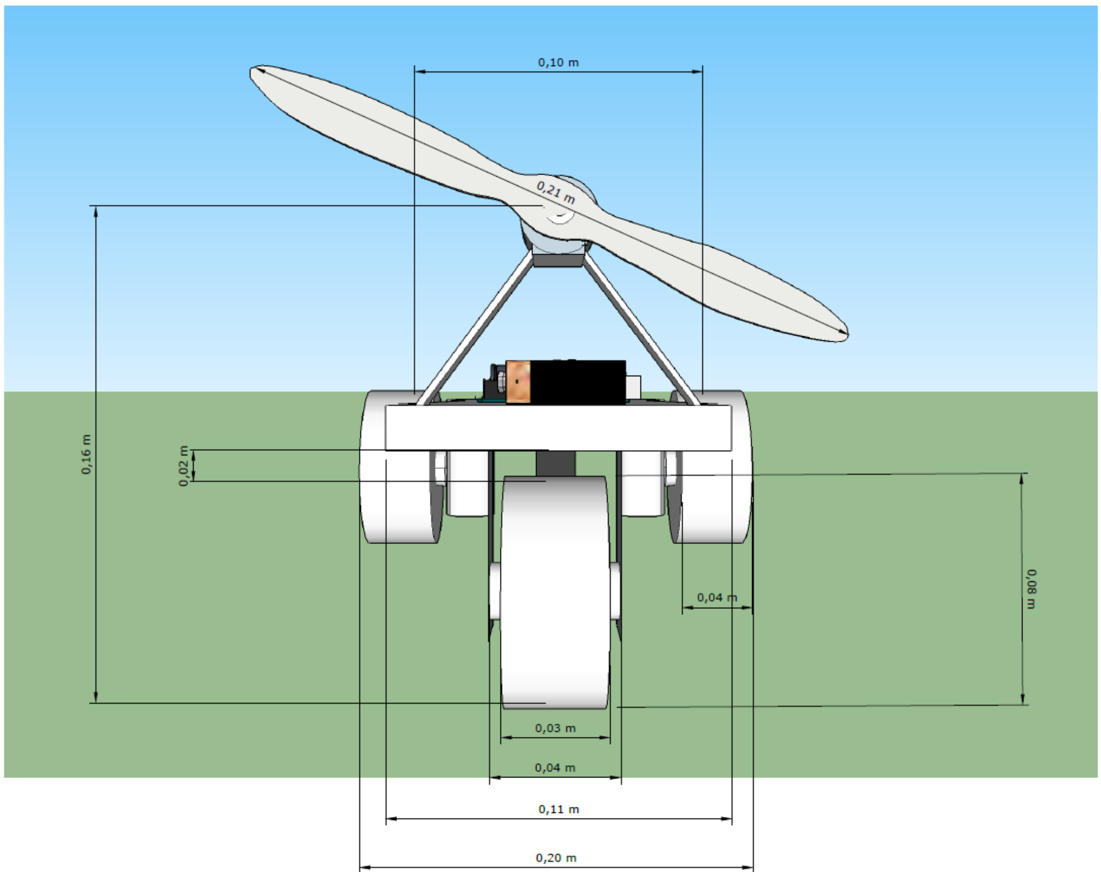

Figure 6: Fan Propelled Light Following Robot Design

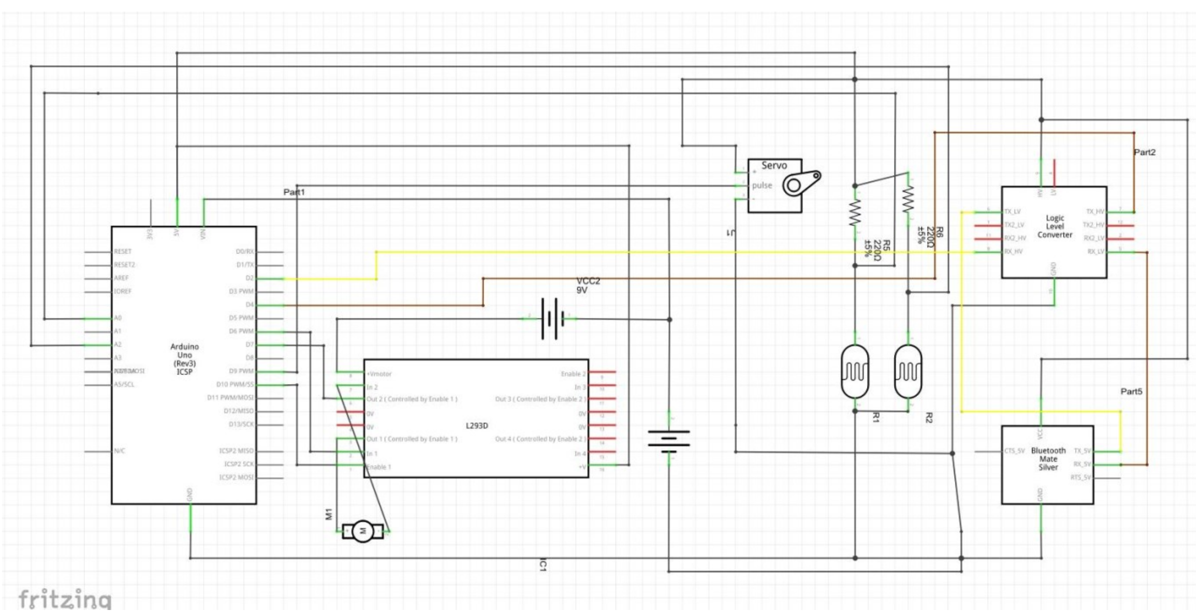

Figure 7: Fan Propelled Light Following Robot Circuit Schematic

When they constructed their robot, Group Four attempted to use a scavenged motor with a custom-built controller. In testing, the group found that these components did not work well together, and could not spin a fan fast enough to move the robot at its build weight. To mitigate this problem, Group Four redesigned their robot to reduce its size and weight, and sought improved drivers for their motor. The group also experimented with gear reductions and multipliers, in an attempt to find the optimal operating point for the propeller drive motor.

When we stopped documenting the club's activities, Group Four's robot had achieved basic fan-driven movement using a *pair* of fans, and could steer by pivoting its front wheels, but did not have a working onboard motor driver and power supply capable of turning both fans. As of 5 December 2014, the group was beginning to experiment with smaller motors, different types of fans and higher-current motor drivers. See Figure 8 for a photograph of Group Four's robot.

Figure 8: Group Four's Fan Driven Robot

4.5.5 Group Five

Group Five proposed the most mechanically complex robot: their design would be driven by omnidirectional wheels, capable of lateral motion in all directions, and equipped with four ultrasonic sensors for obstacle avoidance in all directions. Their robot would also incorporate a Bluetooth module for Android phone control. We approved this project despite its mechanical complexity and the resulting cost, as it gave Group Five a chance to work on complicated controls and simultaneous interfacing to a large number of sensors.

Group Five made a subtle, rather strange design choice early-on. The students prepared a drawing of their robot in which the wheels were oriented only slightly out-of-parallel. Traditional holonomic wheels need to be mounted on two perpendicular axes to achieve maximum mobility; while the group's design would have achieved limited strafing motion, we requested they modify their plan to maximize the robot's omnidirectional effect. The group obliged, and proceeded with a design in which the wheels were mounted on perpendicular axes.

Group Five did not encounter any major hiccups after this part of their design process; as of 5 December 2014, their robot was capable of moving about the floor autonomously, and able to accept Bluetooth remote control commands. The group chose an Android remote application that did not include an analog joystick; as a result, the robot was only capable of movements in four discrete directions. See Figure 9 for a photograph of Group Five's robot.

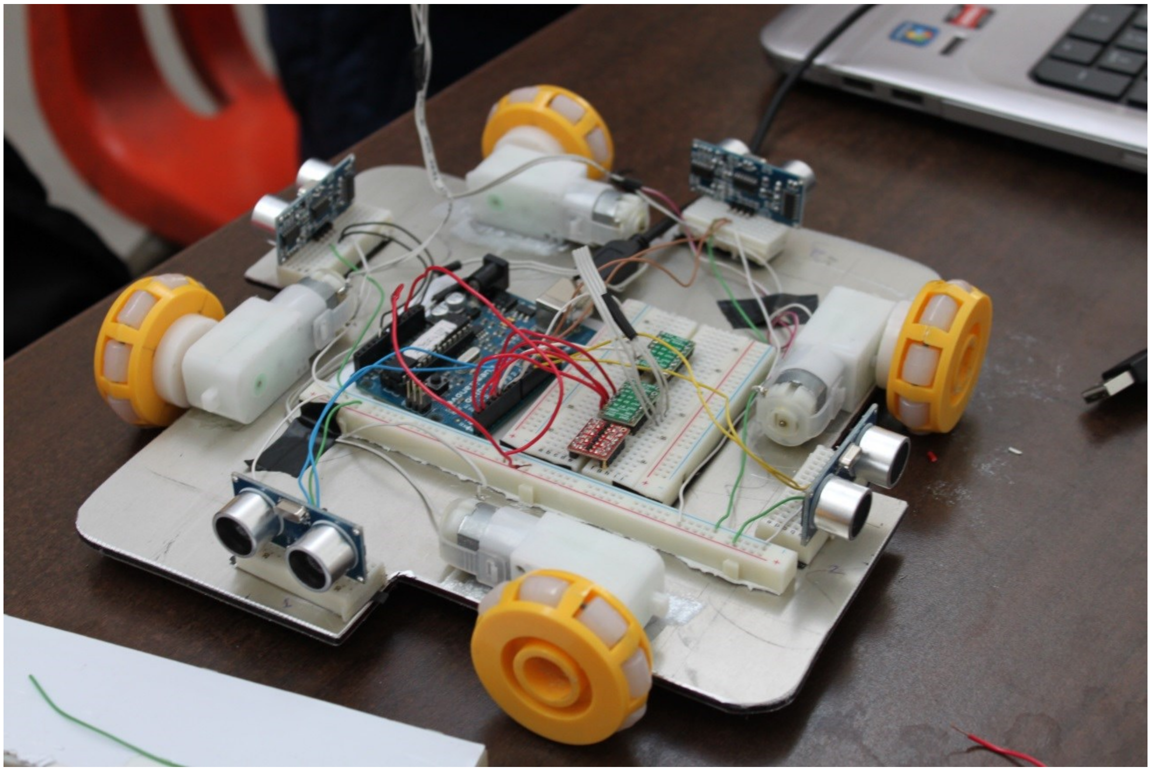

Figure 9: Group Five's Omnidirectional Robot

4.5.6 Group Six

Group Six started later than the others. Under Professor Jaupi's advice, we gave Group Six the existing Blu robot (discussed previously). They proposed a modification to the robot, adding a ball caster (for smoother motion), aesthetic body panels, and a set of sensors to seek sound sources. Professor Jaupi was not keen on this proposal, as it was similar to the robot proposed by Group Two. When we asked Group Six to modify their design, they decided to add line-following functionality to the Blu robot. We determined that this goal, though mechanically simple, would provide Group Six with a suitably complex task, because line following projects incorporate various programming challenges, especially when the robot must follow a line (or maze) with splits, junctions, or merges. We also asked the group to add an ultrasonic range finder to the robot, for versatility.

As of 5 December 2014, Group Six had completely finished their modification of the Blu chassis. The new robot had four line-following sensors and a range finder. Group Six still wanted to add obstacle-detecting functionality, and potentially a system to respond to splits in the line. See Figure 10 for a photograph of Group Six's robot following a tape line.

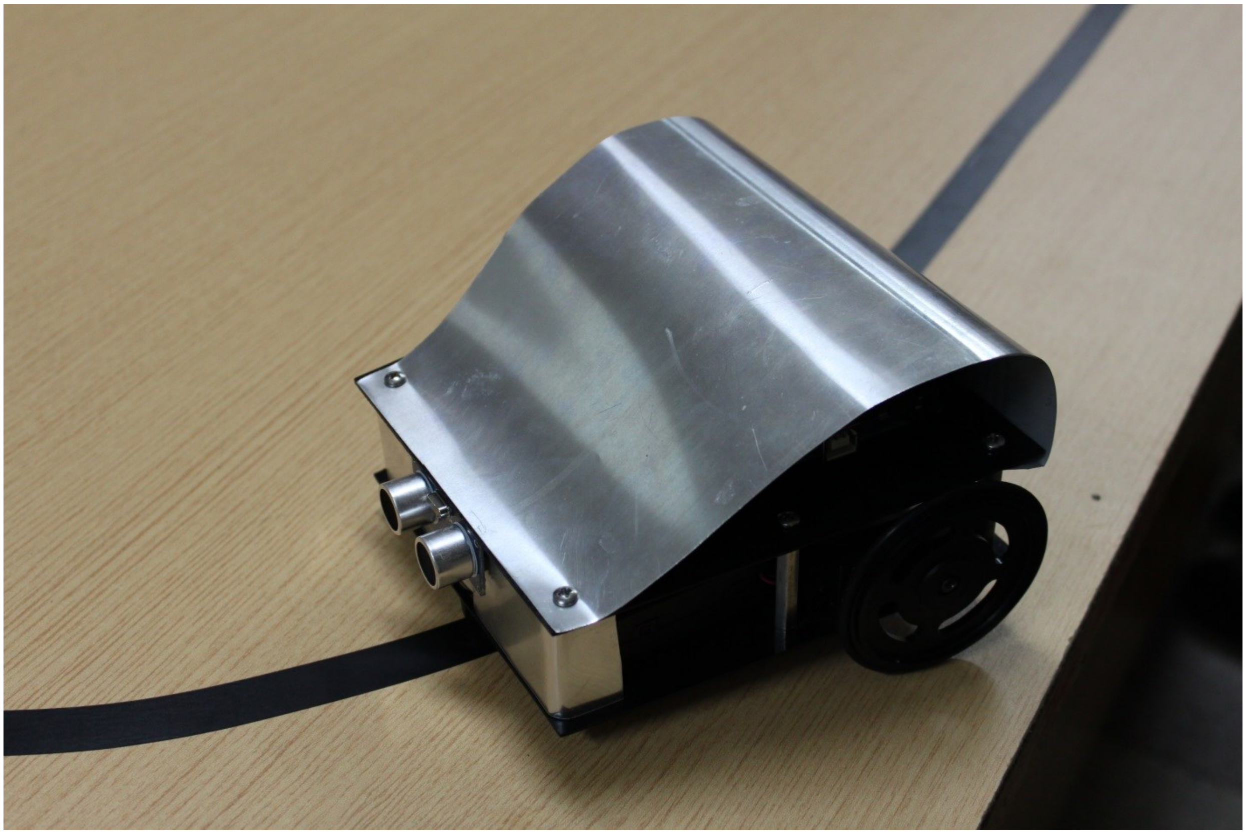

Figure 10: Group Six's Line Following Robot

4.6 Student-Reported Outcomes

In the closing focus group, the students responded to questions about their experiences with the club so far. The focus group took place on 5 December 2014. Eleven students participated, along with Professor Jaupi. This section is broken up in terms of the focus group questions we asked the students, as described in Appendix D.

4.6.1 Club Effects on Students

The full question we posed to the group was "What has this club done for you?" We received the following responses from the students. Note that these statements came from focus group notes and may not be direct quotes.

- Taught us to organize practical and theoretical knowledge together.

- Working with Arduino has taught us how to deal with other programming topics in the future.
- Taught us good mechanical techniques.
- Taught us how to organize teamwork within groups.
- Showed us what the other student participants knew.
- Gave us a great creative experience; required a lot of brainstorming.
- Challenged us in difficult topics.

4.6.2 Future Operation of Club

The full question we posed to the group was “How do you want to see this club run in the future? What would you have done differently, knowing what you know now?” We received the following responses from the students. Note that these statements came from focus group notes and may not be direct quotes.

- The club should keep developing and become bigger.
- It would be good to learn more information about how the electromechanical parts we used work [specifics redacted for anonymity].
- More mathematics work would have been beneficial in the beginning of the project.
- It is good that there are plans for the club to continue operating in the future.
- It would be good to relate robotics to real life, and get involved with industry.
- The club would benefit if it was somehow connected to the school curriculum.

4.6.3 Robotics as a Career

The full question we posed to the group was “What is your opinion of robotics as a career?” We received the following responses from the students. Note that these statements came from focus group notes and may not be direct quotes.

- Robotics would be a dream job.
- It would be exciting to work on robots to help disabled children, such as the visually-impaired.
- It would be interesting to research artificial intelligence.
- It would be good to make a profit off of something that you are interested in.

- It would be exciting if robots could be incorporated into everyday life.

4.6.4 Confidence in Ability to Continue

The full question we posed to the group was "How confident are you in your ability to keep working on your self-assigned technical goals after we [the IQP team] leave the country?" We received the following responses from the students. Note that these statements came from focus group notes and may not be direct quotes.

- Very confident.
- We learned to work, research, build and program on our own.
- We want to keep developing when we regroup at the end of January [timeline suggested by Professor Jaupi].
- We are interested in forming a larger club, and/or working on a large project that is divided into sub-projects between groups.

4.6.5 Effectiveness of Group Mentors

The full question we posed to the group was "What did you think of having (or being) group mentors?" We received the following responses from the students. Note that these statements came from focus group notes and may not be direct quotes.

- If we didn't have group members to help us, we would not have enjoyed the projects.
- Being able to divide the work up was critical.
- Every member is their own leader in some respect.

Note that the students responded to this question in a slightly puzzling way; it seems that some students may have interpreted the word "mentors" as "members". In an additional question, we asked the students whether they would have preferred to start meetings as a whole group, or stick with the existing strategy, in which group mentors went through an initial week of training alone. The students responded that it would have been better to work with everybody, from the beginning, to improve learning efficiency.

4.6.6 Student Comments outside the Focus Group

When asked about the effectiveness of the Arduino training lessons in discussions outside the formal focus group, the students said that what we covered in the lessons was a good introduction to Arduino, considering the limited amount of time we devoted to the topic. Students noted that they would have preferred the Arduino lessons to be about two weeks long, so they could explore more complex topics and develop a better background for programming their robots.

4.7 Discussion of Results

As we originally hypothesized, the student teams functioned well when left to their own devices. We took a *partner's* role when working with the students, asking for some deliverables on some days, but allowing the students to work in their own way. We took this approach to maximize student application of free will, and under-exercised faculty in traditional education. The result was an increased level of student engagement in the design and development processes.

Although this approach worked well with the majority of students, some students seemed reluctant to ask questions in person when the project first began. We mitigated this problem by assuring the students that questions were always welcome. We also made ourselves available to students via email, an avenue in which many students asked questions that touched upon core topics in their projects. It is possible that the privacy afforded by email made the students more comfortable; as time went on, the students became noticeably more relaxed asking questions and participating vocally during club meetings.

The students all completed their robotics projects with at least some amount of success. They reported that they enjoyed the experience. They also reported that, despite having assigned group leaders, they all felt like leaders, and they all got to make their mark on the project. Most of the students expressed interest in more complex projects, and in developing the club to include more students in the future. The students reported that they had learned techniques for working in groups, and improved their knowledge of technical topics. Most importantly, all students expressed a high level of confidence in their ability to continue working on robotics projects in the future, even after we (the WPI IQP group) leave the country.

Note that, in light of the students' successful project work, Professor Jaupi prepared an outline of a plan for the future of the club; this plan is discussed briefly in the Conclusions and Recommendations chapter of this report.

5 Conclusions and Recommendations

5.1 Lessons Learned at the Harry Fultz Institute

While working with the students in the club, we made observations about independent, interest-driven learning. We were trying to help the students operate on their own, but it was difficult at times to avoid becoming highly involved in the technical aspects of the student projects, especially when technical difficulties arose. We did not become overly involved, but this required active effort to allow students to test their ideas and make errors. The student leader system worked well to keep the students self-directed; because of the initial training the leaders received, they had information they could share with their groups without relying solely on our assistance. The students suggested that future programs should train everybody in the club at once, instead of starting with student leaders alone. We are reserved about this idea; we think that such efforts could create a chaotic, hard-to-organize lab environment if none of the students have experience and a small number of teachers or mentors are available to help. It is possible that existing mentors could work with future club members, training them for mentorship roles, to keep the student-teacher ratio in balance and resolve this organizational issue.

The students expressed interest in working on more complex robots. We started them with simple projects because we were unsure of their skill level when we first arrived at the school, but we recommend longer, more complex projects in the future. This will give the students an additional challenge and allow the project to be spread out over a longer period of time. Discussions with students suggested that they valued the practical experiences that the robotics club provided; thus, we recommend that the club maintain a strong focus on hands-on projects. We also learned that these students function well when they are building a robot of their own design. We recommend that the club continue to take this self-guided design approach in the future.

Working with low-cost components had few drawbacks, and exhibited only one major problem: the delay in receiving the components by mail order greatly limited the time that we could spend working on physical components with the students. In the future, the club should order components further in advance whenever possible. It may help to maintain a small stock of common sensors, motors and other robot parts, so that students can start prototyping their ideas more quickly.

We noted that the students were not experienced with documenting their laboratory work, especially in formal reports and notebooks. We recommend that future club leaders spend time teaching laboratory documentation and reporting techniques, so the students become familiar with the documentation practices that are common in real-world engineering projects.

5.2 Future Robotics Projects at the Harry Fultz Institute

During discussions with students, we learned that they had high aspirations for the future of the club. As noted previously, many students expressed interest in more complex robotic projects taking place over a longer time period. Sustainability was a driving factor during the development of the Harry Fultz Institute robotics club, and to help with this, Professor Jaupi has developed a five phase plan based upon our trial program. During Phase 1, Professor Jaupi will help students build simple, fixed-functionality robots without microcontrollers. During Phase 2, students will again work with Arduino boards and interfacing peripherals such as laptops/phones. In Phase 3, students will program Professor Jaupi's robotic arm (discussed in earlier chapters of this report) to complete various tasks, including object manipulation and drawing. In Phase 4, students will work with Professor Jaupi to construct an additional robotic arm of their own design. In Phase 5, students will incorporate advanced vision sensors such as the Microsoft Kinect into the operation of the robotic arms.

Professor Jaupi's plan may yield many months or even years of projects, and we feel it provides a reasonable growth trajectory for the club. We expect that, as time goes on, the club will become even more student-run, and eventually build up the capacity to open up to a larger number of student members (including students from lower grade levels) and work on a wider range of projects. Another goal for the club could be the involvement of the Polytechnic University of Tirana. Professor Jaupi has many ties to the university; he may attempt to involve these people as mentors for the club. This type of partnership may also be the domain of a future WPI Interactive Qualifying Project at the Harry Fultz Institute.

As the Harry Fultz Institute robotics club develops, it can potentially involve the local community in a meaningful way. The club should seek mentors from Tirana companies, or even become sponsored and participate in an international competition such as FIRST (more discussion of this matter follows in the next section). Future WPI projects may also wish to collaborate with the Harry Fultz Institute and Albanian financial sponsors to promote robotics activities at other local schools.

5.3 The Long Term Future of Robotics in Albania

Based upon the response of student robotics club participants at the Harry Fultz Institute, we conclude that robotics activities should be made available to students at other schools in Albania. Recalling the importance of student interest discussed in the Background chapter of this report, we recommend strongly against compulsory participation policies for robotics activities. Notwithstanding this point, it may be reasonable to impose compulsory assignments on students who do choose to participate in a robotics program. We do recommend that teachers and robotics program organizers explain to prospective robotics students the multidisciplinary nature of robotics, as this may garner interest from a wider range of students. Teachers should make it clear to students that robotics activities teach topics that are useful in a wide variety of professional endeavors, even non-technical ones.

We recommend that over the next few years Albanian educators with an interest in teaching robotics (including those at Harry Fultz Institute) attempt to establish a network of sponsored teams in an international robotics competition, such as FIRST. Competitions provide strong, well-defined goals for student participants, and teams in FIRST (and similar programs) benefit from the availability of outside corporate funding. As discussed in the Background chapter of this report, corporate sponsors such as engineering companies are likely to become a driving force behind widespread adoption of robotics programs in Albanian schools with limited budgets. Albanian schools should pursue avenues for robotics education in which corporate and non-profit sponsorship opportunities are most prevalent. Albanian educators should actively seek sponsorship from corporations inside Albania, to show students the opportunities for employment and entrepreneurship within the country, and to show local companies the potential of students with strong engineering skills. Educators should also recruit people from these corporations as engineering mentors (a common practice in FIRST). These types of promotion may spur greater interest in robotics within Albania's existing industrial communities, resulting in a positive feedback loop of sponsorship availability.

5.4 Final Remarks

Before arriving in Albania, we faced uncertainties about attaining the goals of this project. Despite these early concerns, we found that with great support from the students and staff of Harry Fultz Institute, our goals became achievable. The club ran smoothly, and the students interacted professionally. We encountered some difficulties along the way, but no obstacle greatly hindered the club's development. The students were extremely dedicated to their projects, spending many hours designing, building, and programming their robots. They wanted to learn all that they could about robotics, so that they could do more advanced projects in the future. The students performed far beyond our initial expectations, especially considering their lack of past robotics experience. As the club developed, the students became more self-directed. While the students still sought our help, they were able to solve many of their problems by talking to other students in the club and by researching on the internet. The students took to heart the concept of a *student-teacher partnership* in their activities.

Professor Jaupi's dedication proved similarly resolute. He worked constantly to ensure the club's success. He helped mitigate obstacles, which helped the club run much more smoothly. All of this makes us optimistic that the club can continue operating after we leave, as long as it can avoid pitfalls that could hinder its progress. These pitfalls may include long stretches of time without meetings, or taking on overcomplicated projects too quickly. Professor Jaupi has taken some steps to avoid growth problems already; as discussed previously, he has clear plans for the club after our departure.

The school's cooperation and willingness to help us, as well as Professor Jaupi's dedication to the club and the students involved, made this project very enjoyable for all its participants. We expect that this project will have a lasting impact on the Harry Fultz Institute and that the robotics club will continue to operate and grow in the coming years. Finally, we hope that other schools in Albania start to pursue robotics activities in the future.

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Appendix A: Resource Inventory Procedure

To take inventory quickly and effectively, we relied upon our prior knowledge in the field of robotics. We filled out inventory forms (in a tabular format) during the inventory process. Resources were categorized as consumable (usable only in one robot at a time), non-consumable (usable by multiple groups), or computers (categorized separately due to special software documentation considerations). Table 7, Table 8 and Table 9 (below) describe the formats for inventory of robotics resources.

Each inventory question was answered by a member of the IQP team based on his/her knowledge in the field. These inventory forms were not completed for resources that were not available to the robotics club. Note that the data rows in Table 7, Table 8 and Table 9 do not contain actual data; these entries are included to clarify table usage.

Item	*Quantity**	*Reusable**?*	*Why is this item useful?*
Resistor Stock	~100 ea. of standard values at +/- 5%	Limited reusable	Electronic circuit prototyping.

Table 7: Consumable Resource Inventory Format

*Quantities are estimated for bulk items when counting would be impractical. Estimation is indicated by the tilde (~) character.

**Consumable resources marked reusable may be used in more than one robot, but they cannot be used in more than one robot at once. Consumable resources marked as limited reusable will degrade quickly and cannot be reused many times.

Item	*Quantity*	*Why is this item useful?*
Digital Multimeter	5	Electronic circuit prototyping; robot troubleshooting.

Table 8: Non-Consumable Resource Inventory Format

Model/Description	Quantity	Paid Software Installed***
Dell Laptop Inspiron 1000	5	MS Office 2013, Solidworks 2014, LabVIEW

Table 9: Computer Resource Inventory Format

***Only paid software was required to be listed, though it was acceptable to list free software as well. We assumed that free or open source software required by the club could be installed at no cost as part of the club organization process.

Appendix B: Preliminary Student Focus Group Questions

The student focus group discussion was open-ended; participants were free to speak outside the bounds of the specific questions posed. To guide the discussion, however, we provided the following core questions in the discussion:

1. How do you define a "robot"?
2. What types of robotics experiences do you have?
3. What types of activities do you hope to work on in the robotics club?
4. What potential problems do you think could arise when the robotics club gets going?
5. How will you resolve technical problems in the robotics club if and when they arise? For example, nobody knows how to fix a broken motor.
6. What about organizational or social problems? For example, somebody won't contribute to the project, or somebody is uncertain of how to do something but does not ask for help. How will you avoid these situations? What about fixing them when they've already occurred?

Appendix C: Arduino Training Activities

Introduction to Training Activities

In the first two weeks of student meetings, we spent some time helping students establish team robotics project designs. We spent the other portion of the first two weeks training the students in Arduino programming and some of its challenges. As in all areas of this project, we answered any student questions posed in class, or via email, during these weeks.

This appendix is arranged into the two blocks, one for each week during which training activities took place. During the first week of training (week two of the project) only the student team leaders took part in the laboratory activities, while the activities were open to all club members during the following week.

Training Week One (Project Week Two)

In the first week of training, student team leaders worked on the basics of Arduino controller programming. We taught two lectures worth of simple Arduino programming, including setup-loop program structure, digital output (LED blinking), signal duty cycle and pulse-width modulation, serial communication with a personal computer (transmission only) and digital-to-analog conversion. Where applicable, we also took time to relate programming concepts to basic robotics applications in lecture, and asked students to write simple programs demonstrating each idea. Because most of the students had no Arduino experience, but plenty of C++ programming experience, we walked the students through each program on a chalkboard, focusing on Arduino-specific details, instead of language syntax. We then traversed the room and helped students debug mistakes in their individual programs. After giving students a basic program, we sometimes provided an additional challenge. For example, after students successfully wrote an LED-blinking program, we asked them to try changing the duty cycle of the blinking LED. This required students to understand the duty cycle metric, and how it related to their programs.

Training Week Two (Project Week Three)

After spending a week with the student leaders, we decided to use slightly more difficult training exercises in the second week. The goal of this change was to motivate student leaders to become involved with their teams, and to encourage successful teams to help teams that struggled or became confused. We kept the first activity the same (blinking an LED), but asked group leaders to teach the lesson to their student team members, instead of providing a full lecture on the programming required. At the end of this session we spent some time explaining the concepts of duty cycle and pulse-width modulation.

In the second session of group training activities, we provided students with a relatively simple program of 23 lines, edited to contain errors such as improper syntax, missing lines, syntax from other languages, pseudo-code and invalid logic. We explained the goal of the program (counting blackouts in a room using a light sensor, while lighting the room with an LED in the event of a blackout), and then asked the students to correct the erroneous code. The final (corrected) program was sensitive to noise; we used this unexpected failure mode as the basis for a brief introduction to hysteresis as a noise mitigation technique.

In the third group training session, we gave the students a more detailed description of hysteresis, and then asked each team to modify its program to include a noise-reducing hysteresis band. When teams completed this task, we prescribed another, similarly challenging modification: edit the program to blink the Arduino's LED whenever a blackout occurs, with the number of blinks equal to the number of blackouts that have occurred since the Arduino was last reset. When students finished this task using loops and processor delays, we showed them that their programs were not sensitive to blackouts that occurred while the LED was blinking (a common failure mode in systems using hard-coded delays).

Appendix D: Closing Focus Group Questions

The closing focus group discussion was open-ended; participants were free to speak outside the bounds of the specific questions posed. To guide the discussion, however, we asked the students to answer the following questions:

1. What has this club done for you?
2. How do you want to see this club run in the future? What would you have done differently, knowing what you know now?
3. What is your opinion of robotics as a career?
4. How confident are you in your ability to keep working on your self-assigned technical goals after we [the IQP team] leave the country?
5. What did you think of having (or being) group mentors?

Appendix E: Project Schedule Chart

Table 10 below shows a Gantt-style chart for the project schedule.

TASK	START	DURATION	END	28-Oct	31-Oct	7-Nov	14-Nov	21-Nov	28-Nov	5-Dec	12-Dec	17-Dec
Preparatory Research	28-Oct	4 days	31-Oct									
Student Mentor Training/Initial Robot Design Work	3-Nov	5 days	7-Nov									
Group Project Parts Ordering	6-Nov	22 days	27-Nov									
Intro to Arduino (Full Group)	10-Nov	2 days	11-Nov									
Arduino Based Robotic Projects	12-Nov	24 days (Club will continue work after team leaves)	Indefinite									
Closing Focus Groups & Club Supervision*	5-Dec	8 days	12-Dec									
Student Presentations	12-Dec	1 Day	12-Dec									
Final Documentation Prep	12-Dec	7 days	18-Dec									

Table 10: Project Schedule Chart

*Closing research included continued observations in the robotics laboratory, which are not included in this report due to reporting deadlines.