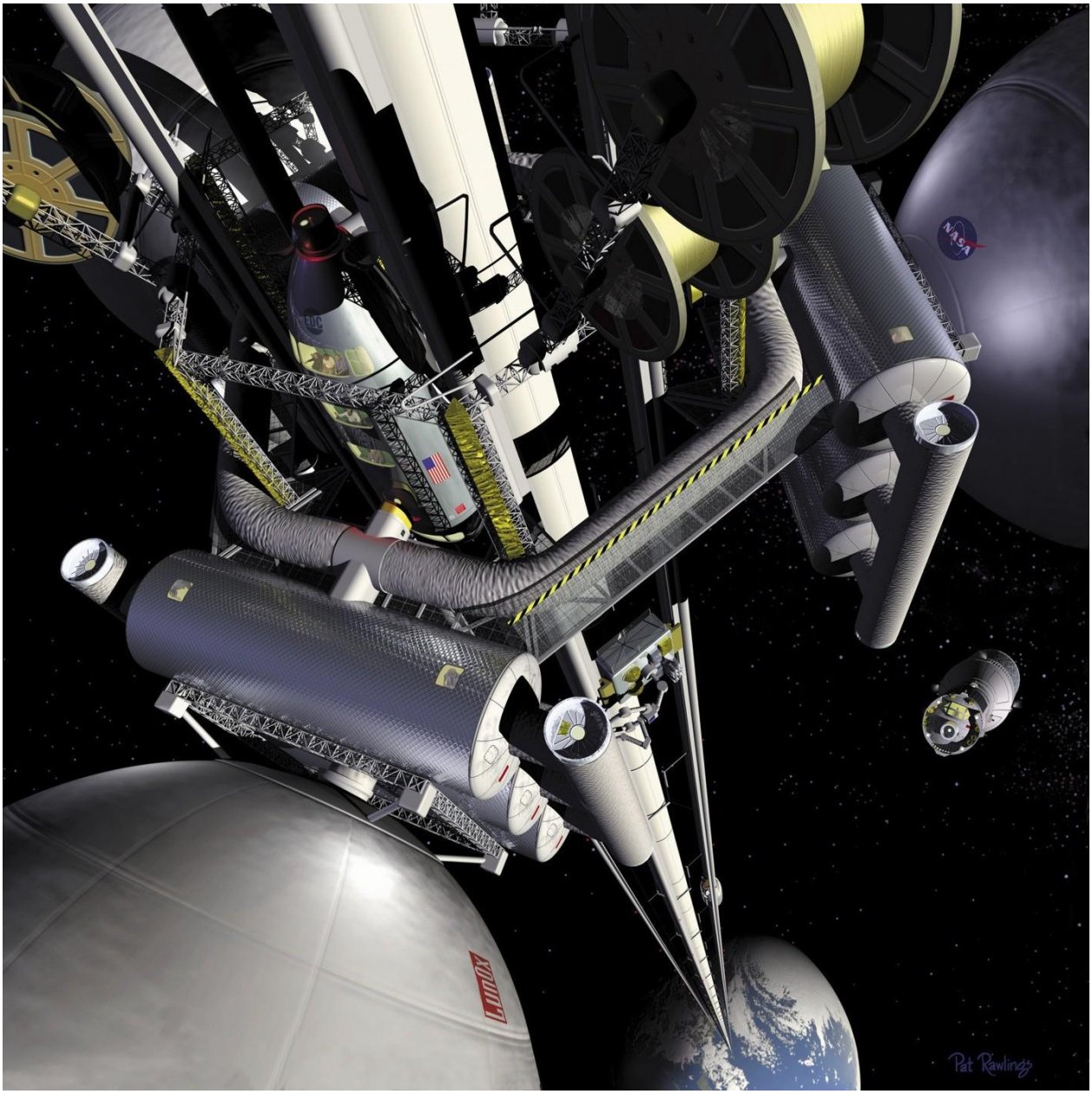
THE STEMOSPHERE

Team 146: Project Engineering Notebook
Rocky Mountain BEST Robotics 2012



STEM SCHOOL ACADEMY

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1 Executive Summary

Warp XX provides a multitude of challenges. In order to surmount all of these challenges and succeed in the competition, we split into separate teams and divided up the work. To further our effectiveness as a team, we also followed the engineering design process. We stated the problem, generated and analyzed concepts, prototyped and designed robot elements, produced the robot parts, integrated components and then tested our machine (see Figure 1). Our strategy team began the six week build period by defining the rules, regulations and requirements. They then developed a basic strategy. Our design team took this strategy and used it to generate prototypes and computer models of our robot. Our mechanical team then took these designs and used them built our final robot. This robot was then rigorously tested and improved via our driver team. Programming of the robot was done throughout this entire process. While our robot was being constructed, our notebook team was simultaneously working to gather documentation of our robot build. This documentation was then used to put together this engineering notebook.

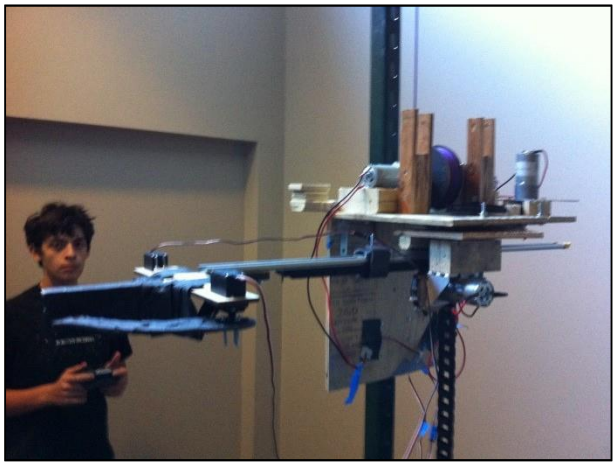


Figure 1: Completed Robot

2 Design Process

2.1 Problem Statement

DARPA has given us the challenge of producing a prototype robotic system that functions as an effective cargo transport between Midway Station and the island on Earth. The robot's constraints are as follows: it must fit in a 24 inch cube, weigh no more than 24 pounds,

have a safety cable and be built entirely out of BEST provided parts. Its requirements include climbing a ten foot tall "space elevator" and manipulating game pieces such as cargo balls, waste balls, fuel bottles, T-structures, solar panels and habitation modules; however, not all of these components have to be handled. The goal of the robot is to manipulate as many of these game field pieces as possible to score well during the competition. All of these requirements, constraints, and goals require not only a great design, but also a well-defined strategy. This strategy must then be converted into an optimal design. This design must then be carefully built using the provided materials. Finally, this large multitude of tasks can only be accomplished if our team develops and utilizes an efficient organizational structure, as well as a strong schedule and sense of time management.

2.2 Overview of Engineering Design Process

The Engineering Design Process aided our time management and our robot's efficiency (see Figure 2). First, we defined the problem statement, as shown above, by reading the rules and determining all of our constraints and requirements. We then selected a strategy from a variety of brainstormed alternatives, and determined a design based off of this strategy. After exploring several design alternatives and prototyping parts, we decided on one design and built it. This robot was then tested rigorously and several more design modifications were explored based on these test results. The best of these design alternatives were combined with our concept/prototype robot to create our final robot.

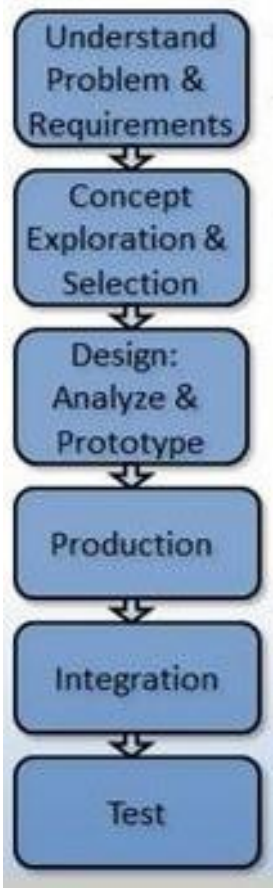


Figure 2: Our design process

2.3 Brainstorming

For our brainstorming method, we used multiple large white boards to write down any and all potential design ideas suggested by team members (see Figure 3). Then the robot team compared these ideas against each other, tested them for their viability and eliminated any ideas that couldn't be fabricated or weren't effective. In short, the robot team conducted an in depth analysis on each design. For the few ideas that were left after this process, we then commenced the process of debating about which designs were more operative, which often led to compromises between ideas and a better end product. This also allowed a point-by-point comparison of the merits of ideas. For example, there was a contentious debate about the material we would use to make the arm move. Such debates also led to possibilities that had not yet been explored. In many cases, there was also math involved in finding the best design, (see Math Analysis section 2.6). For more specific brainstorming pertaining to different parts of the robot, see section 2.5.

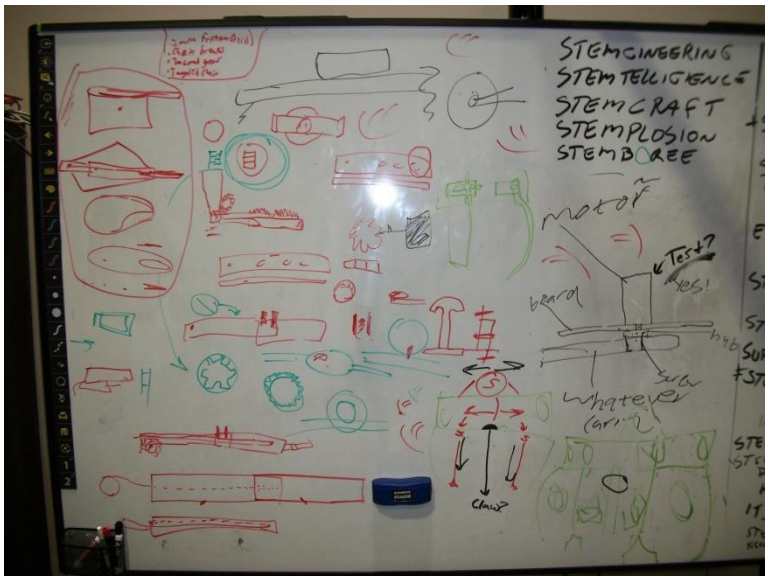


Figure 3: Brainstorming on a white board

2.4 Strategy Evaluation

2.4.1 Strategy Overview

Our strategy was straightforward; we would switch the bottles and then try for the habitation module and solar panels. This would put us at the top of the unitstrut, allowing us to

get the summit bonus. Our secondary objective was to knock off the waste balls, and move the cargo balls if time allowed. The robot design behind this strategy would be a rotating arm with a versatile claw on one end. (See appendix Figures 15 and 28)

2.4.2 Final Strategy

2.4.2.1 Basics

One of the most influential factors on the design of the robot is the strategy. It outlines exactly what the goals of the robot are. Knowing that this strategy will dictate how the robot will perform on game day, we spent a good deal of time outlining, detailing, refining and optimizing our strategies. As this year's game has very little robot interaction, we decided that our offensive strategy was far more important and therefore began working on it first. After developing our offensive strategy, we then proceeded to evaluate how we would react if certain parts of our robot were to stop working. This evaluation was eventually compiled into a detailed defensive strategy. Our offensive and defensive strategies are described below.

2.4.2.2 Offensive Strategy

The offensive strategy was one of the deciding factors in the design of the robot. Only after the strategy is determined can the robot-build team learn the functions the robot needs to perform. The strategy team generated this complexity chart (see Figure 4) to support a quantitative decision. (see appendix for strategy brainstorming in Figure 10,11, 12, and 22)

Objectives	Quantity (# of pieces on game field)	Score value	Relative difficulty Scale of 1(easiest) – 7(hardest)	Absolute difficulty Scale of 1(easiest) – 10(hardest)
Habitation Module	1	11	6	9
T-Structure	1	3	7	10
Fuel Bottle (empty)	1	7	4	6
Fuel Bottle (full)	2	6	3	6
Solar Panel	1	5	5	5
Cargo Ball	4	3	2	4
Waste Ball	2	1	1	2

Color Code	
Do-able	
Not do-able	
Primary objectives	

Figure 4: Complexity Chart

The chart was very helpful because it clearly showed us not only what we could and couldn't do, but also the relative difficulty of doing each of these objectives. The difficulty numbers were deduced by comparing how difficult it would be to design a robot that could accomplish the task

being debated. These comparisons allowed our strategy team to assign a relative difficulty to each task, which ranked the seven possible tasks from easiest to hardest. (See figure 5)

Strategy Evaluation

Strategy #	Specific Strategy	Points Earned (With Bonuses)	Difficulty 1(Easy)-20 Hardest	Efficiency (Points Earned/Difficulty)	Observations
1	Get Everything	73	20	3.65	Not Feasable for 3 Minutes
2	Get Only Fuel Bottles	16	5	3.20	-
3	Get Only Solar Panels	12	5	2.40	-
4	Get Only Cargo Balls	12	7	1.71	Relatively Hard to Grab due to weight
5	Get Only Waste Balls	2	2	1.00	THESE ARE THE TIEBREAKERS!
6	Get Bottles and Panels	28	6	4.67	-
7	Get Bottles and Panels+ Waste Balls	30	7	4.29	***Offensive Strategy***
8	Get Bottles and Panels+ Cargo Balls	40	12	3.33	-

Figure 5: Strategy Decision Matrix

This difficulty factor, and other factors such as the time taken to complete the task, were all compiled into the absolute difficulty. From these numbers, we were able to separate our primary and secondary objectives (the do-ables), from the tasks we decided were too difficult to attempt (the not do-ables).

Based upon these findings, the T-Structure was ruled out as a viable part of our strategy. Moreover, it was determined that the full fuel bottle, the empty fuel bottle, the solar panels and the waste balls were primary objectives. Lastly, the habitation module and the cargo balls were seen as secondary objectives and were only to be attempted if time permits. We then determined the order that we wanted to complete our primary objectives in. This order was established by placing our easiest tasks (in terms of absolute difficulty) first, and then following up with our

harder objectives. This is our final offensive strategy in the sequential order that it will be performed on the field, so long as the need for one of our defensive strategies does not arise:

Primary:

1. Go for the fuel bottles
2. Go for the solar panels
3. Go for the waste balls

Secondary:

4. Get the cargo balls
5. If time permits, mount the habitation module

2.4.2.3 Defensive Strategy

The defensive strategy was heavily based upon Murphy's Law. Multiple failure scenarios were envisioned, and ways to circumvent these setbacks were thought of on an issue-by-issue basis. Every element in these lists is what was evaluated as a viable part of the defensive strategy.

Defensive Strategy, based on failing component(s):

Claw Servos fail	1) Get the waste balls 2) Get the summit indicator 3) Get the solar panels, 4) Mount the habitation module if time allows us to do so
Ascension systems fail	1) Get waste balls 2) Rapid Turnaround bonus
Broken Shoulder	1) Get summit bonus 2) Rapid turnaround bonus 3) Solar Panels
Broken elbow	1) Waste cargo ball 2) Fuel Bottles 3) Summit

	4) Rapid turnaround bonus
Remote Failures	1) We're in trouble 2) Get rapid turnaround bonus

2.4.2.4 Strategies' Effect on Design Elements

Our design needed to meet the requirements of our strategy. It had to be capable of manipulating both solar panels and fuel bottles, ascending and descending the unistrut and toggling the summit indicator. Because our strategy called for switching out the fuel bottles quickly, the optimum design for our robot is a double-clasper claw. This claw also had to carry solar panels, a goal which necessitated a fixed, wooden center piece. Our strategy also needed a rapid ascent and descent, so our robot had to be very light.

2.4.3 Design Elements

2.4.3.1 Offensive design elements

Our robot this year was designed primarily to be an offensive robot, because the lack of robot-to-robot interaction in this year's game diminishes the need for a defensive design. The major offensive points of our robot include our telescopic arm, our dual-grabbing claw, and our two-motor winch, which allowed us to gain a substantial amount of points. The telescopic arm was designed to extend and provide the range of motion needed to manipulate bottles, solar panels, and cargo balls. It provided us with 30 inches of reach, and could swing around 180 degrees, allowing for object handling on both the right and left facing platforms. The claw was also a crucial offensive part of our robot. It was specifically designed to pick up bottles and transport solar panels, coinciding with our offensive strategy. Our two-motor winch allows our robot to gain the summit bonus and move pieces between the base and Midway Station quickly.

2.4.3.2 Defensive Design Elements

Due to this year's game field, our robot didn't have to interact with other robots, which greatly reduced the need for defensive design elements. However, the vertical ascension of our robot required that we protect it from the many forces exerted on it during the climb. Our winch was securely mounted to our base using wood in order to avoid putting stress on the motor shafts. A wooden guard that surrounded the unistrut was placed on the front of the robot in order to prevent the machine from rotating around the strut and thus causing much more stress. This guard also prevented the robot from getting damaged via collisions with the unistrut, as a free swinging robot could hit the strut and get damaged. Another defensive element was our base which was made as light as possible, in order to make our robot faster and more efficient when climbing the "space elevator."

2.5 Robot Design

2.5.1 Preliminary Design Overview

The prerequisites of our design were derived from our already established robot constraints, goals, and requirements. The constraints on our robot mostly came from the official rules, such as the weight requirement and the 24" cube, also with a 24 pound weight limit. Our requirements were things that our robot needed to do to be able to function effectively and conform with the rules. Our goals were derived from the objectives in our strategy.

In the end, the many ideas that we generated while brainstorming were consolidated into one design. This design was then built and rigorously tested. This testing often led to design tweaks and changes, all of which are discussed in our testing section. (See Appendix Figure 14 for basic material.)

2.5.2 Base and Winch

2.5.2.1 Base and Winch Alternatives

With the strategy we chose, our robot was required to go up and down the “space elevator” twice. This put a lot of stress on the ability of the robot to ascend and descend. We had a few different ideas as to how we would accomplish this task. One was a cog wheel system that dug into the slots in the unistrut. This idea was rejected very quickly because of the precision required. The teeth would have to be extremely uniform, and if there was any variation between the unistrut we used to test, and those of the competitions, our ascension mechanism would fail. Another proposed idea was to have two rubber wheels on either side of the unistrut, which used friction to make the robot ascend as they turned. These were also evaluated to be risky, as they may slip, which would be exaggerated the heavier our robot became. Finally, we had the idea of using a winch. The winch would resolve many of the issues of the other mechanisms. It would also be fast and light.

With the ascension method decided, we started discussing platforms to mount the winch, as well as other components to. One of the first designs we went through for the base was having a frame completely made out of PVC. The PVC would provide a full size frame while being significantly lighter than a solid frame. It was decided that a PVC frame would be very difficult to work with, as mounting the components necessary to ascend and manipulate objects would be very impractical. We decided to use wood for the frame instead, because it was light and easy to work with. With the material decided, we needed to find a shape that would meet our requirements of being as light as possible so that we could ascend quickly, while still being able to mount all of the necessary components. Originally we thought of building a box, but this was rejected, due to the weight a wooden box would have. So, it was decided that just the side

adjacent to the pole and the one on top were necessary. This gave us enough space to mount the electronics and other required components, while still being as light as possible. In order to test the validity of our design, we made a prototype robot that was a working representation of the base design.

2.5.2.2 Final Base and Winch

Our base was the most essential part of our robot because it served as the mounting platform for all our other parts. For our final design, we did not alter our prototype much. For our design, we had two pieces of plywood at ninety degree angles to one another. We cut down the size of these platforms to optimize our ascent speed. We also attached blocks of wood lined with PVC, to keep our robot securely attached to the pole. Finally, we found an optimal position to attach the cortex and the battery: near these PVC mounts. Our winch stayed the same from our first design, because it worked effectively in testing.

2.5.3 Arm

2.5.3.1 Arm Alternatives

After we had a solid base, we worked on constructing the arm, so that we could reach all of the game pieces. This was difficult because the strategy required it to extend 30” from the unistrut, while still fitting inside of the 24” cube. It also had to have a 180 degree range of motion, in order to be successful on both platforms. The 30 inch range of motion inside a 24 inch constraint prompted the idea of a telescopic arm. Our first design was built out of PVC. Two PVC tubes were nested inside of each other, and were tensioned with a rubber band. A string would then be attached in such a way that, when pulled, the PVC would extend. When released, the rubber band would snap the pieces back to their resting state. Numerous flaws were

encountered with this design. We realized that the string was not a reliable source of motion, as it would often get frayed, or caught on something, which would immobilize our arm. The arm also didn't provide us with the reach we needed, so we went back to the drawing board. The PVC was replaced with the sliding rail in our second design, and the string was replaced with the wiring conduit, which was used as a chain to pull and push the slider. The conduit was robust, and the slider provided us with a sufficient range of motion.

2.5.3.2 Final Arm

The arm and elbow joint on our robot progressed to more effective designs as we discovered fatal flaws in the previous prototypes. In order to achieve the required reach, we used the slider and conduit design detailed above. The sliders were screwed to the turntable, which was more weight-bearing than the wood pivots we had used previously. A motor mounted to the turntable wrapped and unwrapped the wiring conduit, which was attached to the end of the upper slide (which replaced the inner arm). The decision to use the conduit was made because it was stiff enough to both push and pull the arm. This allows both the upper and lower arm rails to move in and out, greatly extending our range of motion and allowing us to fit in the 2 foot requirements.

2.5.3.3 Regional Arm

During game day and in testing we noticed problems with the extension of the arm. One of the major ones was that the conduit sometimes expanded outward instead of pushing and pulling the arm in a linear fashion. This reduced or eliminated our ability to extend our arm. There were a wide variety of proposed suggestions to fix the arm. There was a suggestion to remove the chain all together and create a notched belt for the gear to mesh with. There was also an idea to turn the sliders for the arm sideways so as to mount them the way they were supposed

to go, and along with that idea come several variations of a string-based pulley to extend and retract the arm. Many of those ideas solved the problem of the conduit unraveling outward, but there were also ideas to restrain that using such things as a zip tie, an extended hook or even a plastic ring wrapping all the way around both rails. However, the best idea was suggested last, which was firstly to reconstruct the base (see Figure 6). Our original design had the back of the arm (fully extended) behind the pivot point of the base. The reconstructed base would bring the back of the arm forwards several inches, which would reduce stress on the arm (preventing the conduit from unraveling), and would also allow us to score the farther solar panel. Furthermore, the reconstructed base would be symmetrical on both sides of the game field. For backup, a full ring would be placed around the sliders to prevent conduit unravelings (see appendix arm related figures 11, 17, and 18).

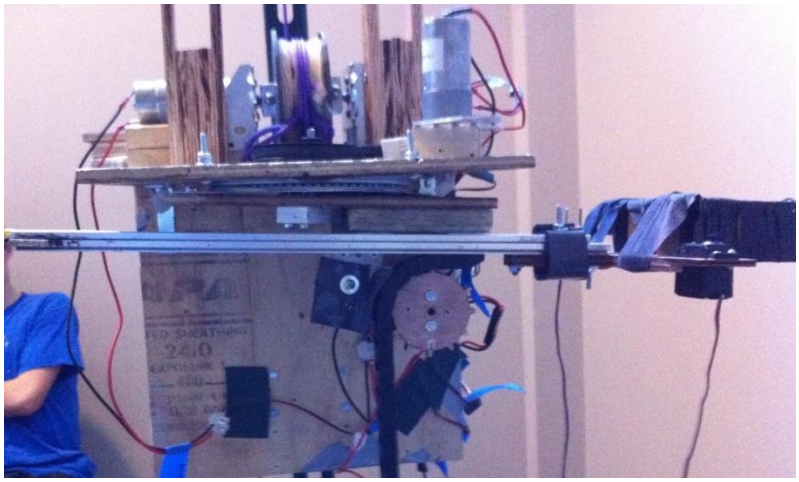


Figure 6: Completed Regional Robot Arm

2.5.4 Claw

2.5.4.1 Claw Alternatives

The claw was easier to design than the base or the arm. The primary reason for this was that the strategy defined very few parameters for the claw. It had to be able to grasp bottles and solar panels easily as well as be able to switch the fuel bottles. First we designed a simple grabber, which satisfied all of the parameters, but in order to switch the fuel bottles, we would have had to

make two trips up the unistrut. This lead to the creation of a double grabber system, in which two independently operated claspers were placed at the end of the arm. One grabber would pick up the full fuel bottle at the bottom, and after the robot had scaled the unistrut, the second grabber would grab the empty fuel bottle, and with a slight sideways movement of our arm, the full fuel bottle would be attached at the top. The empty fuel bottle would then be brought down and placed in its holder. This allowed us to exchange the bottles in just one trip. The claw was also outfitted with a solid, fixed piece of wood in the center that both pincers used as their counterpart (refer to appendix for pictures of the claw in Figures 15, 19, and 28). This center piece was great for handling solar panels because the wood piece conjoined with the center hole of the solar panels.

2.5.4.2 Final Claw

Our final claw design was very similar to the preliminary design. It started with a four way joint connected to the arm on one end, a wooden center piece parallel to the arm and a grabbing clasper on either side of the center wood piece. The servo mounts were made of sheet metal running perpendicular to the arm, with the servos mounted in the middle. These servos connected to the claspers using piano wire. This design worked fairly well, but in the final assembly several improvements were made. To increase the stability of the claw, all of the separate wood pieces were instead cut out of a single block of wood. The servos were mounted closer to the joint so as to add leverage and make it level with the claw surface, and the distance between the pivot point and the joint was decreased to make it easier to grip the fuel containers.

2.5.4.3 Regional Claw

To understand what improvements we'd need to make on our claw, we tested our existing design on our game field. Specifically, our claw was tested to see if we could actually score a

habitation module. Unfortunately, the angle of our arm's rotation made it impossible to hang onto the appropriate hook on the module, so the new claw was designed only to pick up the items that the old claw could- fuel bottles and solar panels. To decrease claw weight, the new design was constructed out of two layers of 1/8” plywood separated by several pieces of the 1/2” thick board. The servos were mounted at the very ends, and the two claw claspers were attached directly to those servos, making them both have the exact same range. The new claw design was shaped so as to optimally grip the bottles at the base, and grip solar panels well at the tip. This allowed both items to be scored more easily, and added reliability for the drivers. That claw design made scoring items more efficient, more reliable, and light enough to minimize the arm's sag (see Figure 7).

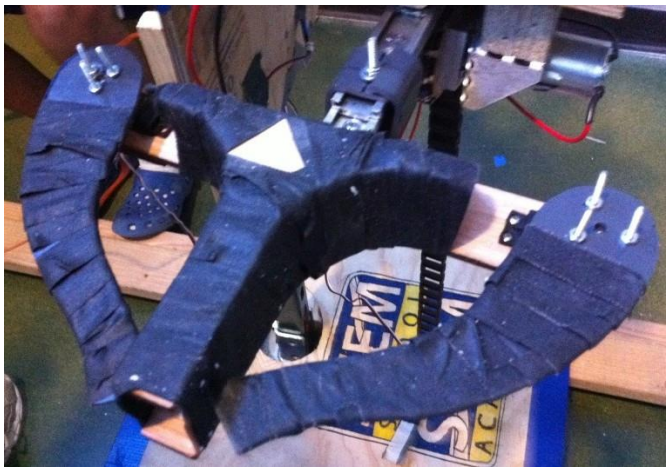


Figure 7: Finished Regional Claw

2.6 Mathematical Analysis

2.6.1 Optimization of Robot winch

The winch, being a very complex system, involved a wide variety of math. We wanted to be able to find the optimal winch radius for any weight that our robot could have. We decided to go with a radius of 1 inch initially for testing, so calculating for the acceleration using a sum of forces equation gives:

$$\sum F = F_{rope} - F_{gravity} = m_{robot} * a$$

$$\frac{F_{rope} - F_{gravity}}{m_{robot}} = a$$

$$\frac{\frac{r_{motor*2}}{r_{wheel}} - m_{robot} * g}{m_{robot}} = a$$

$$\frac{\frac{2.6585Nm * 2}{0.0254m} - 5.443kg * 9.806 \frac{m}{s^2}}{5.443kg} = a$$

$$28.6527 \frac{m}{s^2} = a$$

Using this value for acceleration, and since we know that the height of the pole is 10 ft., it's possible to derive the time it takes to climb the pole.

$$D(t) = \frac{1}{2}(a)t^2 + V_0 t + D_0$$

Assuming that the initial velocity and position $V_0 = D_0 = 0$:

$$3.048m = \frac{1}{2}\left(28.6527 \frac{m}{s^2}\right) t^2$$

$$t = 0.4612535s$$

Obviously this number is unrealistic; the robot can't climb the pole in less than half a second based on actual testing. So what is missing from the equation? Drag! This includes motor and drive train drag and friction along the pole. The linear drag is fairly easy to figure out, as it is just a drag coefficient multiplied by velocity:

$$\sum F = F_{rope} - F_{drag} - F_{gravity} = m_{robot} * a$$

$$F_{rope} - yv - m_{robot} * g = m_{robot} * a$$

The motors' drag, being related to angular velocity was slightly more complicated to calculate. We started by finding a sum of torques equation:

Where I is rotational inertia, and $0''$ is rotational acceleration.

$$\mathbf{L}\ r = r_{motor} - r_{drag} - r_{rope} = I_{winch} * 0''$$

$$r_{motor} - \{30^1 - F_{rope} * r_{winch} = I_{winch} * 0''$$

We solved both equations for F_{rope} and used that to set them equal to each other.

$$yv + m_{robot} * g + m_{robot} * a = \frac{r_{motor} - \{30^1 - I_{winch} * 0^{11}}{r_{winch}}$$

In this equation we had terms of both angular and linear velocity and acceleration. We used the formula for arc length to find a relationship:

$$x_{rope} = r_{winch} * 0$$

$$\frac{x_{rope}}{r_{winch}} = 0$$

Where x_{rope} is the length of rope on the spool and 0 is the amount of radians the spool has turned. Using this, we found $0^1$and $0''$.

$$0^1 = \frac{v}{r_{winch}}$$

$$0^{11} = \frac{a}{r_{winch}}$$

We then used these to put our equation entirely in terms of linear velocity and acceleration.

$$yv + m_{robot} * g + m_{robot} * a = \frac{r_{motor} - \frac{\{3v}{r_{winch}} - \frac{I_{winch} * a}{r_{winch}}}{r_{winch}}$$

We then put this into the ordinary differential equation form

$$m_{robot} * r_{winch} + \frac{I_{winch}}{r_{winch}} a + y * r_{winch} + \frac{\{3}{r_{winch}} v = r_{motor} - r_{winch} * m_{robot} * g$$

Following this, we made some assumptions to make the equation easier to solve.

We assume the term $\frac{!_{winch}}{r_{winch}}$ was much smaller than $m_{robot} * r_{winch}$, so much so that it was irrelevant.

$$m_{robot} * r_{winch} >> \frac{I_{winch}}{r_{winch}}$$

In a similar manner we assumed that the drag was primarily in the motor, meaning that the linear drag was mostly irrelevant.

$$\gamma * r_{winch} << \frac{\beta}{r_{winch}}$$

This left us with:

$$m_{robot} * r_{winch} * a + \frac{\{3v}{r_{winch}} = r_{motor} - r_{winch} * m_{robot} * g$$

During testing of a prototype robot, we noticed that the robot reached a steady velocity very quickly. We calculated the average speed of the robot during the entire time it took for it to climb the pole.

$$s_{robot} = \frac{d_{traveled}}{t_{taken}}$$

$$s_{robot} = \frac{d_{18} - d_0}{18s}$$

$$s_{robot} = \frac{3.048m - .305m}{18s}$$

$$s_{robot} \approx \frac{.152m}{s}$$

Using this we assumed that acceleration was $\approx \frac{0m}{s^2}$ and velocity was $\approx \frac{.152m.}{s}$ Using these we solved for {3

$$\{3 = \frac{(r_{motor} - r_{winch} * m_{robot} * g - m_{robot} * r_{winch} * a) * r_{winch}}{v}$$

$$\{3 = \frac{((5.3\text{Nm}) - (.025\text{m}) * (5.44\text{kg}) * (\frac{9.8\text{m}}{\text{s}^2}) - (5.44\text{kg}) * (.025\text{m}) * (0)) * (.025\text{m})}{(\frac{.152\text{m}}{\text{s}})}$$

$$\{3 = \frac{.6525\text{kg} * \text{m}}{\text{s}}$$

Now we solved the differential equation for v(t) using Wolfram alpha[1].

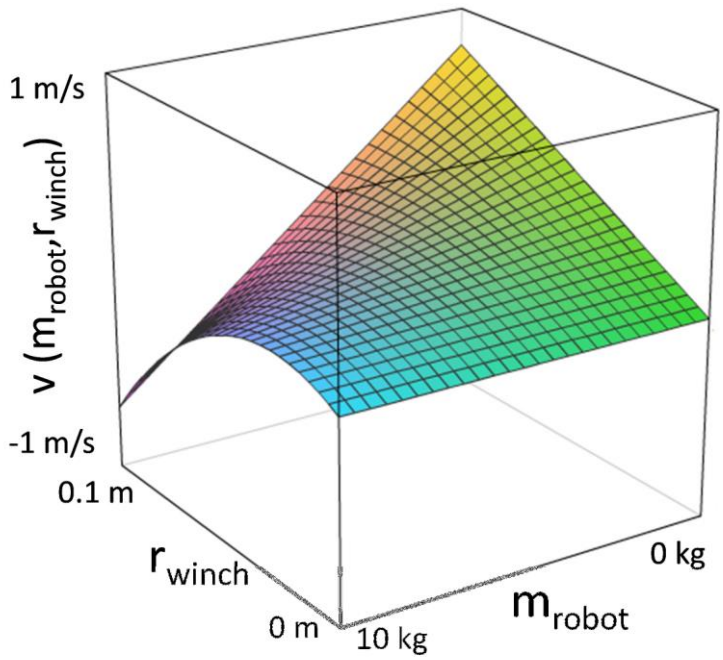
$$m_{robot} * a * r_{winch} + \frac{\{3v}{r_{winch}} = r_{motor} - r_{winch} * m_{robot} * g$$

$$v(t) = -\frac{r_{winch} * (g * m_{robot} * r_{winch} - r_{motor})}{\{3} * (1 - e^{\frac{-\{3t_2}{m_{robot} * r_{winch}}})$$

Inserting our known values and assuming a constant time, we are left with v(m, r).

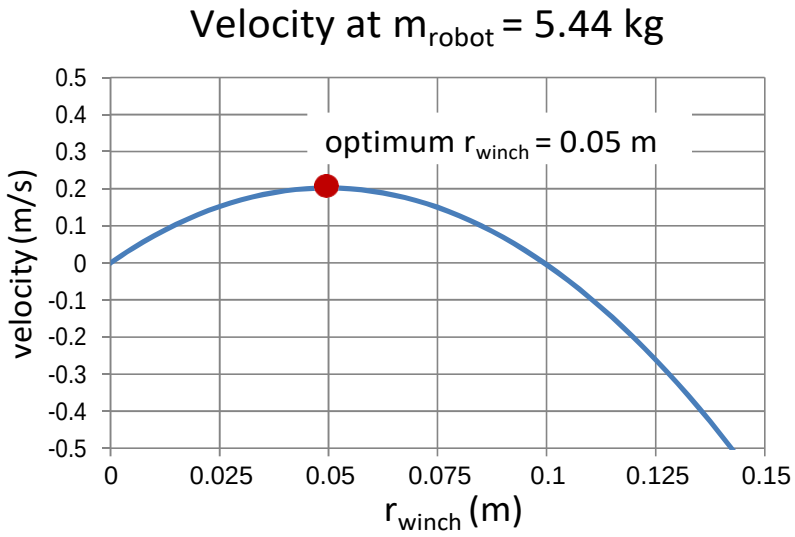
$$v(m_{robot}, r_{winch}) = -\frac{r_{winch} * (9.8 * m_{robot} * r_{winch} - 5.3)}{.6525} * (1 - e^{\frac{-.525*}{m_{robot} * r_{winch}^2}})$$

Graphing this equation we got:



[1] *Wolfram|alpha: Computational knowledge engine*. (2012). Retrieved from http://www.wolframalpha.com/

Evaluating this function for our current robot weight of 5.44 kg:



According to the graph the optimum winch radius would be 2". So we remade our winch to have a radius of 2".

2.7 Programming

Programming is an essential part of any robot. It's what turns a mechanical assembly into a fully functional and controllable robot. We started by making a list of software requirements (see Figure 8).

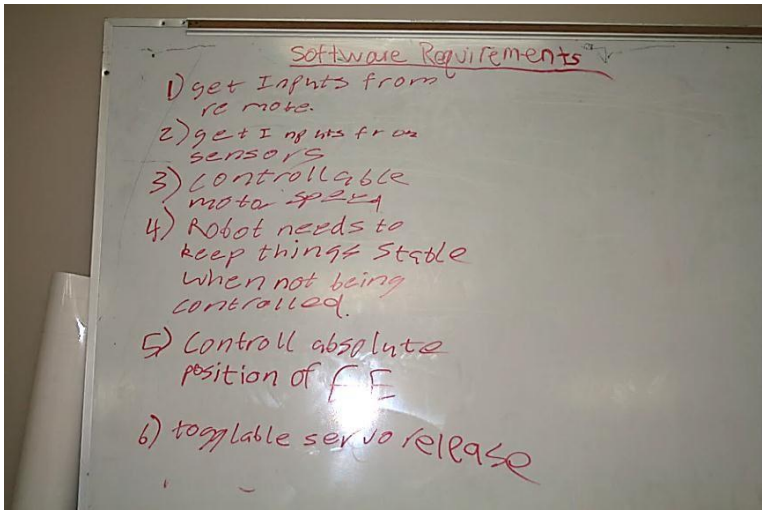


Figure 8: Programming and Software Requirements

Next we designed the way the program would work, keeping the requirements in mind. After that we started doing the actual coding in RobotC, which we chose due to the large amount of freedom it offered. We started by making specific functions in charge of retrieving inputs and controlling actuators. Next came the hard part, creating the code that would use the inputs to determine the appropriate actuator settings. During this process we used a great deal of math, and a large amount of testing. Finally, we had the drive team test the code and followed the feedback they gave us to further improve the program (see appendix figures 16 and 25).

2.8 Robot Integration and Testing

After all of the robot's components had been fabricated, they were tested individually using our personal game field and game pieces. Following testing and refining, these parts were integrated into one system according to our preplanned integration scheme. This outline was drawn out by our robot team to avoid any mechanical interference between parts. After the program was loaded on to our cortex and our robot was assembled and integrated, it was tested on our game field.

After completing our initial robot, we had to test it to ensure proper functionality and work out any bugs. It was beneficial that we did this because we were able to identify game breaking flaws in our arm design, the elbow joint and the shoulder joint, as previously stated in the design alternatives sections. The first thing we tested was the ascension method and the shield that confined the robot to the unistrut. Our ascension method worked quite well, going up in eighteen seconds and down in thirteen seconds. We also tested the elbow joint separately; that is how we identified the problem of our rubber band and PVC arm not being able to meet the standards we required for extension. After revision, we came back and tested it again, this time with it being able to extend to the length that we needed it to. We then had to test the claw, and it managed to

fulfill our expectations by grabbing both fuel bottles and a solar panel (see Figure 9). As previously mentioned, we also tested our completed robot, with all necessary revisions made, on our game field during timed matches to simulate a Game Day experience.

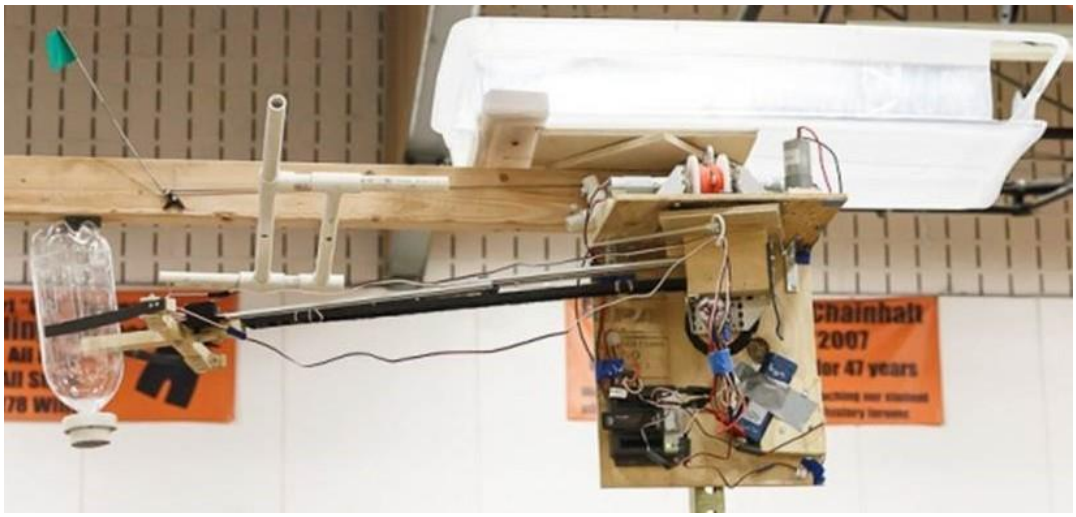


Figure 9: Robot Testing

3 Team Organization and Meeting Minutes

The construction of an efficient, well-constructed robot necessitates good time management as well as effective work distribution. Our team developed a thorough schedule and daily agendas. With our mentors' lessons in project management skills, team leads decided what needed to be done at each meeting. These schedules and agendas were then dynamically updated based on the agendas completed during each meeting. We also divided our team into smaller sub-teams, each of which performed a specific set of tasks. For example, the claw team devised a claw, the arm team built an arm, and the robot lead saw through the integration of all of these pieces. Each team had a lead responsible for his/her team. Leaders were assigned based on skill level, meaning that leads had to have experience in robotic competitions, an understanding of the rules and requirements and good leadership qualities. The rest of the team chose what team they would like to work in based on their interests and their abilities. Our team was organized as

shown in the Appendix. (For appendix figures based on team organization, meeting minutes, and meeting schedules see figures 23, 24, and 27).

4 Safety

In the eyes of the STEMosphere, it's not worth the price of winning the competition if the cost is injured teammates. We strive to create a safe environment where the odds of having an accident are significantly reduced; where all of our teammates watch out for each other and keep each other safe.

We follow all common safety procedures: wearing safety glasses whenever a tool is in use, covering our feet with closed-toed shoes in case anything is dropped, and maintaining a stringent no-horseplay policy in our engineering lab. We also have a no food and drink policy instituted in our lab to prevent spills and other potential safety hazards. In case of an emergency, such as the rare event of a fire, we have practiced procedures that all members of the team are familiar with. For example, should a fire start in our lab, all team members are to proceed in an orderly, quiet fashion to the nearest door and exit the building.

Our team also realizes the importance of using the proper tools in the appropriate situations. All team members are educated on the usage of tools such as drill presses, band saws, etc.. Furthermore, any questions regarding tool usage can be answered by one of our four engineering mentors. Each of these mentors is skilled in the usage of tools, and is prepared to relay any of their knowledge to us students. All broken tools are also supposed to be reported immediately to one of these mentors.

Other standard safety procedures that we follow include not wearing loose clothing in the lab, and tying back long hair. We also have a fifteen minute session at the end of every workday devoted to cleaning up, so that our lab remains clean and organized. We also always use a brush

to clean off machines after we're done using them, because use of our hands could consequently result in cuts and injury.

Much of this wisdom was imparted on us by our school engineering teacher. who has years of personal and professional experience with engineering and proper safety procedures. We spent a meeting taking notes on safety and all of us have a copy of those notes that we are required to have signed by our parents, so as to ensure that we have learned and understood all of the safety procedures.

We learned safety procedures for specific tools as well. For using the band saw, we had to use a push block when the project allowed for it, keeping the block quarter of an inch away from the object being cut and also to wait for the blade to stop completely before removing the cut pieces. For the sander, we had to grip the object, and not use some other device to do so. If there wasn't a safe way to grip it, we would use a file. For the drill press, everything that had to be drilled was clamped down. For the laser engraver, we had to have someone who was trained to actually activate it. Those were our main rules, the rest were common rules such as always having permission to use a machine, always having safety glasses, cleaning up after you were done and other common sense rules such as keeping hands away from the blade. Only mentors were allowed to use more hazardous tools, such as the table saw. (For safety content see appendix Figures 13, 20, 21, and 26).

5 Research Paper

The idea of the space elevator has long been thought of as impossible, a concept to be confined to the realm of science fiction. Having a giant elevator, many miles in length, reaching up through the clouds and to the stars was just too much to hope for. However, that distant idea is becoming a reality as scientists and engineers around the world are contemplating this extraordinary concept.

The original concept of a space elevator came from a Russian scientist by the name of Konstantin Tsiolkovosky around 1903[2]. In an article he published, Tsiolkovosky proposed the idea of an enormous tower that would reach all the way to GSO (Geo-Stationary Orbit), or the point in space where an object would rotate at the same speed as the Earth, causing it to remain over the same point on the Earth.

Ever since Tsiolkovosky first envisioned the idea, the concept of a space elevator has developed and matured[3,4]. The first step in building a space elevator is sending up the first cable. A small satellite would be sent into space aboard a rocket, containing the cable and a means to position itself over the exact location where the elevator is to be built. Once in position, the satellite would then deploy the cable, steadily running its length down. The cable would then be secured at the base station, and a small robot, called a climber would be sent up the cable. As the climber ascends the cable, it would add another cable onto the first, epoxying it into place. When the climber reaches the top of the cable, it would add to the counter weight on the end of the

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2 Price, Steve. "Audacious & Outrageous: Space Elevators." NASA Science Science News (7 Sept. 2000): n. pag. - NASA Science. Web. 19 Oct. 2012. <http://science.nasa.gov/science-news/science-at-nasa/2000/ast07sep_1/>

3 Edwards BC, Westling EA. The Space Elevator: A Revolutionary Earth-to-Space Transportation System. San Francisco, USA: Spageo Inc.; 2002. ISBN 0-9726045-0-2

4 Bonsor, Kevin. "How Space Elevators Will Work." Web log post. HowStuffWorks. N.p., n.d. Web. 19 Oct. 2012. <http://science.howstuffworks.com/space-elevator.htm>

elevator, further strengthening the structure. Subsequent climbers would be sent up the increasingly large cable, each adding its own cable. Climbers would increase in size, with the size of cable added increasing as well. Eventually, the cable would be strong enough to hold the weight of the elevator itself.

Unfortunately, the largest obstacle is creating a cable strong enough to meet the needs of the elevator, since all conventional materials have proven to be insufficiently strong. Not only does it need to support the weight of the climbers, the cable needs to be able to support itself. With the cable needing to reach beyond 62,000 mi[5], which is above GSO, the cable would have to taper outward, increasing in size at certain intervals in order for it to hold its own weight, increasing to an immense, impractical width by GSO.

But with the recent discovery of carbon nanotubes, a viable new material for the cable may be within reach[4]. Carbon nanotubes follow a similar molecular structure to diamonds, only in the form of a tube. Initial measurements of the strength of these tubes have cautiously been placed at 200 Giga-Pascals, an immense sum. This is comparable to a length of nanotubes equal in size to a sewing thread lifting a large car. With estimates of the strength required for the space elevator cable set at around 62 Giga-Pascals, carbon nanotubes are a candidate material. Currently, the longest nanotube created is only about a foot in length, nowhere near the 62,000 miles needed. It may be impossible to grow a nanotube cable that long, but it is possible to use nanotubes in a composite material, connecting individual tubes together with another substance. Other nanotube material technologies such as boron nitride also have potential since they may be easier to grow in long strands.

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[5] Hollingham, Richard. "Space Elevators: Going Up?" *BBC Future* (20 Aug. 2012): n. pag. Web. <http://www.bbc.com/future/story/20120817-space-elevators-going-up>

Another major problem is environmental conditions. The weather is constantly changing so a space elevator could be struck by lightning, hit by a hurricane, collide with a low orbiting satellite, or struck by a meteor. If the foundation of the tower was placed along the equator, hurricane and lightning hazards could be avoided. This is because weather conditions along the equator are far milder than on any other part of the globe. With reduced storms and practically no hurricanes, it's a prime place to construct the space elevator. GSO along the equator is also a shorter distance away from the earth, shortening the distance of cable required. By placing the space elevator foundation onto an off shore platform, similar to those used for oil drilling along the sea bed, the tower could be moved. With advanced warning, operators could move the elevator out of the way of meteors or orbiting objects, as well as the occasional storm, to a safer location out of harm's way.

Based on the new advances in cable and climber technology, a space elevator may be closer to construction than originally expected. Each of the problems a space elevator would have to survive have been planned for and evaluated, and fail safes have been added to the design, confirming the survivability of the space elevator and increasing its longevity. Space elevators still present a large initial investment, estimated at approximately six billion dollars, less than the International Space Station but still a significant investment. This includes all parts of production, from cable manufacturing, ribbon deployment, and climber fabrication based on near-term cost and technology assumptions. This would reduce the cost of getting to space to under $1 per pound, as opposed to the current cost of $10,000 per pound[6]. With the cost so low, the private sector could begin sending up satellites. This would promote private space

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[6] Shelef, Ben. "Elevator:2010." Web log post. *The Spaceward Foundation*. N.p., n.d. Web. 19 Oct. 2012. <http://www.spaceward.org/elevator>

exploration and research. There would also be tourist opportunities, as the cost of space travel drops to that of a first class plane ticket. School classes could hold bake sales to send school projects into space, or even the entire class.

Technological advances provide another benefit to space elevators. Because of the increased work in fields such as nanotechnology, materials created could be used in many other areas of industry, such as transportation and architecture. These advances would further many other areas of science, opening the door to new concepts that were previously unobtainable.

In Colorado, several companies such as Lockheed Martin, United Launch Alliance, and the Aerospace Corporation are working on technologies applicable to space elevators. Research is ongoing in Colorado, as DARPA recently awarded a grant to CU Boulder for work on nanotube technology[7]. Several other companies have also supported research on space elevators, or are conducting their own studies. The research primarily focuses on nanotechnology, an essential part of the nanotubes that would be the basis for space elevator construction.

In conclusion, the space elevator is an innovative idea that would drastically reduce the cost of putting payloads into space. The price would decrease so much that the average person could take a trip to space. This low price would allow greater access to space travel, and could jump start colonization of the solar system. The space elevator could have other benefits, such as variations of materials created for it being used in other products. Current materials are not at a level to begin production, but things are speeding up, and a carbon nanotube cable long enough for the elevator could be ready in the next few decades. The space elevator has long been a

dream of science fiction enthusiasts and engineers everywhere, and that dream may finally be becoming a reality.

6 Appendix

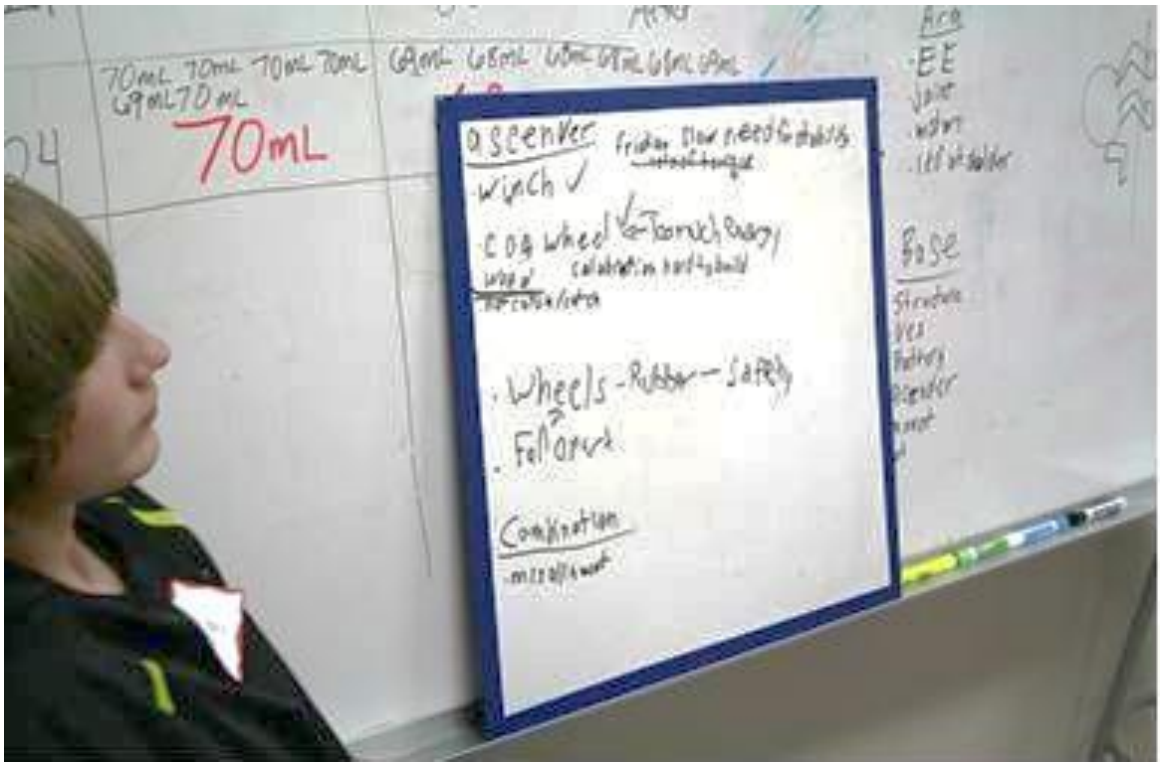

Figure 10: Ascension Method Brainstorming

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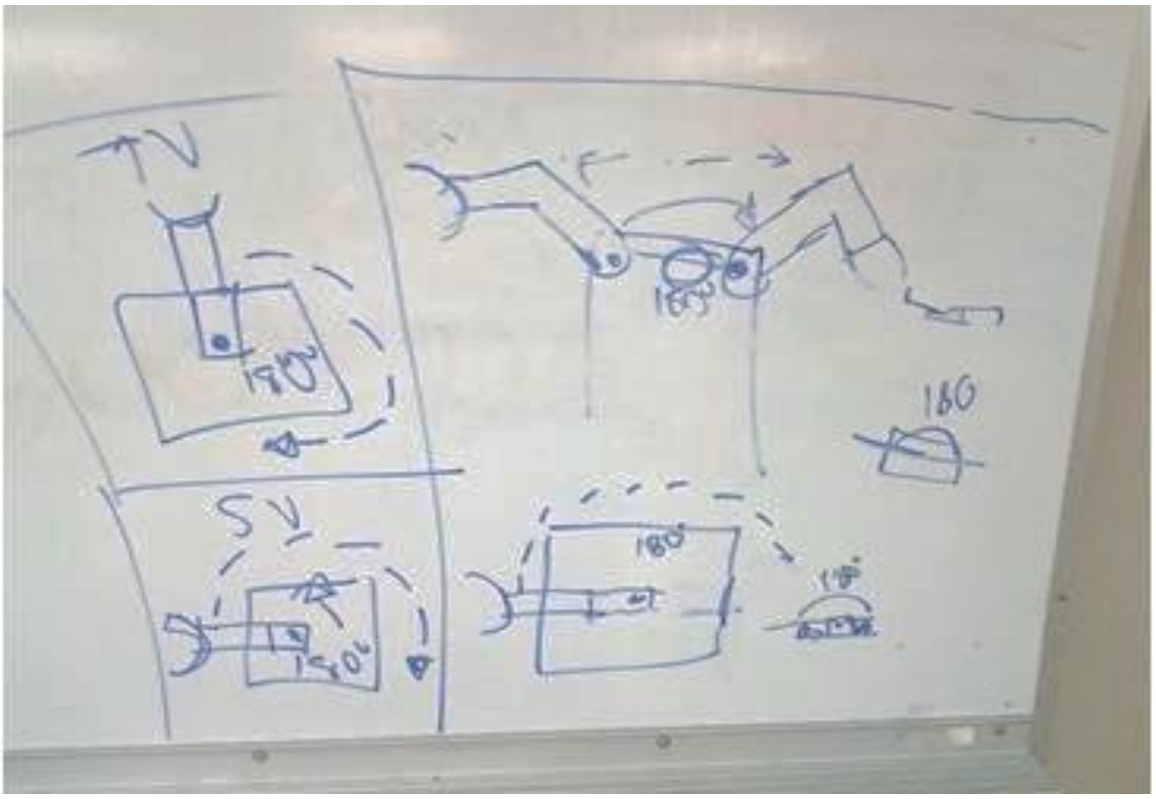

Figure 11: Arm to base attachment diagram.

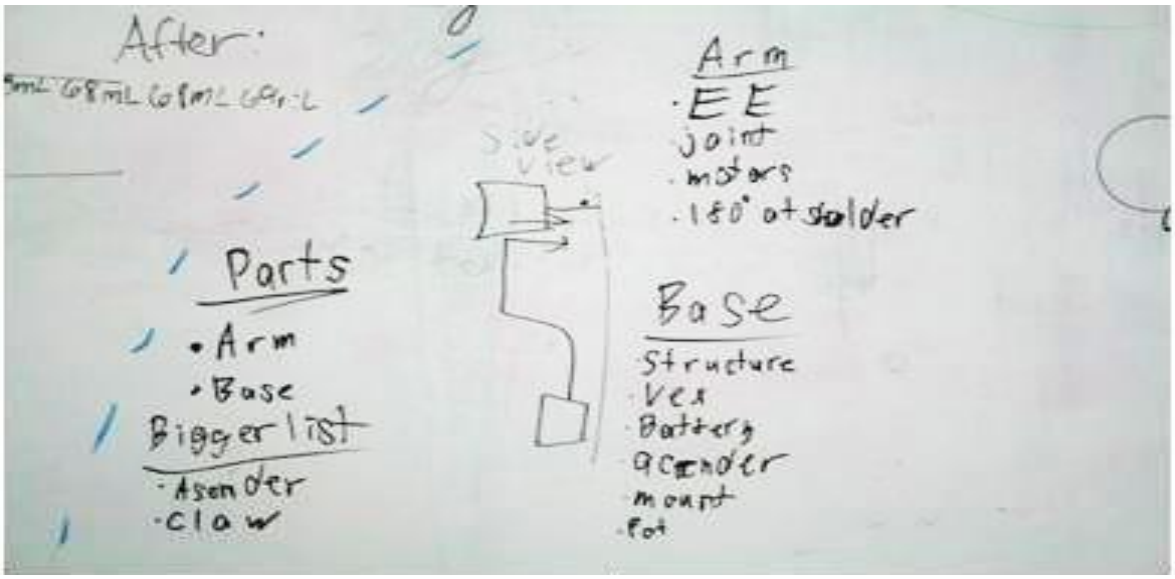

Figure 12: Basic robot parts

Figure 13: Cutting PVC for our first arm design using push block.

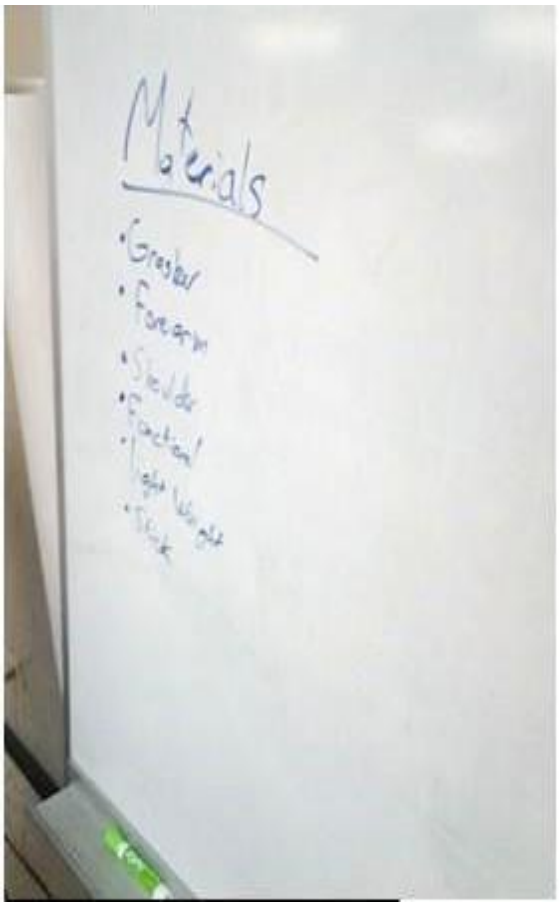

Figure 14: Basic materials list.

Figure 15: Preliminary Claw design

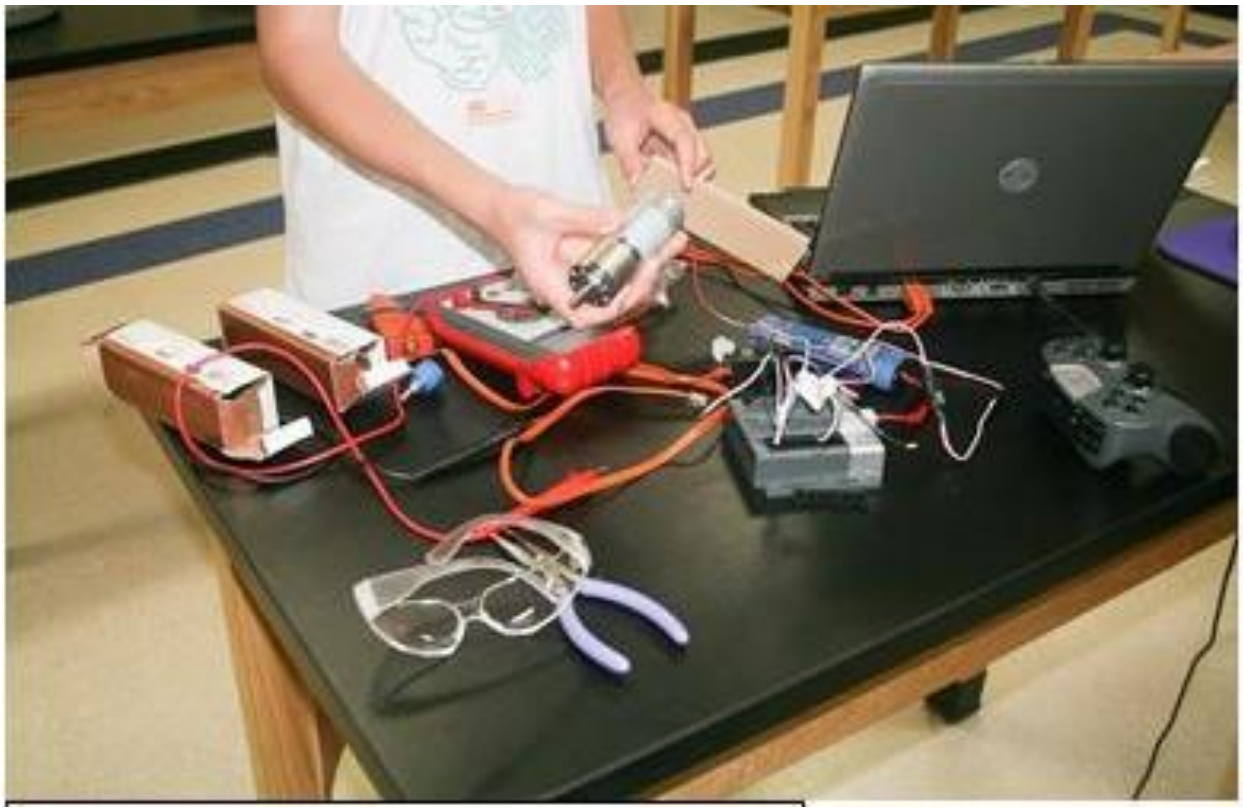

Figure 16: Testing the Motors

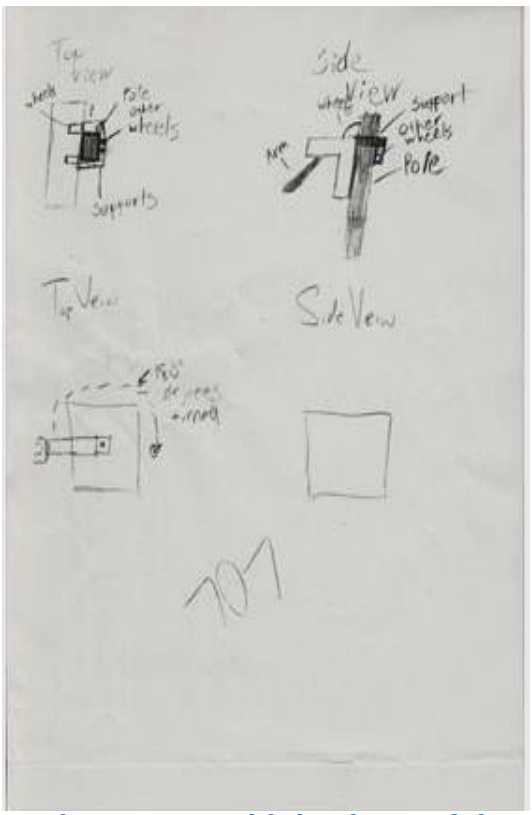

Figure 17: Multiple views of the robot.

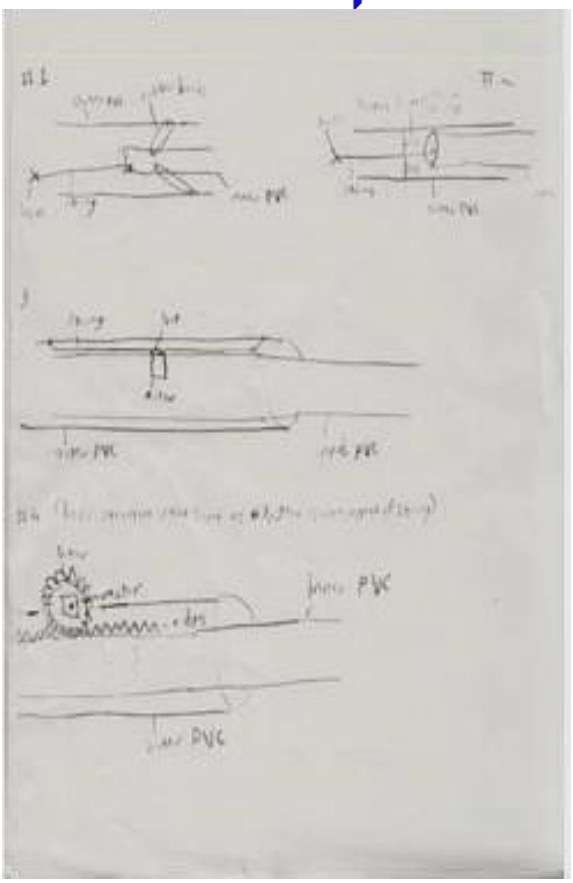

Figure 18: Preliminary elbow design with motor attached.

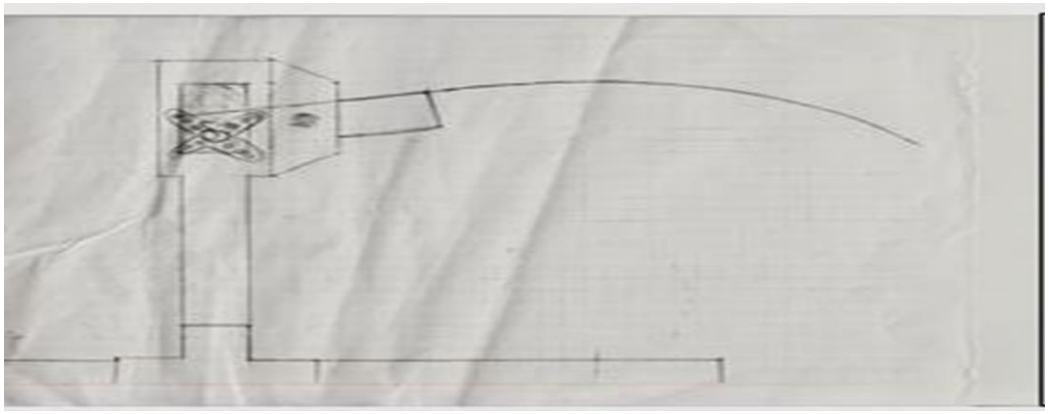

Figure 19: Rotating claw pivot design.

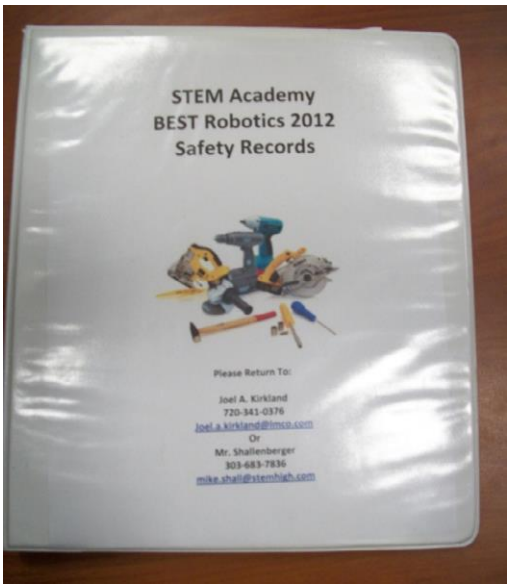

Figure 20: Safety notebook, containing all our safety records.

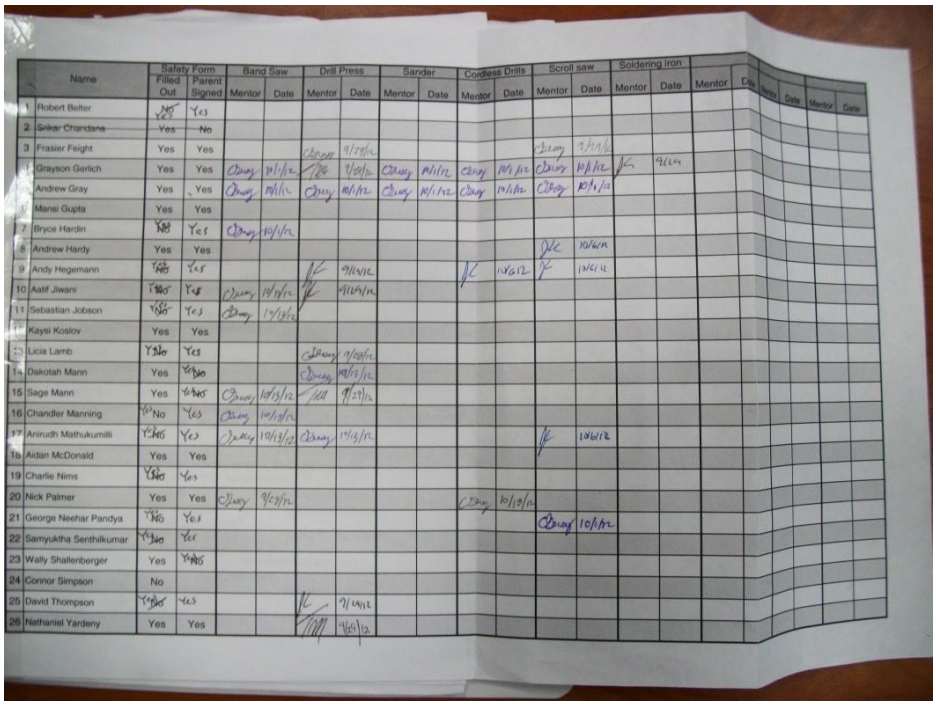

Figure 21: Safety notebook matrix, student vs tool training

Figure 22: Game Piece Strategy Priorities

STEM Academy 2012 BEST Robotics Calendar - Updated Oct 14th

Sun	Mon	Tue	Wed	Thurs	Fri	Sat
Sep 2	3	4	5	6	7 Meeting 6PM - 8PM	8
9	10 Meeting 6PM - 8PM	11	12	13	14 Meeting 6PM - 8:30PM	15 Kickoff Noon-4PM
Sep 16	17 Meeting 6PM - 8PM	18	19	20	21 Meeting 6PM - 8:30PM	22
Sep 23	24 Meeting 6PM - 8PM	25	26	27	28 Meeting 6PM - 8:30PM	29 Workday 9AM-4PM
30	Oct 1 Meeting 6PM - 8PM	2	3	4	5 Meeting 6PM - 8:30PM	6
7	8 Meeting 6PM - 8PM	9	10	11	12 Meeting 6PM - 8:30PM	13 Workday 9AM-4PM Bar mitzvah
14 STEM Fall Break	15 Meeting 6PM - 8PM	16	17 Notebook Meeting 6PM-8:30PM	18	19 Work Day 9AM-8PM	20 Practice Day 9AM-3PM
21 Pres. Meeting 1-3PM Highlands Ranch Library	22 Meeting 6PM - 8PM	23	24	25	26 Meeting 6PM-8:30PM Mrktng Pres 2PM	27 Game Day 7AM-5:30PM

Figure 23: Our calendar of the meetings.

Date	Agenda
21-Sep-12	Robot Finish Understanding the Problem and Requirements Continue Brainstorming and Concept Development (explore possible design space) Consider down selection criteria Kit Inventory Document activities and assign Action Items BEST Award Finish Understanding the Problem - Review Score sheets/kickoff material Continue Brainstorming (generating lists of ideas) Document activities and assign Action Items Marketing Continue Brainstorming (generating lists of ideas) Begin to consider down selection criteria Start to mentor needs for marketing area Document activities and assign Action Items
6-Oct-12	Robot Game Field Completion Electronics Team Layout - Running on a table (breadboard) Claw prototype done (at least 1/2 grabber) Ascension - working mounted to base Shoulder motor mounting & operation BEST Award Presentation Presentation time: 10:30 Primary 11:00 AM Secondary Exhibit Frame Design/Prototype Spirit & Sportsmanship Trace out last poster Poster Glitter T-shirt Designs Decided Notebook Note files we need Appendix start Marketing Flyer
8-Oct-12	Robot Defensive Strategy (see George) Remake spool Shoulder joint integration test

	Finish grabber prototype BEST Award Notebook Robert programming and math input doc George take over strategy doc Appendix/Reference Research paper Exhibit Final materials list BOM (bill of materials) Marketing Letter to DJ
12-Oct-12	Robot PE Team - Make initial SW build (Hopefully) Attach new winch Work on claw Complete shoulder joint BEST Award Notebook Edit programming document Write and edit outreach and marketing document Write preliminary design document Start research paper Start assembling appendix Continue adding references to the appendix wherever appropriate and possible Exhibit FINALIZE materials list Buy materials If we have materials, start building
15-Oct-12	Robot Get the grabber working Test picking up bottles Get the extension joint working Test length of reach Finish the shoulder joint BEST Award Notebook Finalize appendix Finalize design document Put together meeting minutes Exhibit Continue building the exhibit structure

	Begin assembling decorations Continue working on posters Continue working on the power point presentation Marketing Goddard Pre-School Activity Ben Franklin Presentation

Figure 24: Meeting Notes

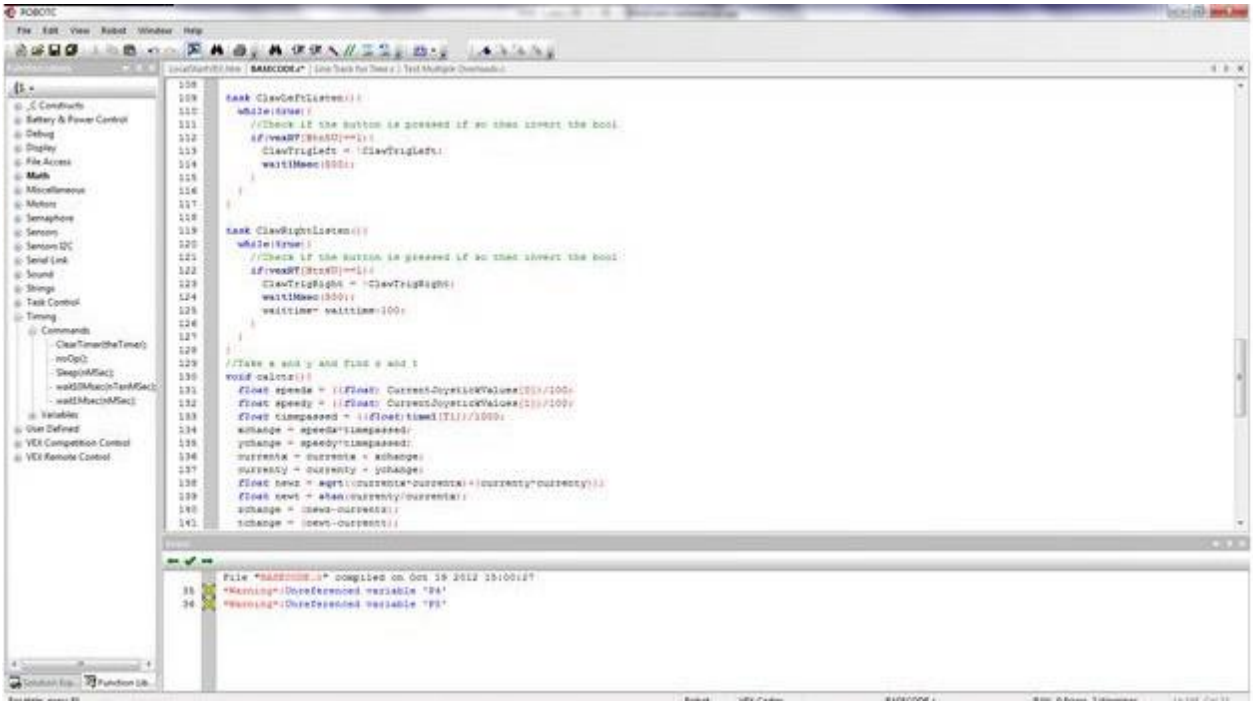

Figure 25: An example of the coding that was used on the robot.

Figure 26: An example of a STEMosphere team member practicing proper safety practices. He is using safety glasses and following our other rules when it comes to using the Drill Press.

Total Interest	Total Primary	Total Secondary	Name	Lead
2	0	1	Program Manager/Team Captain	
8	3	4	Finance	
3	1	2	Planner	
1	1	0	Brainstormer	
7	2	4	Robot Lead	
9	3	5	Strategy Lead	
8	2	5	Requirements	
11	4	6	Drivers	
8	2	5	Game Field Lead	
7	0	6	Robot Kit Inventory	
11	7	3	Prog/Elec Designer and Builder	
12	10	2	Mech Designer and Builder	
5	2	3	CAD Drafter	
9	3	5	BEST Award Lead	
6	0	4	Notebook Lead	
7	3	4	Notebook Research Paper	
5	2	3	Notebook Writer	
8	2	6	Notebook Editor	
4	1	2	Presentation Lead	
9	5	4	Presentor	
6	2	3	Exhibit Lead	
12	5	7	Exhibit Designer	
7	4	2	Spirit Lead	
5	2	3	T-shirt Designer	
4	0	4	Spirit Item Designer	
5	3	1	Marketing Lead	
5	2	3	Community outreach	
5	3	2	Fund Raising	
8	0	7	Website	
4	3	1	Photographer and Videographer	

Primary S Support

Figure 27: Leaders are shown under the Lead Column, and were chosen based on their skill set. Teams that do not have a designated Lead have responsibility shared by the members of that team. Dark blue squares with a P on the chart indicate a primary role, and light blue squares with an S on the chart indicate a secondary role.

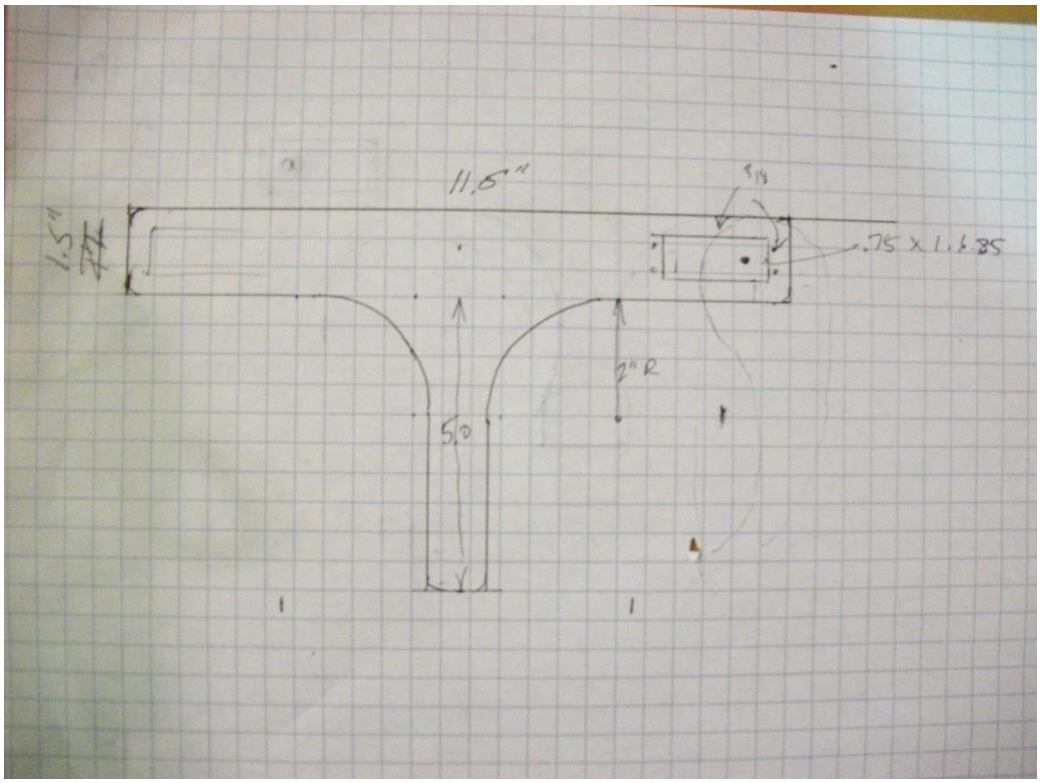

Figure28: Regional Claw Structure Drawing

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