Wonder Factory Team

Background Report

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EXECUTIVE SUMMARY

The following document covers the Wonder Factory Capstone team work throughout and entire academic year. The team starts at providing initial research and information of their clients and a background of what the Wonder Factory is and what their goal is. The team then beings its initial stage of research of other interactive science centers and what makes them appealing and successful to its audience. The capstone team then begins to research and list specific projects and concepts at selected science centers and moves into the concept generation portion of the project. The team begins to provide 100 ideas of possible devices that can be used for the Wonder Factory and the team begins to narrow down the ideas by voting and debating the top device. The criteria of the voting is stated and chosen idea is then described and studied in order to provide dimensions. The team begins to establish engineering requirements and correlate that with the client's needs and vision with allows the team to get dimensions as well as testing procedures to help in accuracy and construction of the device. Research is then provided for the mechanical portions as well as electrical portion of the device. The ideas are implement and the project moves to the second half of the semester to being construction of the device. The team list the challenges faces as well as the manufacturing process which is then followed up by design changes to devices based upon multiple listed criteria and situations. The team then test the devices and provides feedback for the overall project.

ACKNOWLEDGEMENTS

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1 BACKGROUND

1.1 Introduction

The team's project is to design and build a display for Wonder Factory. The Wonder Factory is a non-profit organization whose goal is to create a more interactive science center for children in Flagstaff Arizona. The purpose of this project is to build a safe interactive display and prototype for children and adults. The prototype needs to be able to cover Science, technology, engineering, art, and math (STEAM) concepts in order to generate learning through playing with the prototype. The prototype must be mobile so the Wonder Factory may take it with them to science displays while they look for a permanent location. This document will contain information regarding the team's work and research towards an interactive display and prototype.

1.2 Project Description

The Wonder Factory is a science, engineering, art, and technology center in Flagstaff, AZ providing hands-on, interactive experiences for the young and young at heart. It was founded by Jackee and Steve Alston as a movement of concerned citizens working towards getting a STEM/STEAM-based play center in Flagstaff. The Wonder Factory's goal is to lead the next generation of young minds into their place as the thinkers, the makers, and the creators of the future through hands-on interactions with science, technology, engineering, art, and mathematics.

The team's task is to generate lots of interactive display ideas and to ultimately design build and test one final display ready for public consumption. The final design must:

- Must be safe to all users per applicable safety standards. Safety is the first priority.
- Must be ready upon completion of this capstone sequence
- Should generate up to 100 ideas –including existing, new, wacky, and off the wall concepts
- Must select, design, build, and test one final unique idea
- Should test the interactive display in a similar setting to expected everyday use
- Must raise some of the funds required to finish the project
- Must interact with the clients in order to maintain parity with their expectations

With the criteria listed above the team will share the goal of the Wonder Factory of generating learning through play. The team will also donate the final product as well as develop their own goal for the project.

1.3 The Wonder Factory

The Wonder Factory was studied through meetings with Mr. and Mrs. Alston who are the current founders. Their reasoning behind starting this project was inspired three years ago while on a trip to Utah with their children. They noticed multiple science centers that children could go to and wondered why there were so few options in Flagstaff for their children. This lead to the Alston's creating a survey that was disturbed through Facebook to find out what the Flagstaff locals thought about the science centers offered in Flagstaff Arizona. They also wanted to know if the locals noticed gaps of knowledge and interactions within the current science centers. After noticing that the majority of the survey takers the same thing the Alston's began to work on creating the Wonder Factory

The Wonder Factory is in its beginning stages where they are still fundraising and advertising to receive a more permanent location. Through their estimated research, they have concluded they need at least $615,000 dollars to secure a permanent location. As of right now, they are currently working with Northern Arizona University to promote their goal as well as provide senior capstone projects for engineering students at Northern Arizona University.

Due to not having an permanent location the Alston's have a mobile unit where they are able to go to different science night and festivals to demonstrate and promote their organization. They plan to attend monthly events as often as they can and coordinate with Northern Arizona University (NAU) capstone teams to attend. This allows the capstone teams to get 'firsthand' experience in seeing how their targeted audience interacts with their project. This is a successful means of operations due to having access to multiple students to promote their goal and help in their set-ups during science nights. The big challenge the Wonder Factory faces is the need for a permanent location. In order to do this they need more funding, which means that capstone teams must create a mobile device.

2 REQUIREMENTS

This section will cover the requirements imposed on our team by the client. In order to begin designing the team needs to create engineering requirements that also fulfill the customer requirements. Failure to do so will lead to an inadequate design that will not be satisfactory to the client. This sections also includes the House of Quality that was created to organize and list all the important criteria for the design in order ensure quality of the design.

2.1 Customer Requirements (CRs)

This section will cover the Customer requirements that was given by the client. Due to the open-ended nature of our project, the requirements were left general to promote creativity. Table 1 shows the customer requirements that are ranked in order.

Table 1: Complete List of Customer Requirements

Customer Requirements	Weighting
Safety	5
Wow Factor	5
Hands-on	5
Integration of STEAM concepts	4
Simple Instruction	4
Durability	4
Visually Appealing	3
Narratives	3
Easy Assembly	2
Multiple Visitor	2
Mobility	1

As in all projects, it is important to make sure the device is safe so no harm comes to the user. If a project injures the audience, it could permanently ruin the reputation of the Wonder Factory and potentially set back the progress the Alston's have made. The next customer requirement is the WOW factor, which is the unexpected result that causes surprise and amazement of the targeted audience. The device must capture the audience's attention and keep for at least one minute when the audience interacts with the device. The device must also be hands on to promote learning through play. In addition, the device must be simple enough to hold the attention of a child otherwise; the child will lose interest and move on to another device or become frustrated and break the device. When children lose interest, at times they try to force a solution, which leads to the next criteria of the device needing to be durable. Children tend to play rough and the device must be able to withstand the play of a child. Further, the device must be visually appealing and have great narratives to give the device the "cool" factor for children.

Finally, the device must be completed and easy for the Wonder Factory to work with even after we graduate. By creating multiple prototypes, multiple children may play with the devices as well as being devices the Wonder Factory can use in case one breaks. On that same note, the device must be mobile for now so the Alstons can take it with them on their mobile unit.

2.2 Engineering Requirements (ERs)

The Wonder Factory team created Engineering Requirements (ERs) in order to measure the Customer Requirements. Table 2 gives a list of the ERs, target values, and rationale of why requirement was chosen.

Table 2: Engineering Requirements

Engineering Requirements	Target	Rationale
Total Weight	50 lbs	Light weight ensure easy to carry and assemble
Laser Frequency	650 nanometers	A longer wavelength laser has a lower energy and should translate to a lower power density for the same amount of illumination
Cost of Production	$800	Little cost ensures multiple devices can be assembled
Expected Life Span	2 years	Longer life span reduces cost of repair and assembly
Dimensions	3 ft^3	Device must be able to fit on display table
Amount of Illumination in Device	60 lux	Illumination must be achieved or lasers will not be visible to audience
Cost of Repair	$40	Low cost of repair helps overall budget
Number of Steps for Completion	3	Fewer steps helps broaden the age use of device
Degrees of Freedom of Rotatable Mirror	2	Limited degrees of freedom decreases possibility of laser hitting audience's eyes
Surprised Facial Expression from Audience	N/A	Measurements must be done to see if the audience enjoys the device
Noise loudness upon completion of devise	80 decibel	Noise helps with the WOW factor of the device
Number of Devices	1	More devices increases audience interaction
Time for set up	8 minutes	Ease of set up makes it more practical for client
Solvability	45 seconds	Device must not be too hard to solve otherwise audience members will move on
Max Compressive Stress on device casing	500 Newtons	The case must withstand at least 100 lbs to handle forces by the audience
Amount of time spent on device	2 minutes	Longer time spent on the device proves the audience interest in device
Number of times laser changes trajectory	10	More reflective surfaces allows more shapes to be created for aesthetic appeal

2.3 Testing Procedures (TPs)

In order to verify the overall design meets the Engineering Requirements testing procedures needed to be created. Table 2 gives the target values of the team and the following info below are the testing procedures.

2.3.1 A bathroom scale will measure the weight of the device. The measurement will be taken by first weighing a member of the team, and then weighing the same member with the device in hand. The difference of the two measurements will provide the final weight of the device.

2.3.2 When purchasing the lasers either online, or from a store the team will check the listed laser wavelength to make sure it fits within tolerance of 500 to 700 nanometers.

2.3.3 A bill of materials will be generated in order to compare cost with invoices received to ensure the team does not go over budget.

2.3.4 Team will determine the life span of parts that are most likely to fail by testing the device. The laser will be turned on and the hand crack will be turned multiple times in order to calculate expected life span of device.

2.3.5 The Wonder Factory team will measure the device with measuring tape in order to make sure device fits within dimensions targeted.

2.3.6 The team will place a message at the bottom of device with size eight font according to Microsoft Word and will see if the team can read it once lasers are activated in a dark room.

2.3.7 To track degrees of freedom as well as rotation the team will take several photos and measure angles with a protractor to ensure devices has only one degree of freedom that does not vary in the z-axis

2.3.8 To track the WOW factor the team will take notes as well as videos of the audience interactions with the device to measure how often they smiled and had a surprised expression on their faces.

2.3.9 To make sure the noise level is appropriate for the audience the Wonder Factory team will record videos from certain distances to see how far away the device can be heard. This method indirectly measures the amount of decibels heard while depending on distance from the device.

2.3.10 To track the time parameters the team will time with a stopwatch of how long it takes to set up the device for ease of use. In addition, they will measure how long it takes the audience to solve the device and how long they interact with it.

2.3.11 To ensure the durability of the device one team member will stand on the display case to ensure device can handle the compressive forces as well as perform analysis based on teammate’s weight.

2.3.12 To track the number of times the mirror changes its trajectory the team will count the number of mirror and surfaces that will cause this change in the laser’s path.

2.4 Design Links (DLs)

A description of the ERs and how they correlate with the CRs is listed below:

1. The weight of the device plays a huge role of how safe the device will be as well as how the audience should interact with it. If the device is light and is easy to move there is a risk of the child pushing the device of the table it is set upon. This may cause damage to the device and injure the audience. If too heavy, the client will have difficulty maneuvering the device to multiple locations. The device is targeted to be forty pounds to ensure safety as well as maintain easy mobility.
2. The wavelength of the laser is critical to the safety of the audience, which is the most important customer requirement. In order to aid the safety factor the team chose a laser within the safer side of the light spectrum between five hundred to seven hundred nanometers.
3. The cost of the entire device factors in almost every customer requirement. Buying sturdier equipment may cost more but will ensure that the device is safer as well as more durable. A bill of

materials is created to keep track of projected cost of building the device as well as cost of repair. An invoice will also ensure that the team does not go over budget while buying better equipment to improve the device.

4. Expected life span factors in the durability of the device as well as the overall cost. The device casing, chain, mirrors, and hand crank are all design to have large life spans. The laser does have to be run on battery power, which will be factored in. The device should have a large lifespan under normal conditions however the team will be examining abnormal conditions to study weak points of the casing that may break due to dropping the device or a child climbing on it.
5. The team notice that at a science event that the Wonder Factory attended and participated in the Wonder Factory was limited to a small space. Also only had access to three tables. To ensure ease of mobility the casing dimensions are small enough to fit on a standard table of 36 inches by 48 inches.
6. The lasers need to be seen within the casing otherwise, the device does not complete its objective. Illumination needs to be achieved and the brighter the laser the greater the WOW factor which will guarantee learning through play.
7. The laser within the casing will be fixed, however there are at least two mirrors that will be rotating. With rotating mirrors there is a risk of the lasers reflecting back to the audience which is a large safety issue. The device must ensure that the rotation of the mirrors only changes in one plane of axis and does not vary at all in the z axis. By placing the mirrors on rotating shafts that are firmly placed in the casing will ensure that the mirrors never tilt in any other planes of freedom.
8. The team must fulfill the WOW factor requirement given by the client. The lasers trajectory change is meant to fulfill this by having the laser form different images as the hand crank is turned to have the laser hit multiple different mirrors. To measure excitement the team will view the facial expressions of the audience. By taking notes, photos, and video of audience interactions the team can count the amount of smiles and enthusiastic expressions to track if the device is fulfilling the WOW factor.
9. Sound plays a big part in how the audience interacts with a device and in how it keeps their attention. To add more excitement to the device the team will add speakers that will be triggered once the audience completes the device by hitting a target with the laser. This adds to the WOW factor especially if popular music is played.
10. Upon meeting with the client, Mr. Alston mentioned that he wanted a device that was capable of being used by more than just one individual. Meaning he wanted to make sure more than just one or two kids could interact with the device. The team decided that by creating multiple devices the team could achieve the same result.
11. Setting up the device depends on the dimensions of the device and on how mobile it is. In order to ensure the device has acceptable dimensions and is not too heavy the team will time how long it will take for one or two people to set up the device.
12. To maintain multiple CRs the device must not be too difficult to solve. The WOW factor will be lost if the audience cannot figure out how to solve the device or if it takes too long to solve. The targeted audience is children and if the device does not hold their attention or peak their curiosity they will not take an interest in the STEAM concepts that are occurring within the device. Therefore the team designed the device to have three steps which are turning on the laser, turning the hand crank to hit any mirror to view images, and lastly move mirrors in order to hit a certain target to trigger completion music. The targeted solvability is within two minutes.
13. The device does need to be durable otherwise safety becomes an issue for the audience. The team

will perform the necessary calculations to ensure the device does not break and will test this by having one teammate standing on the device to ensure the device has the ability to handle at least 500 newton force.

14. To track if the device is visually appealing and is holding the audience's attention the team needs to track time spent with device. If the audience does not spend enough time with the device the team will know that they must redesign the device to meet the customer requirements.
15. A big factor in the device is to ensure that the material can create multiple images with the laser and mirrors. In order to achieve more complex and visually appealing images more mirrors must be used.

2.5 House of Quality (HoQ)

A house of quality (HoQ) is a tool that correlates the relationship between customer and engineering requirements. Most of the time there is a disconnect between what the customer asks and what the engineers are designing. A simple example would be designing the casing of the device. The customer may ask for the casing to be tough and light weight. Generally, those two do not go together so it is up to the engineers to come up with quantifiable measurements to make the customer requirements are fulfilled. Next, the engineering requirements, and customer requirements are weighted together, and a list of importance is created based on the weighted criteria. Table 3 shows a small portion of actual House of Quality. See Appendix A for a view of the entire House of Quality.

Table 3: Modified HoQ

Customer Requirement	**Weight**	**Engineering Requirement**	Total Weight	Laser Frequency	Cost of Production	Expected Life Span	Dimensions
1. Saftey	5	-	3	5	5		1
2. WOW Factor	5	-			4		
3. Hands-On	5	-	3	2	3		2
4. Integration of STEAM concepts	4	-		4			
5. Simple Instructions	4	-					
6. Durability	4	-	1		4	4	
7. Visually appealing	3	-	3	3	4		4
8. Narratives	3	-					
9. Easy Assembly	2	-	2		3		2
10. Multiple Visitor	2	-			1		2
11. Mobility	1	-	5		3		5
Absolute Technical Importance (ATI)			52	60	99	16	40
Relative Technical Importance (RTI)			6	4	1	15	12
Target(s)			40	650	300	2	3
Tolerance(s)			< 50	500< X < 700	X < 400	1 < X < 3	X < 5
Units			Lbs	Nanometers	Dollars	Years	ft cubed
Testing Procedure (TP#)			2.3.1	2.3.2	2.3.3	2.3.4	2.3.5
Design Link (DL#)			1	2	3	4	5

3 EXISTING DESIGNS

Before beginning the concept generation process, the team needed to meet with the client, Jackee Alston, as well as conduct personal research of existing systems and designs. Hundreds of science centers around the world have the same dream as the Wonder Factory of making science fun for children, in order to promote more learning of STEAM concepts. Therefore, the team searched and analyzed how these systems were structured and how they stood out from the rest. A few of these science centers include Ottobock, the Rochester Museum & Science Center (RMSC), March Airfield Museum, the Museum of Science Industry, and the Kuwait scientific Center.

3.1 Design Research

The Wonder Factory team needed to performed individual research based on multiple methods in order to benchmark existing systems and designs that fit the customer's needs. One method of research was the team networked with Professor Wade and, Jackee Alston, in order to begin brainstorming and narrowing down research on existing systems and designs. Other individuals in the networking process included other Wonder Factory capstone teams who had performed pervious research on science centers. Once a focal point was established, the team began online research but also made sure to view the authenticity of site, system, and design. Pictures of the exhibits were studied as well as portable document formats (pdfs) from the science centers were studied to gain a further understanding of subsystems displays and the concept variant being portrayed in the subsystem. To avoid hindering creativity within the research there were few boundaries or requirements that were establish but there was an emphasis of incorporating electrical concepts. The reasoning behind this was to help cover gaps in the Wonder Factory displays to ensure more variety of concept variants.

3.2 System Level

After research was collected, the team gathered to discuss potential benchmarking designs from the existing systems and subsystems that are presented online. The following systems below are only the top four that stood out the most. A more detailed list can be found in further reports or in the appendix.

3.2.1 Ottobock Science Center

Discover What Moves Us is a permanent exhibition that is funded by the company Ottobock. The Company Ottobock was founded in Berlin Germany in 1919 as a prosthetics company to help patients from World War I who lost a limb. The company has now made big advancements in the medical field of prosthetics but is now promoting "inspiration and education about human mobility" [1].

Figure 1: Ottobock Building from the street view [2]

The Science Center has topics ranging from grasping, walking, bionics, and medical technology. They have an approximated 100,000 visitors per year and hold about 300 tours a year. There are 29 permanent exhibits on displayed and is usually run by 13 employees. This show the efficiency of running the tour and not needing many employees which is a good structure for a starting up company like the Wonder Factory [3].

Figure 2: Ottobock Facility [4]

According to the German media, the architecture from the outside has the appearance of a “muscle house” which “catches the eye of the observer” [2]. The building’s appearance has a sleek and advance look that that is visually appealing that brings a sense of calm to the audience. This is good for those who are looking for a calm, safe, clean environment to take their children or even themselves, which allows them to focus more intently on the message being provided. This is a unique way of displaying the system that could be benchmarked if chosen.

3.2.1.1 Existing Design #1: Virtual Adapting Floor

To help explain the kinematics and kinetics of the human body, the audience first plays a game with a virtual floor that gives the appearance of walking over a ravine. The floor continues to change making the audience member change footing in order not to fall into the virtual ravine. This provides a great attention grabber in order to segue into an explanation of the 600 muscles and 208 bones of the body and how they need to work together. [5]

3.2.1.2 Existing Design #2: Demographic Pillar

The demographic pillar is a station that starts by identifying most common problems humans experience in their life such as diabetes, arthritis, osteoporosis, etc. Then it relates the information back to and helps you look at how it statistically relate to you. The pillar than explains how these are the most common causes for needing a prosthesis or wheelchair which than promotes their business and helps segue into the next section of the company displays. [5]

3.2.1.3 Existing Design #3: Medical Product Stations

Ottobock has a large array of prosthetics that can be picked up and handled to show how they are used and useful if they are needed. One of the attractions is a well-crafted display of a prosthetic hand that moves and interacts based on the measurable electric muscle currents in your arm control a prosthesis. [5]

3.2.2 March Airfield

March Airfield Museum is located in Riverside California and was established in 1979 as a nonprofit organization. It displays one of the largest collections of military aircraft on the West Coast. The museum’s main function is educating people about the history of aviation with actual aircraft on display and presenting the exhibits in a chronological order starting from early aviation days. Whole aircraft are present in addition to some select rocket/jet/radial engines. [6]

Figure 3: March Field Museum Air View [7]

Approximately 130 volunteers and only a paid staff of 11 staff the organization. This would be a great benchmark for the Wonder Factory in getting engineering students to volunteer in exchange for experience. One of the reasons this system is successful and credible is this museum was once an official U.S Air Force museum and attracts military personal and those who enjoy planes.

3.2.2.1 Existing Design #1: Flight Simulator

Flight simulators do present an enjoyable experience for those of all ages. This is shown with the success of roller coaster in amusement parks. The audience takes experiences an illusion of flying but presents an enjoyable experience by feeling the forces act on them as they control the simulated aircraft.

3.2.2.2 Existing Design #2: Tours of existing Air Craft

March Mayfield and selected Air Force Bases do have displays of different aircraft throughout the ages. The way this is modeled is the air craft remains stationary while individuals are able to observe and even step into the cockpit to get a small feeling of what a pilot feels.

3.2.2.3 Existing Design #3: Paper Plane Workshop

Although not listed in the March Mayfield website the idea of paper plane workshops is an idea that was discussed. A proper benchmark and system that has this idea is still under review but by having, a customized launcher that will launch the paper airplanes while instructors give a lesson of why the paper airplanes go farther will physically display the children’s progress.

3.2.3 Manchester Science Museum

The Manchester Science Museum was established in 1969 but was not officially moved to permanent residence until 1983. The mission of this establishment is to “devoted to inspiring our visitors through ideas that change the world, from the Industrial Revolution to today and beyond.” [9]. The system has been developing since 1830 and have made great advancements in electricity. Though the center does not have a specific targeted audience, it still has attractions for children, which is the team’s targeted audience.

3.2.3.1 Existing Design #1: Models for Atomic Theory

The Museum of Science has models used by John Dalton to demonstrate his atomic theory. John’s studies helped formulate a new atomic theory to explain chemical reactions, which helped, lay the foundations of modern chemistry. This display holds such a significant amount of history that you can touch with your hands. The design may not be intended for kids however, if the Wonder Factory came across a prototype drone this could gain the audience’s attention more. [9]

3.2.3.2 Existing Design #2: Steam Mill Engines

This display is an actual ride that shows living history that is still functional. Unlike Stonehenge, this display actually moves while captivating as the science of steam engines is displayed with the history of the industrial revolution. [9]

3.2.3.3 Existing Design #3: Tour of first Commercial Computer

The Manchester Science Museum has the displays of the first commercially available computer. This show the history of the computer that started with the advancements in radar and code-breaking equipment. This display has close ties with a cinematic movie that could help the audience learn visually. The display focuses on the beginning stages of coding as well as electronics. Studying and implementing this will help children and adults understand that coding is not as complex as it may seem. [9]

4 DESIGNS CONSIDERED

Following the research the team gathered to discuss the research and analysis how to move forward. The team decided that in order to reach the targeted one hundred concept variants, each team member must generate twenty-five concept variants each. To team did individual brainstorming as well as group brainstorming such as the three-five-three method. Once the goal was reached, the team decided that it was impractical to create a Pugh chart for one hundred ideas that may have repeating ideas or concepts. Therefore, the team met and went over each idea and voted which ideas to keep. This eliminated sixty-seven ideas, which meant that a Pugh chart of thirty-three ideas would be possible. See Appendix C for Pugh chart.

Upon discussion with the instructor, it was decided that using another Wonder Factory capstone project for a datum was the best option to compare the reaming ideas on the Pugh chart. The capstone's project was analyzed at a science night that occurred on March 6th 2017. The team paid attention to the project according to the customer requirements list of importance as well as how the children interacted with the project. The voting of the Pugh chart was done individually to get everyone's perspective on a project and then the numerical results were then added together to find the highest rating ideas as well as repeating favorites.

Table 4: Numerical Results of Pugh Chart

Wonder Factory Team	Dyed Roses with color lights	Robotic Arm	Vaporization (smoke pellots and Vacum)	Tonic Water and Blacklight	Balloon Powered light	Water Tracks Hydoelectric Dam	Modeling Car	High Energy Laser balloon popping	Armor	Tesla Wire	Mirror Reflections	Wind Turbine
Team member #1	12	18	17	-1	-1	0	14	20	17	6	0	17
Team member #2	29	30	10	38	1	21	20	-16	-19	-4	25	33
Team member #3	6	14	7	-5	17	14	-7	13	3	4	10	8
Total	47	62	34	32	17	35	27	17	1	6	35	58

The team was able to reduce the remaining concept variants to eight, which was then taken to the client for further analysis of if the team was moving in the correct direction according to the vision and goal of the Wonder Factory. The client expressed interest in three ideas however; their main concern was how the team would make sure the project would be interactive with the audience. The advice was taken in consideration with the final three designs on how the top design would be selected. The following section reviews ten concepts generated by the team, which included the top ideas as well as favorites from individual teammates. The general weighting and explanation will be based on team member's opinions and not a consensus of the whole group with the exception of the top three ideas.

4.1 Design #1: Robotic Arm

The STEAM concept for this concept is robotics and electronics. The robotic arm is a design that is appropriate for the team due to the integration of computer coding and electrical components. This project would also be more challenging in order to help the team learn and grow. Having a robotic arm for display definitely hits the WOW factor that our client is looking for especially if we are able to have the targeted audience control it with sensors attached to their hands. The design would be more difficult to work with which is why we would have to start simple and build upon it. This is an expensive idea with working with metals and electronics, which would require the team to fundraise more in order to create a working prototype. If budget constrictions hinder the progress, the team can look into building a simple crane device that does not have to run on electricity. This concept may have the possibility to be incorporated into other ideas where you have to control the arm to activate another device but the cost is the biggest hindrance.

4.2 Design #2: Mirror Images with Lasers

The STEAM concept for this concept is geometry, light spectrum, and reflective surfaces. The mirror maze as well as laser tag inspired this idea. Kids usually enjoy laser tag as it gives them an opportunity to run around and simulate the feeling of shooting something. Laser tag was introduced however, the concept evolved into using several different mirrors to try to see another image that may be in another room or have a laser reflect off of multiple surfaces to hit a target. This idea does not hit the wow factor as hard as other ideas however; this idea is versatile and open ended to other ideas. By incorporating moving surfaces, the laser in a sense can create multiple images by hitting different sets of mirrors and focal points. This affordable option can be scaled up or down easily by incorporating the same angles and lengthens as long as they are scaled appropriately. This is a useful feature when the Wonder Factory receives their own base of operations in Flagstaff Arizona so they may even dedicate and entire room to this concept.

4.3 Design #3: Combat Armor

The STEAM concept would be about normal stresses and the relationship of distributing a force over a larger area. Soldiers and superheroes at times wear armor and having armor where a kid can see if be put on one of the team members and be able to hit it would be very interactive for kids. This allows the child to use a lot of energy to see the effects of normal stress being reduces by area in affect. This idea is particle but not as safe or family friendly. If there is in a sense a WOW factor of seeing someone get hit really hard or getting to hit someone really hard but this may not be the message the team wants to send to kids. This is a risk of parental complaints to the influence of violence. However if implemented correctly this concept would be a great idea.

4.4 Design #4: Gas Powered Grappling Hook

The majority of children in the U.S know who Batman is and know that he has a grappling hook. The idea behind this is propulsion and trajectory of a path however this idea is very dangerous. The idea of trying to shoot a sharp metal projectile at high speeds in order to stick to a surface is not child friendly at all. The idea of seeing it in action is great however with how expensive this is and how dangerous it will be to work with these types of materials not only cause risk to the audience but the team as well. If different ideas such as creating another launch devise or has a controlled area where the grappling hook is fired and then people could come in and interact would be ideal but the benefits are not high enough to out weight the risks.

4.5 Design #5: Electrical Generator

In this game, the children will have a small that has different kind of Electricity generators. The first kind is Electromagnetic and in this kind, the children will learn how we create electricity using magnetic. In second kind, they will learn how to create electricity using solar power and how it save money. However, this section has some disadvantages for example it will not be safe for children to use electricity also it hard for children to learn it so it might not attract them.

4.6 Design #6: Kidzania

This idea need a big place where children can learn many things. They will learn how to do first aid when they face emergency case. Some of them can work as a police officer or work in a restaurant also; they can work as a firefighter. Therefore, they can learn how to interact with each kind of job as people in older age. This idea is difficult to apply because we need a big place and huge budget.

4.7 Design #7: Chemicals

Children can learn chemistry in a fun way. They will be able to play with chemical and see how elements effect on each other and they will learn the benefits of Chemistry. This section will be useful for the children for their future for example it will give them a great background about chemistry for their study. However, it dangerous for children to play with chemical because they might use acids which might burn them.

4.8 Design #8: Wind Turbine Assembling Game

The wind turbine game, children must assemble a wind turbine and try to reach a specific voltage to turn up the light. This game includes blades, pole, generator and lights. First, the child will have a brief description about wind turbines and why we are using them today. Then they have a timed round to assemble the wind turbine. After assembling, they need to test the wind turbine-using fan to generate wind in order to move the blades and produce electricity. Lastly, the lights will light up when it has enough voltage through the lights. The pros of this game is to teach children more about renewable energy sources, having the ability to create electricity and try many voltages difference to light the bulbs. In addition, the cons of this game, it is not safety for children to use because they will be interacting with many electricity sources like unplug the wire and try to connect the wires which will lead to electrical shock. In addition, children may not be amazed about the result of the game and this will not meet our client requirement of wow factor.

4.9 Design #9: Exploded View of Engines

Having an engine unassembled and separated into individual parts. After taking the engine apart, we have each part hanged on a wall with a brief description of the part function in the engine. The child will read each description and try to build Lego parts to create an engine. The pros of the exploded view of engines is affordable to make, children can be amazed of how and engine of a car opened into part which will increase the wow factor. The cons of the game is that can be hard for the children to understand each part of the engine and it function in order to build an engine.

4.10 Design #10: Resistor and Generator

The resistor and generator game, first we have to build multiple stages, and each stage have a circuit. The circuit include a resistor, generator and a bulb. We know that each resistor have its own resistance which will delay current transportation through a wire. The idea of this game is to have multiple resistors with generators and bulb each stage have a deferent resistor. The child will move the generator crank to produce electricity to light up the bulb, but from the multiple stages, the child will feel how hard it is going to be to produce electricity for the bulb. The pros of the game are the child will learn more about renewable energy and circuit. The cons of the game is it contain many expensive parts like generators and resistor have a life time which will lead to maintain the game monthly or yearly. Children will also not be amazed about the result of the game, which will lead us not meeting our client requirement the wow factor.

5 DESIGN SELECTED – First Semester

Using the research, Pugh chart, and talks with the client, the team voted upon the lasers reflection off multiple mirror design. The next sections describe the reasoning behind selecting this device as well has how the team plans to construct it.

5.1 Rationale for Design Selection

As mentioned in section four, the team had narrowed down one-hundred ideas to the top three concept variants. The team than discussed each idea based on the customer requirements as well as the engineering requirements. The team met together to discuss the results of the Pugh charts due to the range of results. By only taking, the summed values of each Pugh chart of each teammate would not reflect the overall results due to the individual voting. A representation of the situation is seen in Table 5.

Table 5: Numerical Results Disagreements

Wonder Factory Team	Dyed Roses with color lights	Robotic Arm	Vaporization (smoke pellets and Vacuum)	Water Tracks Hydroelectric Dam	Modeling Car	Mirror Reflections	Wind Turbine
Team member #1	12	18	17	0	14	0	17
Team member #2	29	30	10	21	20	25	33
Team member #3	6	14	7	14	-7	10	8
Total	47	62	34	35	27	35	58

As you can see, the Dyed Roses concept variant scored a 47, which is much higher than the mirror reflection variant, which is the design that was selected. The reasoning that more voting needed to continue is based on how each teammate voted. Based on the Pugh charts of each teammate the total value did not give a consensus which lead to the analysis of repeated favorites of the team. After the repeated favorites were identified the team discussed with the client the top ten ideas. After meeting with the client, the team voted on the top three ideas and selected the mirror reflection variant.

The Wonder Factory team thought of two designs of how they wanted to construct their device. Both scored the same on absolute relative importance on the HoQ except in the Hands-On row and Solvability column. The first design concept was to use a mirror arrangement that could not change its orientation with the exception of the rotatable mirror.

The second design concept used the idea of movable mirror orientation using wooden pegs. The wooden pegs would fit in to holes cut into the base of the plywood so that the mirrors could be moved to any hole in the plywood. This would increase the audience interaction when comparing to the absolute relative importance to the first design. The team decided to build the latter option and if time permitted, the team may build a second device using the first design concept for inspiration.

5.2 Design Description

The team performed their own individual analysis in order to make sure multiple components of the device could be properly studied to ensure safety in key locations. The analysis is broken into sections such as the casing, chain, shaft, laser, and electronic components. This was also done in order to properly build a more efficient design for the audience.

5.2.1 Casing Design

The device will have a casing that contains the laser fixtures, shafts, and mirrors of the device. This casing should be strong enough to withstand the max force a child could reasonably exert such as standing on the device. The following analysis will determine whether the casing is structurally sound. In the event that the casing is not structurally sound, further work will be done to address it.

5.2.1.1 Casing Equations and Methods

The equations that will be used for this analysis are mostly stress equations to determine failure of the materials under an estimated load based off the weight of a 10-year-old child.

Table 6: Summary of Equations

	Formula Name	Equation	Expected Units	Variables
1	Fixed Beam Deflection	$\delta = \frac{W \cdot L^3}{192 \cdot E \cdot I}$	Meters (m)	δ, Deflection (m) W, Load (N) E, Modulus of Elasticity (Pa) I, 2nd Moment of Area (m^4)
2	Tensile Stress From Bending Moment	$\sigma = \frac{\tau \cdot y}{I}$	Pascals (Pa)	σ, Stress (Pa) τ, Bending Moment (Nm) y, distance to furthest edge (m) I, 2nd Moment of Area (m^4)
3	Stress On A Cross Section	$\tau, \sigma = \frac{F}{N \cdot A}$	Pascals (Pa)	σ, Stress (Pa) τ, Shear (Pa) F, Load (N) A, Area of Cross Section (m^2) N, Number of Members being analyzed

The Fixed Beam Deflection Equation is used to determine the amount that a support beam will bend and move at the place of maximum displacement. This is important because it will determine whether the support beam will remain rigid enough such that other materials in the empty area between beams will not be crushed when loaded.

The Tensile Stress from Bending Moment equation is used to determine the stress developed within support beams from a bending moment caused by loading. This equation will determine whether a support beam will fail under loading or not. The Stress on a Cross Section equation is used to determine axial stress under loading. It will be used to determine if any vertically aligned beams will be crushed under loading.

For the analysis the assumptions were made when precise data was not available or unpredictable factors. The first assumption is that the screws that will hold the structure together will be made of AISI 1018 Steel. [10] This is an assumption because during the initial search for parts, the information for the material of the screws were vague. This will be researched further. The second assumption that was made was that the type of wood that would be used as support beams is Eastern White Pine.[11] This assumption is being mad because of vague material descriptions by suppliers. This will also be researched further. The last assumption is that the testing load for the analysis will be equivalent of a 10 year old. With data from New Health Advisor [12] we will assume a load of 68 lb. or 302.5N.

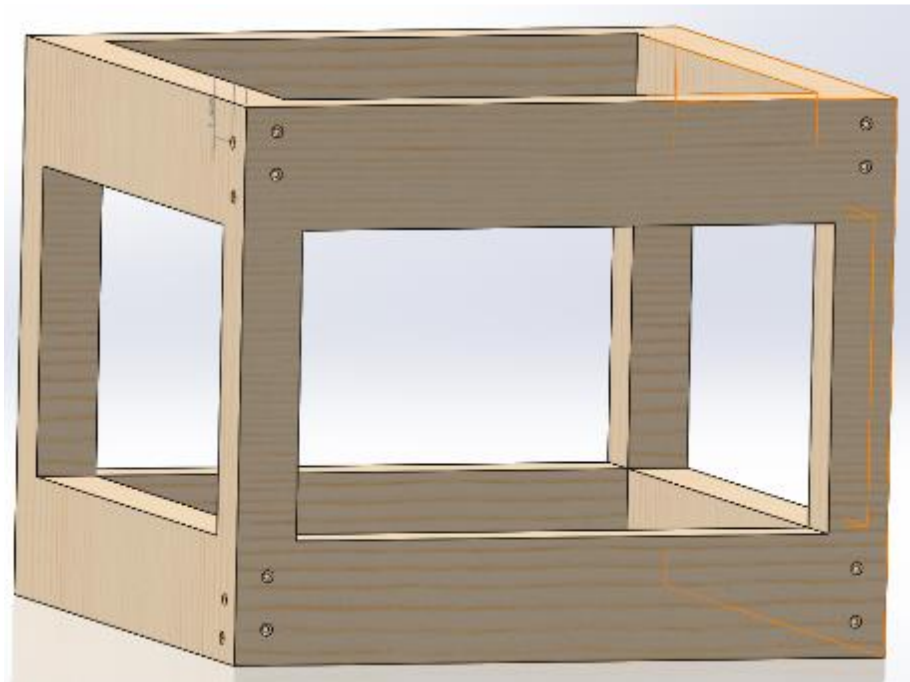


Figure 4: Basic model of casing

5.2.1.2 Casing Results

Based off of the calculations found in Appendix E the casing is able to withstand the force a child could exert on it. This leads to future work looking into ways to optimize the use of materials such that the casing is still strong enough but not as bulky or over engineered.

5.2.2 Shaft and Chain Design

Research for a conveyor belt, bike chain, and gear box assemblies are done in order to make the device more interactive for the audience. One of the goals for the device was to make the lasers reflect off multiple surfaces until the laser hits a target. Instead of having the children control the laser and cause possible injuries to someone's eye, the safer option is for certain mirrors to have the capability of rotating while the laser remains fixed and out of reach of children. In order to achieve this the team will have a conveyor belt or a gearbox that is operated by a hand crank. The hand crank is operated by the audience fulfilling the client's need of making it more interactive and safe.

5.2.2.1 Research

Tsubaki and IWIS are two companies that have prepared two documents that give a very detailed analysis on chain engineering. Excel spread sheets were created in order to find ideal settings for chain however, difficulties were discovered due to the fact that the majority of the chains being analyzed were chains meant for high loads that are far above stress and loads that will be experience in the device. However, in order to have the design more affordable it may be useful to design the chain in order to machine or repair within the team. [13][14]

5.2.2.2 Bike Chain Setup

A bike chain setup inspired the idea of a rotating conveyor belt to rotate the mirrors. The rider of a bike is able to use their feet to turn a chain that transfers rotational force to the rear tire to provide forward motion on the bike. In a similar set up, the team may be able to take the bike chain itself and put in under the display case. Covering this set up with its own displace case and placing an extended shaft that can be the base for one of the mirrors.

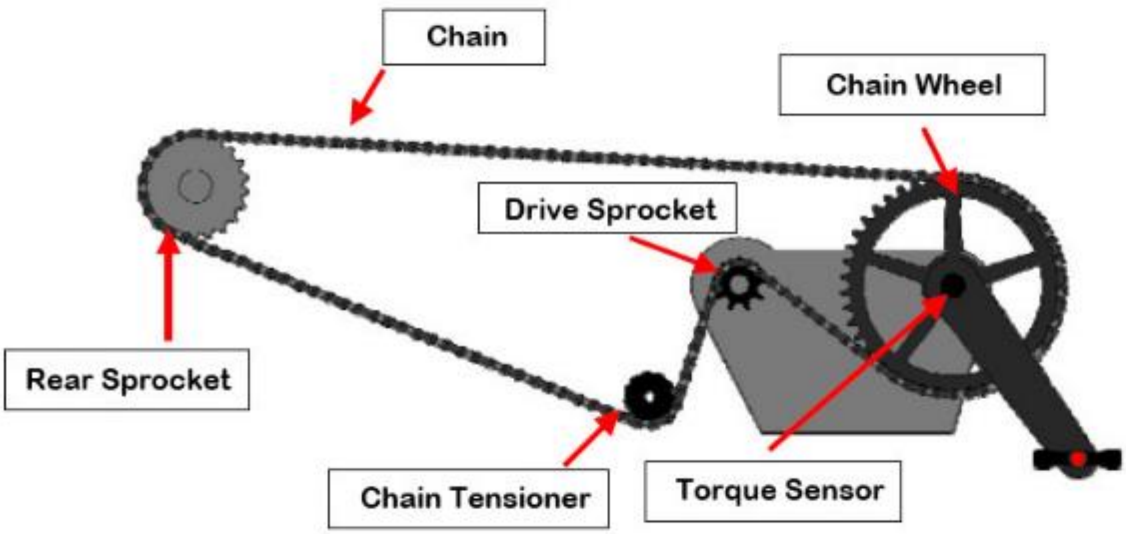


Figure 5: Bike Chain Set up [15]

Research conducted on chains is necessary in order to calculate efficiency, safety factor, and life span to ensure that the Wonder Factory would have a device that needs little repair once the team graduates. Tsubaki, Inc. created an article that is used for basic calculations that will be refined once bike chain prices and cost are established [2]. A single aluminum chain is chosen for the analysis to study how much force and speed will be generated by the audience using a hand crank. Starting calculations required an assumption that the audience will turn the hand crank of an average of 22.24 Newtons [1], which is approximately five pounds, which is more than enough to turn the chain. Another assumption is that if the audience continuously turned the hand crank it would average to sixty rotations per minute.

Table 7: Angular Velocity for Chain Wheel

Radius one		0.095	m
Rpm	assumption	60	rpm
angular velocity (w)	w=v/r	6.2832	rad/sec
Linear Velocity (v)	v=r*RPM*.10472	0.596904	m/s

Table 7: Angular Velocity for Rear Sprocket

Radius two		0.0485	m
Rpm	assumption	60	rpm
angular velocity (w)	w=v/r	12.28948	rad/sec
Linear Velocity (v)	v=r*RPM*.10472	0.59604	m/s

The results conclude that the angular velocity and linear velocity are within an acceptable operating range for any bike chain array. The assumption is that the chain will be able to have a large life span because bike chain systems are able to withstand a much higher amount of forces. The next step will be to setting up a device that will reduce the chain's angular velocity so that no damage will occur to the mirrors. The average time that the audience would need to interact with the hand crank should be an average of forty-five seconds. Another consideration is that the audience does not need to rotate the hand crank the entire rotation of the wheel in order to reach angles needed to have the laser hit its target.

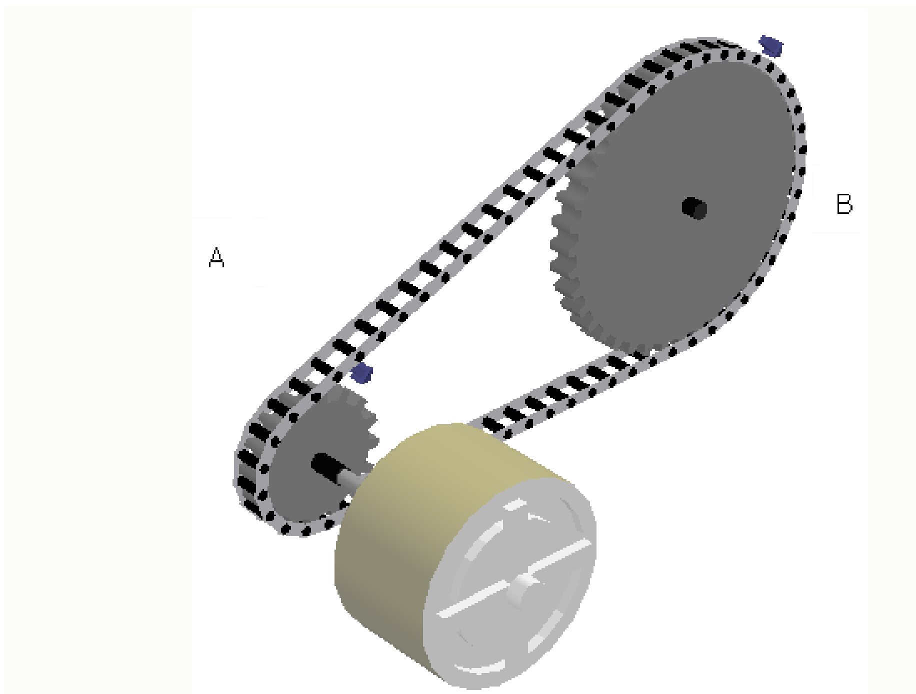


Figure 6: Desired Chain Setup [16]

The figure above gives a more accurate depiction of what is intended with the bike chain. By connecting a metal shaft to the rear sprocket by soldering or welding. The other end of the shaft will have a large surface that is the base for the mirror. The base would have a full range of motion and can be made out of affordable material as well as wood in order to match the display case.

5.2.2.3 Gear Set up

Another method to set up the display area would be to create a simple gear box set up that can be set up with by 3-d printing affordable gears that can perform the same task as the bike chain. The material properties of plastic would factor in that the gears have a higher chance of breaking and needing to be repaired. Multiple gears would be need to be printed in order for them to be replaced but due the gear ration a gearbox will allow the child to rotate the hand crank more in order to rotate the mirror base.

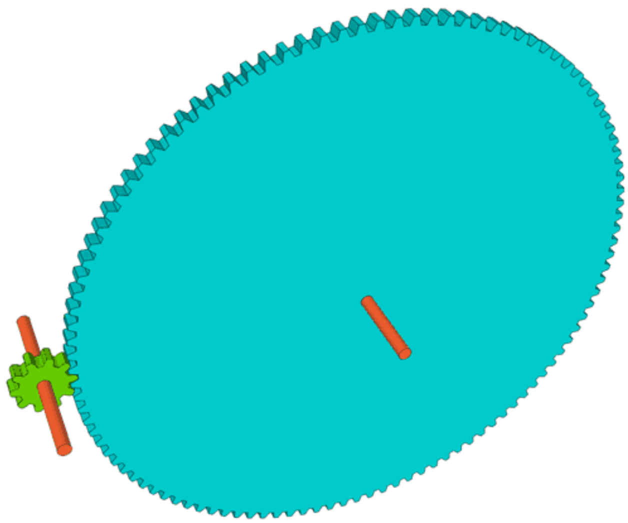


Figure 7: Possible Gear Setup [17]

5.2.2.4 Shaft Calculation

A shaft is one idea to transfer torque from the chain or gearbox to the floor surface however, if welding is done incorrectly or calculations are not right the results can include breakage. Therefore, a rough estimation of the torsional load is calculated using principals from a MIT PowerPoint slide of the shaft applications.

Table 8: Calculations for Shafts

Shaft: Torsional Load			
shear stress	(Kt*16*Torque)/(pi*d^3)	68827.63278	Pa
kt	Table A-15-5	1.4	
D	Chosen	0.1016	m
d	Chosen	0.0889	m
Force	Chosen	22.24	N
Crank Arm Length	Chosen	0.3048	m

With this research, the team created a SolidWorks image to fit the design specifications as well as safety factors that can be tested. The shaft device has two placeholders for the bike sprockets, which will be used to secure the sprockets and chain. The hand crank will then be added so that rotation can be transferred from the hand crank to the additional shaft that has been design to hold the mirror surface.

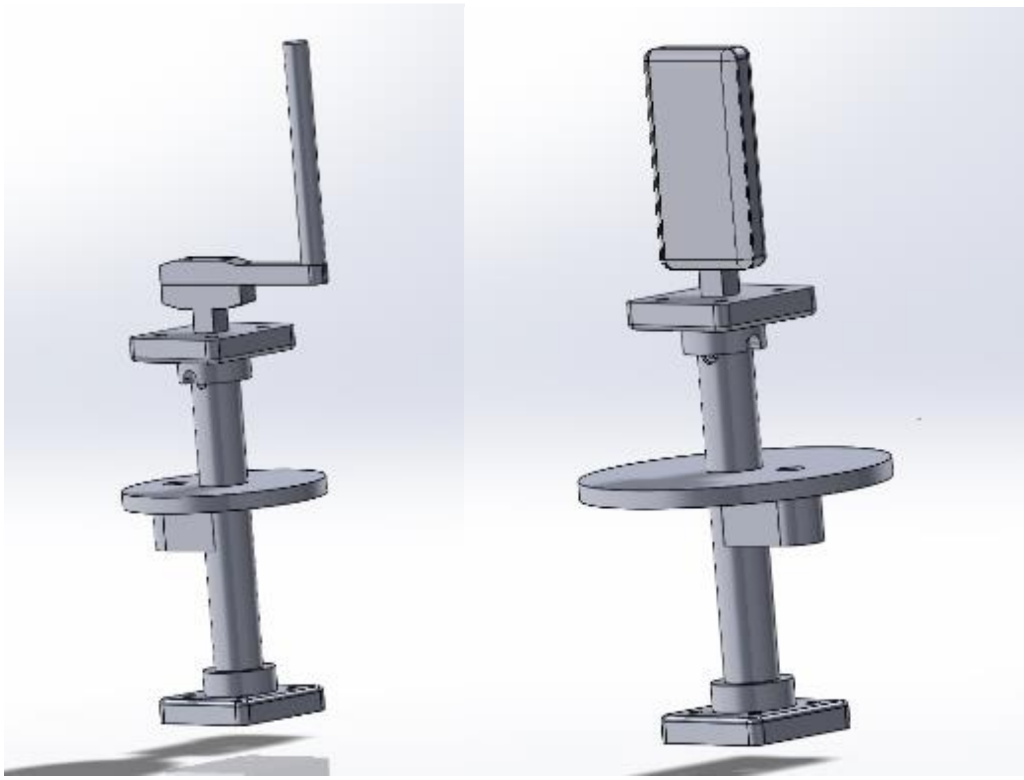


Figure 8: SolidWorks Shaft Design

5.2.3 Laser Design

A laser is a gadget that produces light through a procedure of optical intensification in view of the invigorated discharge of electromagnetic radiation. A laser varies from different wellsprings of light in that it radiates light intelligibly. Spatial intelligence enables a laser to be engaged to a tight spot, empowering applications, for example, laser cutting and lithography. In order to ensure that the laser is safe for the clients the laser were analyzed based on laser intensity to ensure that no harm would come to people or other objects.

Laser 1: Multi color Laser Light

This laser device emit red or green or purple laser light as it is available in these colors and it emits the laser light of 5mw power. Laser device is capable of producing the pointer light of 405nm wavelength. It is a high performance laser light and it the device body is made up of aluminum. It operates on AAA battery with 540mAh rating.

Laser Power: 5mW

Working Voltage: 3.0V

Working Current: 1100 mA

Battery rating: 540mAh x 2

Price: $5.66

$$Battery\ Life = \frac{Battery\ Capacity}{Device\ Consumption} * 0.7$$

$$Battery\ Life = \frac{540 * 2}{1100} * 0.7$$

$$Battery\ life = 0.687\ Hours$$

Laser 2: JD-301 Laser Light

This laser device has a model name JD-301 and it emits green or red light. It emits the laser light of 5mW power. Laser device is capable of producing the pointer light of 532 nm wavelength. Body of this laser device has made up of aviation aluminum alloy and it operates on rechargeable 18650 battery.

Laser Power: 5mW
Working Voltage: 3.7V
Working Current: 650mA
Battery rating: 3000mAh
Price: $11.71

$$Battery\ Life = \frac{Battery\ Capacity}{Device\ Consumption} * 0.7$$

$$Battery\ Life = \frac{3000}{1100} * 0.7$$

$$Battery\ life = 3.23\ Hours$$

Laser 3: Silver Laser light

This laser device is silver in color and produces only red laser light. It emits the laser light of 5mW power. Laser derive is capable of producing the pointer light of 650 nm wavelength. Body of this laser device has made up of silver and aluminum. It operates on rechargeable 16340 battery.

Laser Power: 5mW
Working Voltage: 3.6V
Working Current: 650mA
Battery Rating: 700mAh
Price: $13.79

$$Battery\ Life = \frac{Battery\ Capacity}{Device\ Consumption} * 0.7$$

$$Battery\ Life = \frac{700}{650} * 0.7$$

$$Battery\ life = 0.75\ Hours$$

Conclusion

From the comparison of above three, we can conclude that the cheapest one is the first laser device but we have to look for the safety as well. Laser safety depends on the wavelength of laser light and the laser power. We have seen all the three lasers are under 5mW but all three have different wavelengths. Larger the wavelength, safer the laser is. Therefore, first laser is not safe because it has very small wavelength. Wavelength of laser 3 is large but is costly and the battery life is very small, we can operate it only for less than an hour with one time charging. If we see all these constraints, and see the battery life and safety then the Laser 2 is best option to use. Because it's price is $10 with rechargeable battery and battery charger as well. So no need to purchase the new battery again and battery is powerful as well because it will keep the laser on for 3 and half hours. Therefore, the recommended laser is Laser 2 which is JD-301 laser.

5.2.4 Electronics Design

The wonder factory is a place that generate learning through playing and the targeted audience is children with their families. Mr. Steve and Mrs. Jackee Alston are the founders of the Wonder factory idea; their exhibits must have STEAM concepts + ART. Us as a team our goal is to design a device that can help the wonder factory founders to reach the purpose of the museum, which is to generate learning through playing using STEAM concepts +ART. The design we approached was the mirror reflection project. The design is to hit a target-using laser and mirrors. The child must adjust the mirrors to a specific angle to hit a target using laser gun. The STEAM concept with in our design is to teach the children about the light spectrum and geometry. After sitting with our clients, they mentioned a requirement, which is the WOW factor. The WOW factor requirement is how amazed, excited and happy the children will be after playing with the device. Therefore, we have to apply the WOW factor in our design for the client because it is the most important requirement after the safety of the device. In order to achieve the requirement we want to apply a target with an output of light and sound. Therefore, the child must set the mirrors in angels he think that will make the reflection of the laser will hit the target and the output will start.

My individual analysis part is to research for the electrical system of the project. The system will have an input and output. The input part of the system is the target, the output part is the light and the sound .Since the child will be using laser to hit a target we need some sort of sensor to run the electrical circuit we will apply in the design to play the music and light. The electrical circuit will be programmed to work properly with our design. This analysis is going to contain the sensors, microcontroller and the device that will play the music and light. First, the target is going to be a sensor. Because we are using lasers, we need to use a photodiode, as the target that will run the circuit. The photodiode is going to be the receiver component of the circuit. It will run only of the laser beam comes in light with the photodiode

There are many types of photodiodes and they are:

- PIN photodiode
- PN photodiode
- Avalanche photodiode
- Schottky photodiode

They all have the same specification but the most suitable for our project is PIN Photodiode because it collects the light photons more efficiently than the other photodiodes and also it offers a low capacitance. Offering a low capacitance is important for our design because a photodiode with high capacitance specification is going to run current even if the laser was not reached to the target [22]. Also in the figure1, we can see the photodiode response for the light spectrum. I advise the team to use a red light laser because as shown in the figure the red spectrum is the relative response in the light spectrum.

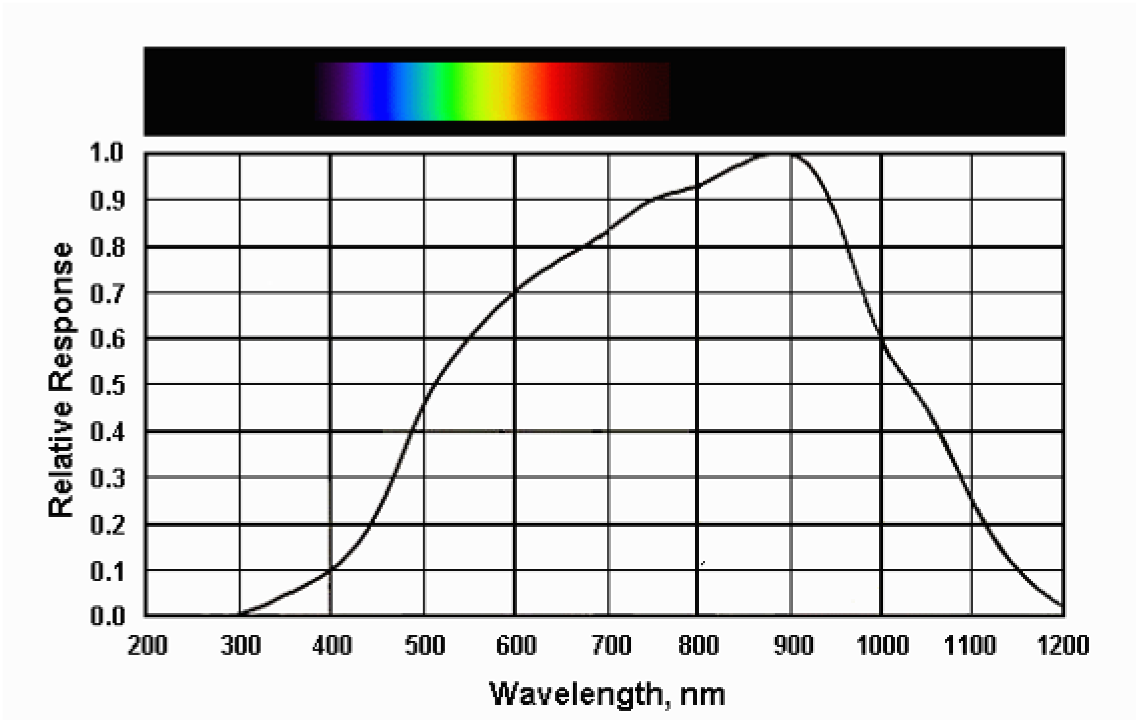


Figure 9: Silicon Photodiode Spectral Response

The second part of the analysis is the programing system and the microcontroller. The best program to use is the Arduino program. Because, Arduino program offers many microcontrollers in the market and Arduino is an open-source platform where we can program anything using the Arduino microcontroller. And in our case we will use the Uno microcontroller because, it is efficient for everything in programing circuits and it have many pins for inputs and outputs for our design circuit. The Uno microcontrollers have 14 pins for inputs and output, 6 analog input and a USB connection. It can be programmed using Arduino language for coding. The coding language in Arduino is similar to C program.
Why Arduino?
Arduino program offer simple and straightforward commands for coding. Also, any beginners can use the Arduino system for programing and designing projects. This will beneficial for our case for programing the device in a professional way to master the electrical component in our project.
Then the microcontrollers offered by Arduino is [23]:
Inexpensive

- The board are relatively affordable comparing it to other microcontroller in the market.

Cross-platform

- The microcontroller software is accessible for any Windows , MAC and liux operating systems.

Simple, clear programming environment

- The microcontroller is easy to operate and use. yet flexible for advanced project. Open source and extensible software

Open source and extensible software

- The Arduino microcontroller is design as an open source for users

Open source and extensible hardware

- The hardware tools offers can help circuit designers to be creative and use it for multitasks projects.

Coding sample offered by the Arduino software:

The Arduino program offers many code samples in their libraries for many proposes. In our design, we will use the sensors code offered by the Arduino software and change the input and outputs to match our design. Here are some of the code samples.

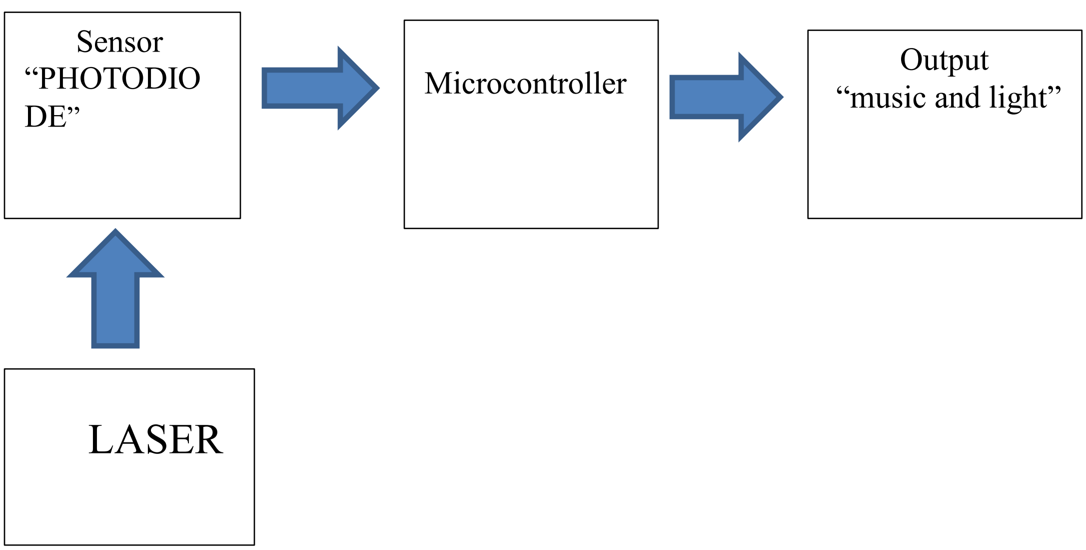
Code

Example codes can be found in Appendix E

Conclusion:

The electrical system is sensors which is photodiodes, microcontroller and output for sound and light. This electrical circuit is very critical for our project in order to reach the maximum value of the wow factor for our design. In addition, in the block diagram shows the electrical system algorithm to work.

Figure 10: Laser Outcome



5.3 3-D Solid Works Assembly

The device has been modeled in SolidWorks. The overall form of the model are final however small changes are likely to occur in the future. The models will be kept up to date whenever modifications are added to the device. The model has helped convey visual information about the device and using SolidWorks some characteristics can be estimated such as weight and volume.

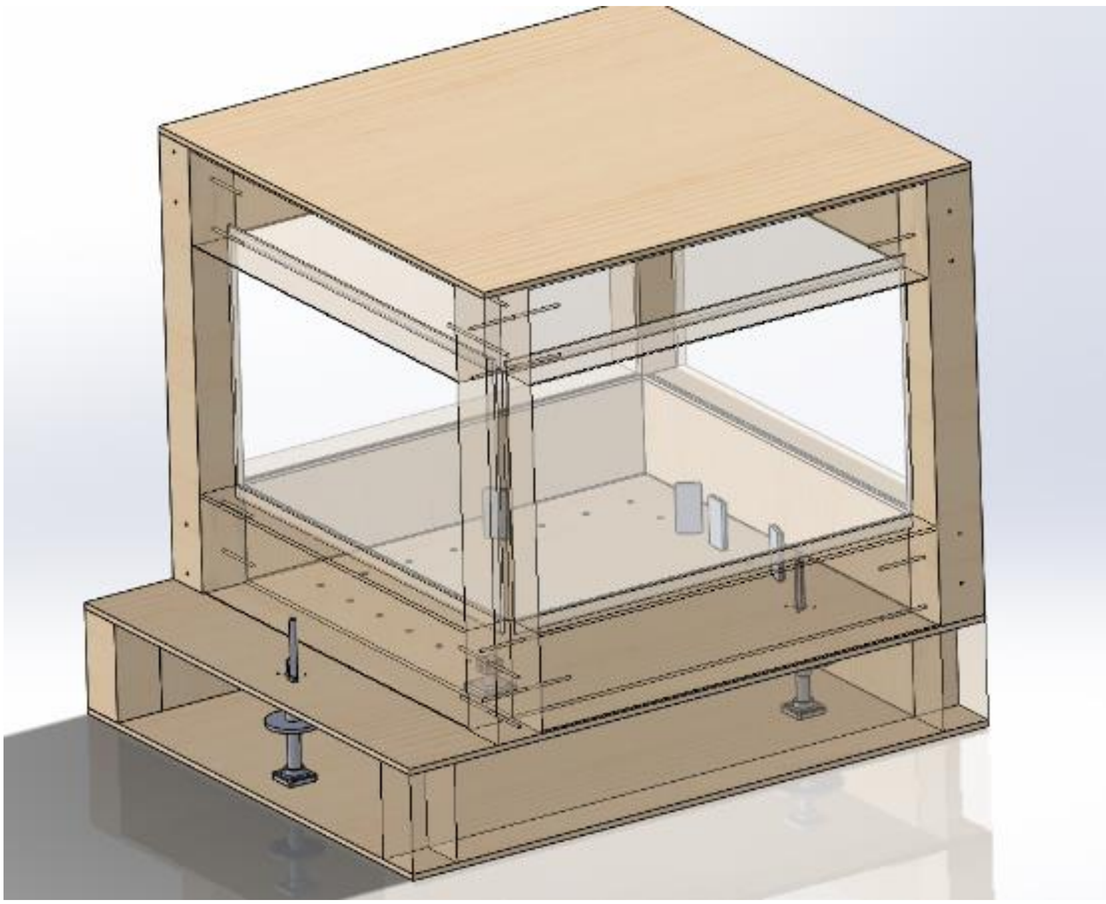


Figure 11: SolidWorks Isometric View of Device

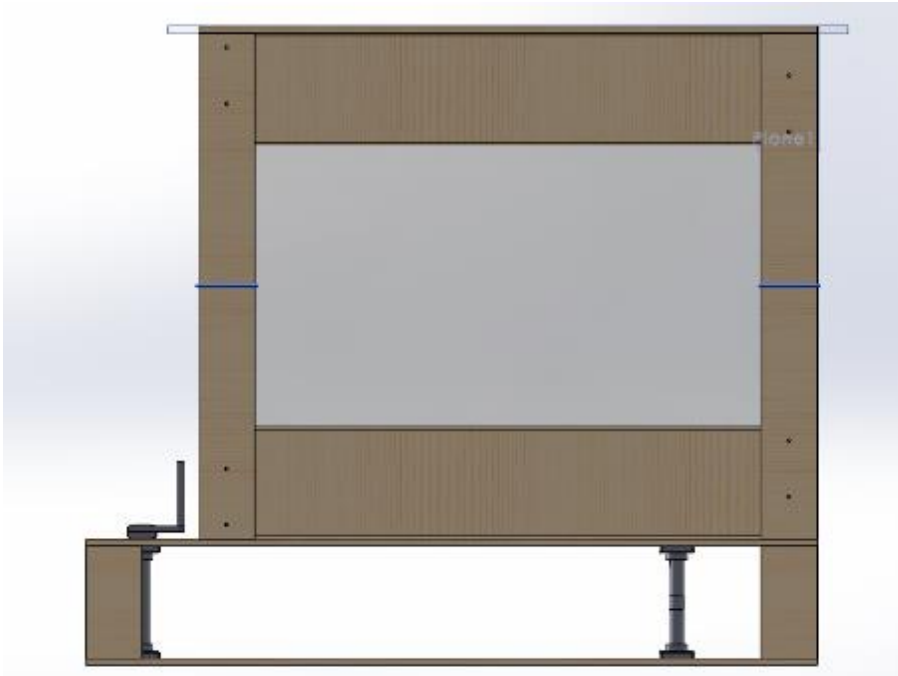


Figure 12: SolidWorks Side View of Device

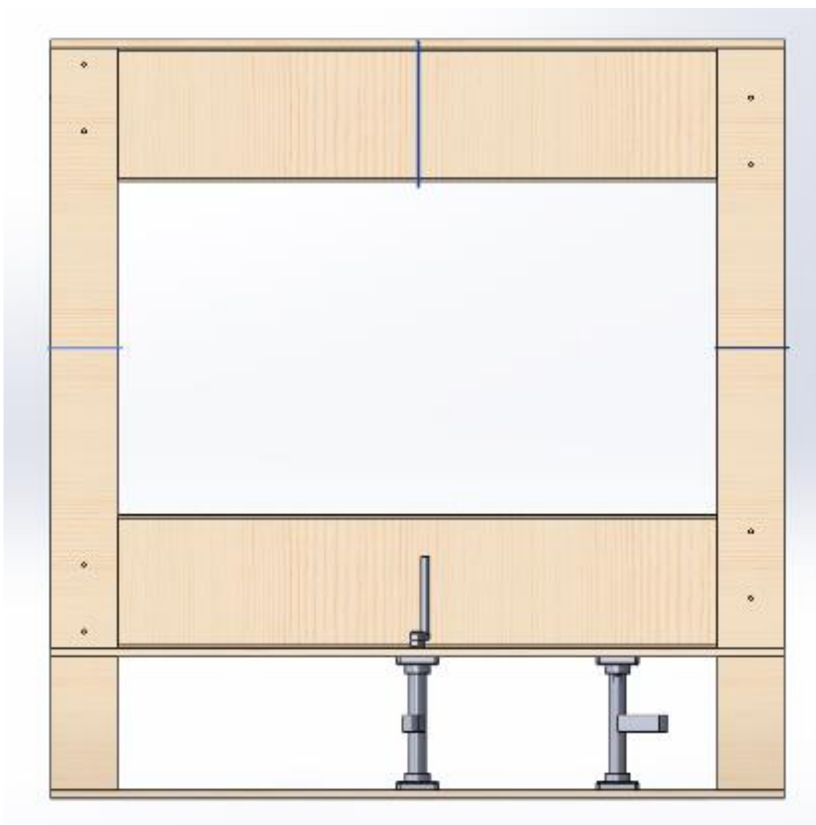


Figure 13: SolidWorks Front View of Device

6 PROPOSED DESIGN – First Semester

With all of the design specifications, the Wonder Factory team created a prototype to demonstrate to the client. This allowed the team to test the basic specifications to help them foresee potential problems they could occur when constructing the devise. The Wonder Factory team will begin construction of the device in the Fall 2017 semester.

6.1 Timeline

The following tables indicate the anticipated time frame of the project planning and construction. Table 9 is the work that is done in the Spring of 2017 which started with the concept generation and selection. This lead to the planning and designing portion of the project which set the ground work the next semester.

Table 9: Spring 2017 WBS

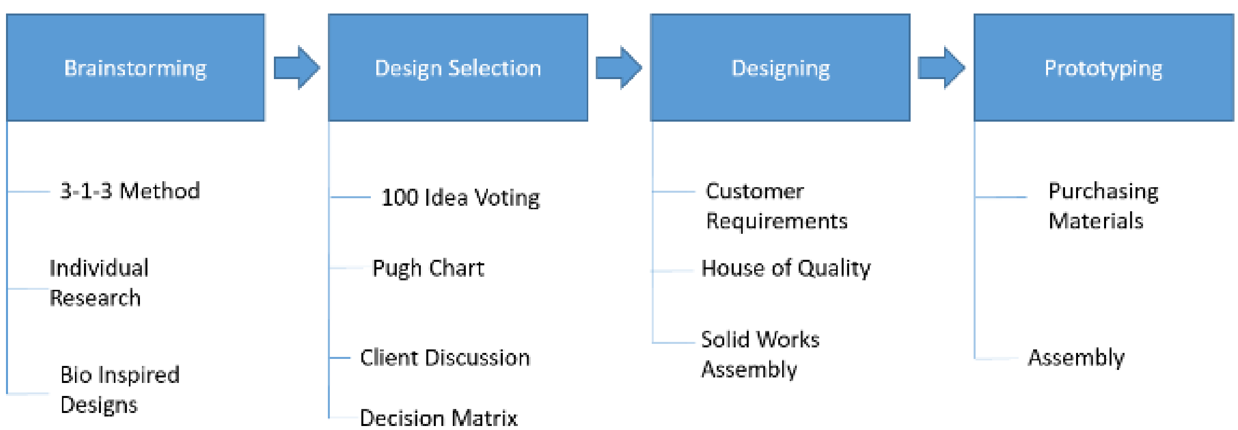


Table 10 is the work break down schedule (WBS) for the first half of the Fall semester. This phase of the plan includes constructing the device according to the SolidWorks design from the first semester. The team will then test the device with the Wonder Factory at science events in order to get direct feedback from the audience. Then the team will work on redesigning any portion of the project that needs to be adjusted due to testing. The time frame for this portion of the project is August 28th to October 8th.

Table 10: First Half of Fall 2017 WBS

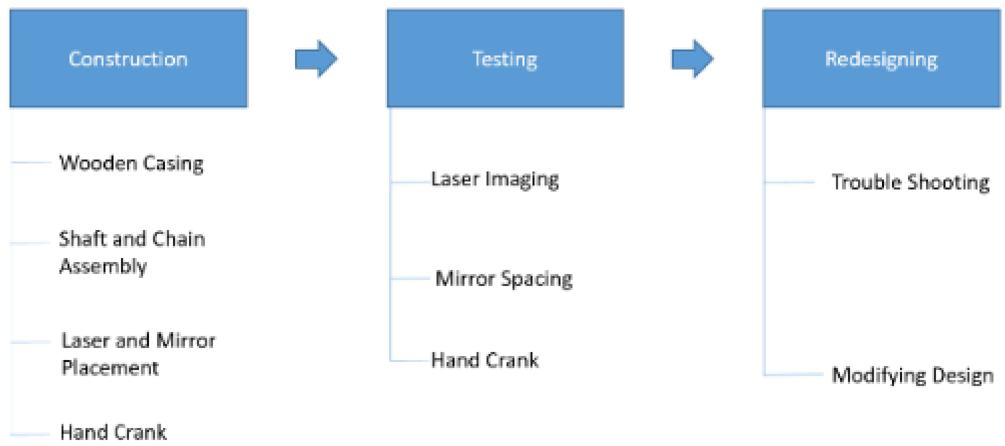
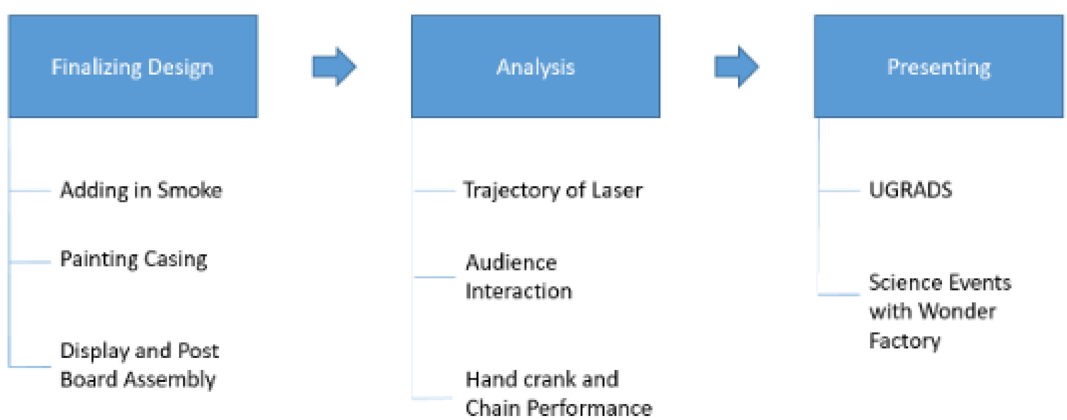


Table 11 is the final WBS of last half of the semester. The team will be finalizing the device by adding in additional features such as smoke and painting the device to get a more aesthetic feel for the final presentations at UGRADS. Next, the team will finish analyzing the performance of the device as well as begin working on the final paperwork and poster boards for UGRADS. Finally, the team will present and display their device at UGRADS as well as to the clients. The time frame is from October 9th to December 15th.

Table 11: Second Half of Fall 2017 WBS



6.2 Construction

The following is an overview of the construction of the device:

6.2.1 Casing

The casing of the device will be created first by using lumber from home depot. The Team will use a power drill and screws that is owned by one of the teammates in order to assemble the casing to design dimensions. A wood saw will be used to cut the wood with a wood saw that the team also has at their disposal. The wooden frame will then be sanded down in order to create a smooth surface with sand paper which can be acquired from home depot.

There will be several open slots where flexible tinted glass can be placed to protect the audience from the possibility of the laser reflecting back into their eyes. The glass material can also be purchased from Home Depot and can be cut to specifications by the team.

6.2.2 Shaft and Chain Assembly

The shaft of the project will need to be machined in the machine shop using the Computer Numerical Control (CNC) machine in order to achieve exact measurements. The specifications are in the 3-D SolidWorks model, which allows the team to hand the image to the machine shop managers in a computer flash drive. The shaft will have a smooth extended surface that will serve as a sprocket holder for the chain assembly.

Two sprockets will be purchased from a local bike shop called Single Track in Flagstaff Arizona. They will be placed on the shaft place holder where a chain from Single Track will be placed on the sprocket's teeth in order to provide tension between the two shafts.

6.2.3 Hand Crank

The Wonder Factory team is creating a solid works model for a hand crank in order to machine from the machine shop using the CNC machine. An alternative option would be to purchase an inexpensive hand crank from Amazon and design the shaft to have the correct orientation for the hand crank to be assembled with the shaft by holding it together with washers, and bolts.

6.2.4 Mirror surfaces

The mirrors used in the device will be purchased from online sources such as Consumer Crafts, which sell one inch craft mirrors for seventy seven cents. A rubber coating will be placed around the mirrors to reduce sharp edges. These mirrors will then be placed in their arranged setting using adhesive in order for the laser to create multiple images for the audience to see using the hand crank.

6.2.5 Laser

The laser that will be mounted in the device will be obtainable from an online source such as Amazon. The mount that the laser will be held in will be adjusted to work with the geometry of the laser. Modification will be done to the laser to allow for operation on a toggle switch rather than a contact switch that requires constant force to activate. The power source will also be modified such that removing the laser from its mount will not be necessary to change the batteries.

6.2.6 Electronics

An electronic module that will detect the laser and emit a sound will be built and placed within the device. The source of the parts for this module will be from online sources such as Amazon. An electronic circuit will also be added to disable the laser when the top cover is not on.

6.3 Bill of Materials

The following table is a portion of the Bill of Materials (BOM). The entire BOM can be found in Appendix F. The pricing was researched through online sources and is listed in the Bill of Materials. The team's goal is to spend less than $400 in constructing the device. This leaves $350 for the remaining budget. This leave plenty of funds in case of unforeseen costs.

Table 12: Summary of Bill of Materials

Part #	Part Name	Description	Qty	Units	Supplier	Unit Cost	Cost
1	16 Tooth Sprocket	Bike Sprocket	1	N/A	Roller Chain	$ 5.14	$ 5.14
2	22 Tooth Sprocket	Bike Sprocket	1	N/A	Roller Chain	$ 6.09	$ 6.09
3	Pine Wood	Wood for Casing	3	2in X 4in X 10 ft	Home Depot	$ 3.52	$ 10.56
4	Pine Plywood	Wood for Casing	1	1/4in X 4ft X 8ft	Home Depot	$ 21.02	$ 21.02
5	Aluminum Axel	Aluminum for Axels	2	2.5in X 4in X 1in	Speedy Metals	$ 12.05	$ 24.10
6	Aluminum Holders	Aluminum for Axle Holders	4	2in X 2in X 1in	Speedy Metals	$ 5.22	$ 20.88
7	Aluminum Billet	Crank to handle Base	1	1.25in X 1.25in X 1in	Speedy Metals	$ 2.73	$ 2.73
8	Aluminum Billet	Crank Handle	1	3in X 3in X 1in	Speedy Metals	$ 9.59	$ 9.59
9	Aluminum Billet	Axle to Mirrors	1	1in X 3in X 1in	Speedy Metals	$ 3.61	$ 3.61
10	Aluminum Billet	Mirror Pegs	18	1.25in 2.5in X 1in	Speedy Metals	$ 3.67	$ 66.06
11	ZINC Wooden Screws	Wooden Screws for casing	1	#10 X 4in	Copper State	$ 11.61	$ 11.61
12	Machine Screws	Screws for Assembly	1	TBD	Copper State	$ 12.00	$ 12.00
13	Laser	Laser for Design	1	3.7 Volt	Amazon	$ 11.71	$ 11.71
14	Craft Mirrors	Reflective Surfaces (25 pack)	1	.5in X .5in	Consumer Crafts	$ 1.27	$ 1.27
15	Acrylic Panel	Transparent Viewing Glass	4	12in X 24in X 1/8in	Amazon	$ 8.01	$ 32.04
16	Electronics	Additional Cost for electronics	1	TBD	TBD	$ 60.00	$ 60.00
	Total		**42**				**$298.41**

7 IMPLEMENTATION – Second Semester

This section cover the manufacturing process of the proposed design. The topics covered are the purchasing and cutting of the wood. The problems that were encounter as well as the decision to switch to aluminum for the design.

7.1 Manufacturing Wooded Material

In order to create the proposed design from section 6 the team needs to stick to the Bill of Materials in Table 13. All of the wooded materials such as the two by four and ply wood are available for purchase at Home Depot. The wood needs to be pine wood due to the steadiness and toughness of the wood. By having tougher material will prevent fractured pieces when the children play with the device. With all of the materials the team will partner with a workshop in order to use wood tools such as a circular saw in order to cut the wood to the measurements needed for the casing. In order to work with material that is not cut perfectly the team will use a sander to sand down the measurements that are not exact from cutting with the circular saw. The sanding process will ensure the parts fit together so that the casing will be leveled and aligned with itself.

The wooded material will then be secured by using 4in wooded screws to hold the casing together. The frame will then be complete and the holes for the mirrors will be drilled through the plywood using a hand drill with a ¼ in drill bit. Figure 13 gives a visual representation of the intended design. These holes will provide a space for the mirrors to be inserted into using wooded pegs of ¼ in diameter with the exception of the mirror that will be fixed upon the aluminum shaft in order to rotate with the use of the hand crank.

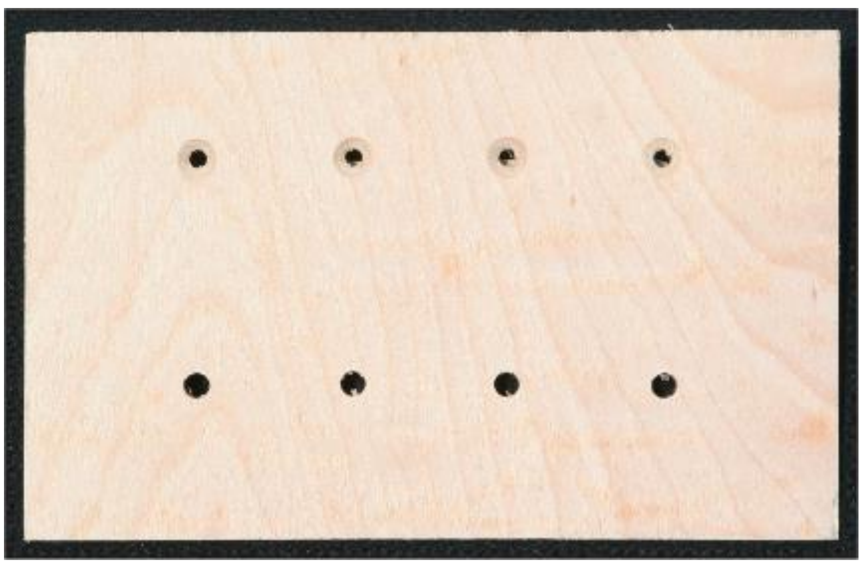


Figure 15: Holes in plywood for Mirror Pegs [24]

Once all of the holes are created the team will then order aluminum billets from the supplier Speedy Metals so the shaft assembly can be created using a lathe machine in the NAU metal shop. An extra billet will be ordered just in case there are errors with the machining of the first billet. The aluminum will house the base for the rotating mirror and connect to the bike chain which will be purchased after the dimensions of the shaft are completed with machining. A picture of the lathe can be seen in Figure 16 which is specifically design to make rotational cuts on metal.

Figure 16: Lathe Machine

The reason being that the bike chain and gears are ordered last is to ensure that the right dimensions will be purchased due to the uncertainty of the actual measurements after using the lathe. This will then allow the team to connect the shaft assembly to the hand crank.

The electrical components will be purchased and housed within a protective case within the wooded case. The copper wires will be connected to the breadboard that will be connected to the Arduino micro-controller and the laser sensor. With all of the electrical components connected together the program will be run by C programming due to the easier use rather than using Roseberry Pie. The list of parts needed to be purchased can be seen in Table 14.

Table 13: Electronic Wish list

Parts	Quantity	Estimated Cost ($)
Arduino Micro-Controller	2	21.49
Laser Sensor	1	12.52
LED	7	0.15
Wires	14	12.75
Breadboard	2	4.5
Laser	1	11.71
Push Button	1	2.52

The projected budget for this design is $700 dollars which is more than enough due to the projected cost being $300. With a remainder budget of $400 the team plans to make more prototypes and designs so more children can interact with the design rather than just one at a time. Although after the overall budget did change to $1000 when the team switched over to aluminum material which will be elaborated on in the design change section.

7.2 Manufacturing Aluminum Material

After design changes were made to switch over to aluminum the NAU machine shop was now available to use for the project. However with the material switch the team needed to place in all the order quickly in order to allow time for all of the material to arrive in a timely manner which did not occur with the majority of the material not arriving till weeks before the semester ended. The first list of the materials that arrived was the aluminum slots for the walls of the device from 8020 which needed the drill press in order to drill holes 1.5 inches into the Aluminum walls in order to provide space for the electrical wiring. Figure 17 shows the NAU drill press that was used to make drilled holes in Figure 18.

Figure 17: Drill Press

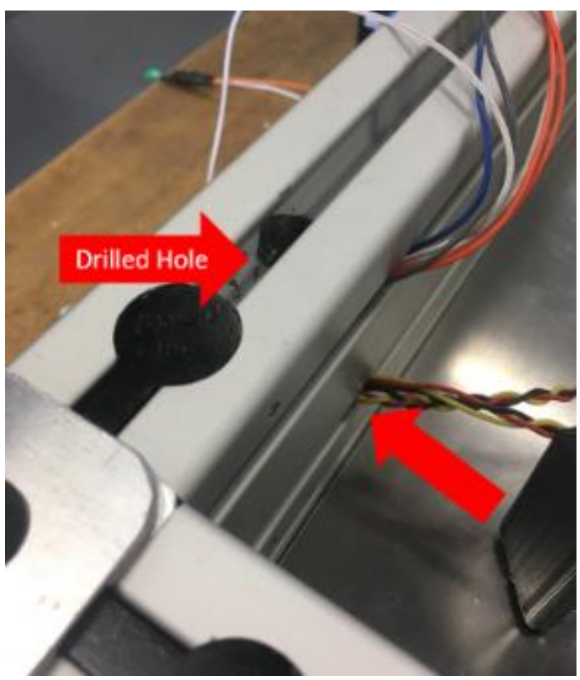


Figure 18: 5/8in Drilled Holes in Casing

In addition to 5/8 inch drilled holes in the wall casing the drill press was used to create multiple holes for the device within the aluminum walls. Also holes needed to be drilled to create spacing for screws and bolts at 5/16 of an inch and 1/8 of an inch. Which after needed to be taped to create threads in order to insert the screws and bolts in the device as seen in figure 19, 20, and 21.

Figure 19: Drilled and Tape Holes on Hand Crank

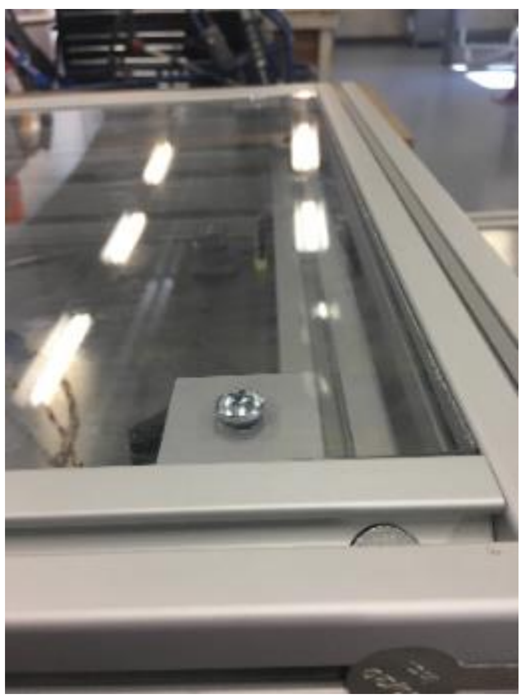


Figure 20: Drilled Holes for Screws on Display Casing

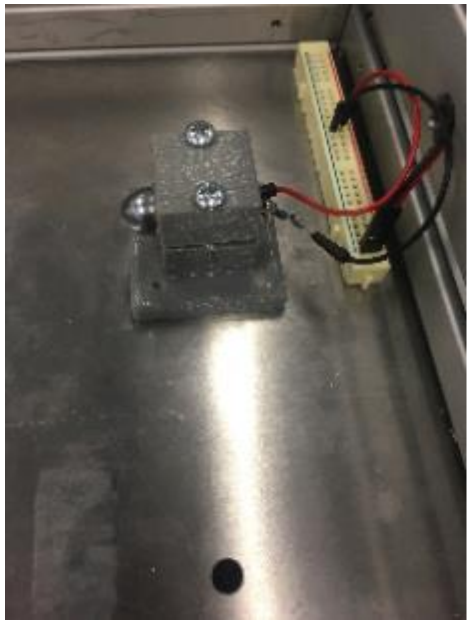


Figure 21: Drill and Taped Holes on Electronics

After all holes were made the frame work for the device would be set up with Allen wrenches. The reason this was possible was when ordering the device the specifications of the aluminum material were made so that the device could be fitted together from 8020. Despite specific order specifications a belt sander was used on portions of the aluminum frame work to sand down the aluminum to exact specifications that were needed for the device to properly fit together. Figure 22 shows the one of the locations were the Allen wrench is used to tighten the aluminum walls together.

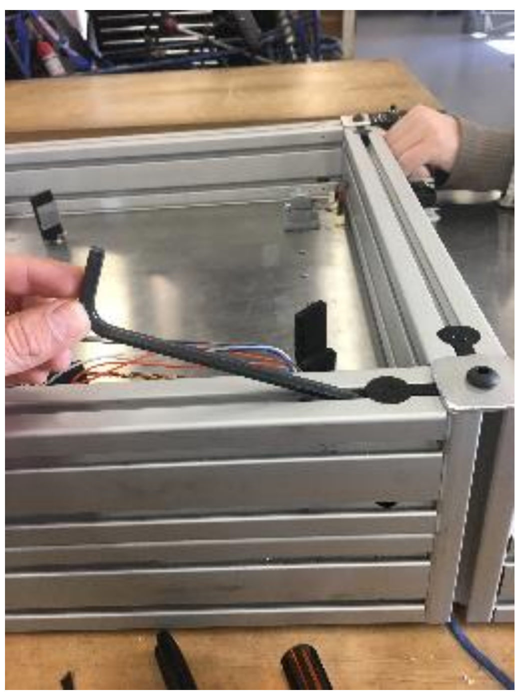


Figure 22: Casing Assembled by Allen Wrench

The aluminum plates arrived next and the drill press was used again to drill out holes at ¼ in for the mirror post. The shaft holder for the rotating mirror was also drilled out at ½ an in as seen in Figure 23.

Figure 23: Drilled Holes for Mirror Post

The next challenge faced was to properly secure and protect the electrical components. The electrical components could not be drilled into however specific dimensions were needed to provide a space in the aluminum plating in order to glue and solder the material into. In order to meet small dimensions a vertical mill was used in order to cut specific dimensions that were too small to cut in any other machine besides a CNC machine which would have been unrealistic due to the amount of cost to use. The vertical mill can be seen in Figure 24.

Figure 24: NAU Vertical Mill

7.3 Design Changes

To follow the designs from the previous Wood was the primary material chosen to manufacture the design. The reason being was that wood with the right set of tools could be easy to cut as well as assemble. The material would be cheap and allow the team to manufacture more than one prototype to test. The material would also be lighter than metal allowing the team to meet the requirement of being easy to move and carry for the client.

Pine wood was not found in the dimensions needed according to the Home Depot website so the team chose a different material of wood. White wood was purchased at home depot and the reason white wood was chosen was due to the hardness. With white wood also being a sturdy and durable material the frame work of the project would be able to withstand the weight of a 70lb child and even an adult. The total cost for all the wooded pieces turned out to be over $50. The purchasing process was the easy portion of the project and the team encountered its first problem with assembly.

None of the team had a large enough vehicle to be able to move the material to any given location and local friends with trucks were called upon to help out in the shipping process of the materials. However this lead to the next problem with the NAU metal shop not wanting the team to store the wooded material in their shop. The metal shop runs a very high risk of fire with wooded material being there and none of the machines are meant to cut wood for that very reason. The team was not able to use tools at the machine shop for a short period of time while communication with other workshops was in process. Initially the team was going to partner with the Alston's with their workshop at their home however with deadlines approaching and limited time to connect with the Alston the team decided to wait till the machine shop finally allowed the team to use their materials and facility. The machine shop had circular saws and vice grips that help in the cutting of the wood as seen in Figure 15 and 16.

Figure 25: Cutting Process on Wonder Factory Team

Figure 26: Cutting of the White Wood

With a location to store the material the next step was to cut the wood however the hardness of the white wood proved to be a hindrance. The saws at the metal shop proved to be difficult in the cutting process of the wood. While cutting with a circular saw the white wood would burn while cutting with evidence of burn marks on the inside of the wood as seen in Figure 17.

Figure 27: Burn Marks from Circular Saw

The process also was very time consuming with the delicate cutting of the wood to ensure little burning occurred on the wood as well as to protect the saw blade. With the time consuming process the team notice that they were losing time due to the limited time slot available with the machine shop. The reason being that the priority of the Fall semester went to the manufacturing students. With that in mind the team discovered that the cutting process was not going as to be expected. The material would not come out perfectly with the fact that human error was occurring in the process of cutting the wood. This meant that exact measurements were not meant and the fitting of the wooded frame was an on-going process with the effort to sand the material in to a better shape. Figure 18 shows the prototype wooded frame of the project.

Figured 28: Assembled Wooden Prototype

Sanding only proved to be more difficult than cutting which lead to the team vote of switching to aluminum. During hardware review one it was proposed that the team use the website 8020.net to order aluminum parts for the manufacturing portion of the frame. The team met and looked at the materials offered at 8020.net to see the materials offered. The team found that there were very specific pieces that the company had already machined to fit together which would save time and effort for the team in the assembly process. However the switch to metal would prove to be more expensive by a projected $600.

7.3.1 Design Changes Aluminum

With the transition to aluminum the team needed to request that the team budget be increased to $1000 in order to have sufficient funds for all of the materials. Additionally the materials needed to be ordered quickly to begin the manufacturing process however, the cost played a huge factor in the decision of assembly. The metal frame did cost the most however other materials and websites were researched in order to see if there was a better cost analysis. Different materials such as plastics were looked into because of the material being less expensive however, there was the concern of the material not merging together well or deforming under certain pressure points. The team decided to switch to an aluminum frame which would prove to have a higher durability factor as well as a more ascetically pleasing view. The team order list can be seen in Table 14.

Table 14: 8020 Material List and Estimated Cost

Part Number	Quantity	Subtotal
1515-S	2	$14.88
1515-S	2	$38.59
1530-S	8	$236.72
1530-S	2	$43.37
3097	20	$121
3098	2	$11.60
2488	12	$47.40
14017	2	$35.50
3122	4	$1.20
1517-LS	1	$12.69
3679	2	$2.70
3789	2	$0.50
1515-S	1	$13.08
1515-S	4	$36.12

The team has placed the order for all the materials and will begin assembly of the project as soon as the material arrives. Once the material arrives the assembly process will only be screwing in fitted parts that are already designed to fit together. With the frame completed the team will then focus on the machining of the shaft design for the use of the hand crank using the lathe machine.

The shaft design is still the same as proposed in the previous section however the machining of the holes for the mirrors needs to be machined using a vertical mill. If dimensions for the sheet metal are too large a vertical drill will be used. Therefore the mirrors will be ordered later once the holes have been drilled.

As for the electronic components nothing has changed and all of the parts are readily available once the metal frame is finished. The code for the Adreno system can be seen in Appendix E. The main problem for the team is now waiting for the parts to come in. The time frame now has to be considered with half of the semester already past and the team still does not have a fully completed design to test. Once the parts come in the team will assemble the design and present it to the Alston's and testing will begin according to the engineering and customer requirements.

One last change that was implemented due to late arrival of the aluminum billets the team decided to 3-D print the shaft pieces as well as the hand crank. This allowed the team to be able to quickly receive the material as well as be able to sand the material down if dimensions were too big for drilled holes as well as specific dimensions for mirrors and lasers. The team made sure to have the plastic parts be completely filled as well as have the strongest material mix to ensure no breakage will our with multiple use.

8 TESTING

After the device was fully assembled the team was able to test the device according to the testing procedures listed in section 2.3. This section goes into detail about all of the test as well as mentions the future test that will be conducted at future science events with the Wonder Factory

8.1 Weight

The first procedure was to test the actual weight of the device which was very straightforward as far as testing. A scale was used to weight the device. The overall weight ended up being 63 lbs. which exceeded out limit of 50 lbs. The group did not intend for the device to be made out of metal which explains for the extra weight of the device. In order to avoid this problem in the future the device can be made smaller in order to make multiple device that fit within specifications. The reason the weight limit was set was we did not want the device to be dangerous if it ended up falling off a table. Future redesigns will need to be done with a smaller volume or a different material with less density.

8.2 Dimensions of the device

The device had the overall dimensions thanks to solid works and the team was able to order all parts according to the SOLIDWORKS model however the team needed to make sure the device actually fit within specifications projected. The group intended for the device to be within 3 cubic feet and the group did meet specifications with the device being 10in X 32 in X 21 in with the exception of no additional height where the hand crank is on the device which made the overall material being 2.8 inches which fit within expected parameters.

8.3 Degrees of Freedom

In order to make sure the device meet safety requirements the team decided to make the device within one degree of freedom to make sure the laser did not reflect back into the y-axis and into someone's eyes. In order to test this the team actually measured the change in elevations based upon where the laser was position and then measured the height of where the light would meet each mirror. The results being that the laser was not in one degree of freedom. The trajectory did in fact change by 2.8 degrees after every trajectory change as seen in Figure 29, 30, and 31.

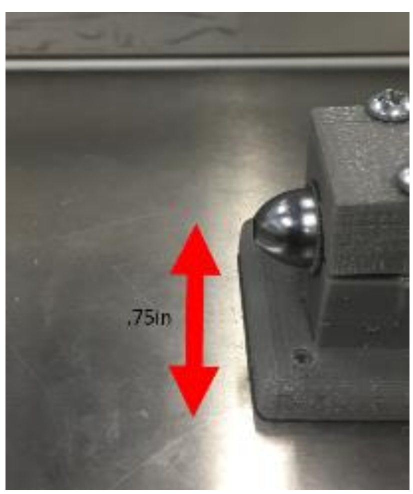


Figure 29: Project Laser Trajectory

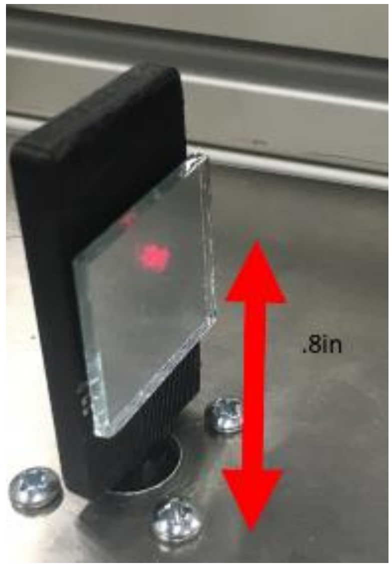


Figure 30: Project Laser Trajectory

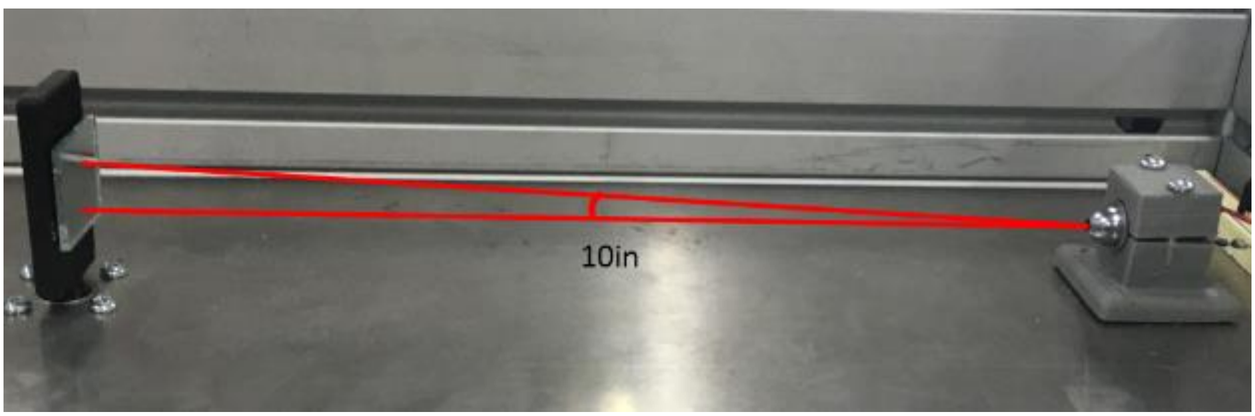


Figure 31: Project Laser Trajectory

The reason for this occurrence was that the laser when placed in secured holder was tightened to having a slight angle change. The problem was that when trying to fix this problem the team realized that when moving the device the laser would change slightly every time due to secured holder. Another reason for uncertainty was the placement of the mirror post in the selected holes. By having the mirrors adjustable the mirrors could be placed back at an angle which would cause the laser to change trajectory. The way to fix this problem in the redesign would be to focus on one of the original designs of the device and have the mirrors not adjustable and just have permanent mirrors that had different could have multiple laser images pre-set and would be seen just by using the hand crank.

8.4 WOW Factor

The WOW Factor was one of the biggest factors of importance for the device and the team was not able to test this result by taking it to a science event or even test it with other students or locals to NAU. The reason for this happening was that the device was finished late in the semester to where there were no science events to attend in order to actually gauge the audience reaction to the device for possible redesign. The Wonder Factory does plan to test the device next semester with aide from the original team who created the device in order to make modifications to help further the concept of the device.

8.5 Noise Level

The team decided to put in a speaker in order to provide sound to the device once the laser hit the sensors however due to time constraints no speakers or coding was done on device. The redesign will focus on making sure to get electronics set up early to ensure everything is working in proper order so there will be plenty of time to add in speakers to the device.

8.6 Set up

The device does meet requirements as there is no set up time required for the device. The device is created to where you can transport it to any location and set it down and it is ready for use.

8.7 Trajectory Changes

At the beginning of the project the team decided that there needed to be at least 10 trajectory changes of the laser in order to add a bigger wow factor. However the team did not take into account the redesign of adjustable mirrors rather than having preset mirror images. The adjustable mirrors at this time due to angle changes has a maximum of three trajectory changes as seen in Figure 32.

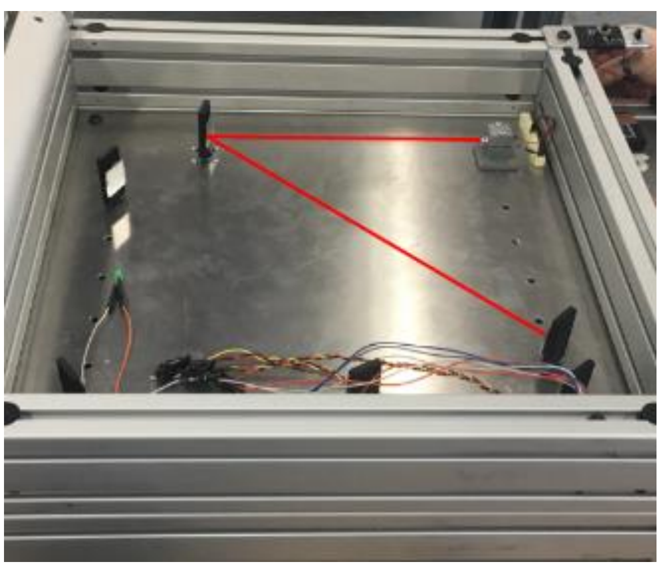


Figure 32: Project Laser Trajectory

The redesign of the project will require the team to go with original idea of having pre-set mirrors and images based on angle arrangements. This way the device can be scaled up or down for when the Wonder Factory opens a science Center in Flagstaff.

9 CONCLUSIONS

The final section is to answer the Post Mortem question based on the overall capstone experience based upon requirements set by NAU as well as standards set by the Wonder Factory Team. Figure 33 is taken from the team charter that was created at the beginning of the Spring Semester of 2017. This image will be used to reference established criteria for the future sections.

- The formation of this team is to build a stronger correspondence between Northern Arizona University and the company Wonder Factory through producing a hands-on project.

-The stakeholders in this project are the university professors Drs. Oman, Wade, and clientele from Wonder Factory.

- Project Expectations from our stake holders are as detailed
  - Must be safe to all users per applicable safety standards. Safety is your first priority.
  - Must be ready upon completion of this capstone sequence
  - Should generate up to 100 ideas –including existing, new, wacky, and off the wall concepts
  - Must select, design, build, and test one final unique idea
  - Should test the interactive display in a similar setting to expected everyday use
  - Must raise some of the funds required to finish the project
  - Must interact with the clients in order to maintain parity with their expectations

3. Team Goals:

- Team Project goal: Help promote Wonder Factory's goal in promoting awareness and interest in science through our project.

- Team's process goal: To build a project that will be simple, realistic, and entertaining for targeted audience

- Team quality goals: To build an aesthetically pleasing devise that operates and is safe. Team is committing to stay on task during the summer to ensure that quality of work is not hindered.

Figure 33: Capstone Team Charter

9.1 Contributors to Project Success

This project consisted of an entire academic year and was the first class that was offered in spring. There were bound to be new challenges however the team did perform very well in the concept generation portion of the project. The team performed well at coming up with solutions and mixing ideas to create very unique ideas that all have potential use for the Wonder Factory. The first part of the project which was the concept generation section of the Capstone project was the most interactive portion for the entire team. All teammates were able to share ideas and contributed the equal work and ideas which proves that the team had great potential to be design engineers. The team was also worked well with adaptability when presented with new challenges throughout the entire project. A few of the challenges faced being the unique hours and scheduling conflicts with the team and the machine shop. The priority of the machine shop during the Fall semester was given to the Labs for the manufacturing class which caused issues that were eventually worked out with the shop managers by finding different work hours for the shop. There was also the issue with the machine shop policy of who is allowed to use the machines and under what conditions. The policy was set to where there would be safety training offered for the Capstone teams every other weekend which was an all-day event. However the team was under the impression that if a student was enrolled in the lab and received the same safety training that would be offered on the weekends the team would be able to use the Lab right away or even after receiving training on a specific machine. This is not the case and the requirement was that the machines could only be used after the course had ended. Due to confusion the team was pushed back in early machining due to misunderstood policies. The design change made half way through the semester from wood to aluminum did not help the time management of the project as the majority of the projected ended up being late due to switch and lead to late arrival of raw materials. The team did learn from all of the challenges faced and made sure to designate task of importance based on time frame of the project during the latter half of the semester.

Continuing on to the team charter the team has created a device that has match the majority of the overall stated requirements. The team came up with 100 new ideas of possible projects for the Wonder Factory that would be deemed fun and interactive and maintained connection with the Client and included them in the final design selection with the top ten ides. Another requirement was to build a stronger correspondence with the Wonder Factory however the team met the bare minimum standard by attending a few science events as well as fund raising opportunities to help promote the Organization. The team was able to fulfill all of the requirements however the big concern that was missed was the safety factor of the device which was listed to be of big importance for the clients. The overall quality of the device was improved by having the device built out of metal however due to this design change the time spent on completing the casing of the device increased and less time was spend on making sure the device was actually safe for use. Under supervision the device is able to be use however the safety concerns are the corner edges, the exposed glass from mirrors, total weight of the device, and laser reflecting back into the audience eye with a large enough degree shift. With more time the team can fix the safety concerns but for now the team does fulfill the purpose and the majority of the goals although by being the bare minimum standard.

Overall the project was a great learning experience in how materials come together and why any given product may have multiple manufactures to different pieces just due to the amount of precision and accuracy needed for each individual part to come together. This project was a great learning experience of the engineering design and manufacturing process of a project as what is drawn up in a SOLIDWORKS image may not always be possible to machine or even receive material to specific dimensions due to practicality. Other skill learned was the machining of devices as well hands on experience with electrical components. With the experience both in machining and electrical hardware the team learned how to make technical decisions based upon intuition and practicality of how the progress of the device is going.

9.2 Opportunities/areas for improvement

The ground rules and coping strategies were establish at the very beginning of the project and was intended to make sure that the entire group contributed evenly to the ideas and the overall project. The ideas that were shared were intended to make sure that the group stayed on task and also allow the team to be the most productive by making sure each individual contributed or put in their input and ideas. There were consequences on missed deadlines and the entire group agreed upon criteria. At the beginning of the project the entire team did a good job at trying to make sure all criteria was followed however, as the semester progressed the team began to adapt to challenges that arose and found it easier to adapt to changes rather than forcing confrontation in every meeting or when new challenges arose. The team concluded that this does not happen on every team and that there needs to be more of an accountability to help keep the teams on track however the only solution that was presented was to have instructors sit in on team meetings to make sure that they actually get done. Another suggestion to help improve the course would be to have a few more assignments based on individual reports or updates based on the job the team decided on. If more accountability in chosen jobs was given there would be more updates and lack of tendency to blow off assignments or jobs in this regard.

Areas where the team could have improved upon was time management. The team always tried to meet together often however there were struggles with being punctual and being present at meetings. This lead to missed deadlines and decisions that needed to me made as a whole group that were at times only made by half of the team. This also meant that when deadlines were set the team needed to meet them so that there would be plenty of time to do re-edits as well as early submission to instructor to make sure the assignments and projects were going in the right direction according to assignment guidelines. However with teammates at times missing deadlines and sending materials late and incorrect this lead to adapting the assignment to few individuals to fix error or do entire section by themselves. Another portion of the project that could have been improved upon was the overall quality of the project. The mechanical casing of the devise is smooth however there is a lot of disorganization of all the electrical components that were meant to have a place that ended up being left randomly along the project. A way to improve these areas would have been to make sure there was more accountability in each section of the project to ensure that there was progress being made throughout the entire project rather than just waiting or being told how to do an assignment and not using decision making skills or intuition.

An issue that was stated in a previous section was the machine shop hours. There was a difficult time being able to have access to the machine shop due to the class schedule confliction with Labs occurring for other classes. If there would be a second machine shop on campus or to have the possibility of having hours on the weekend this would help combat the issue of conflicting schedules. Another idea to help would be to provide information of a wood shop that is on campus just in case a team does decide to work with wood material. These are few suggested solutions however the engineering department and staff is doing a remarkable job in all regards as well as adapting to know challenges and struggles.

10 REFERENCES

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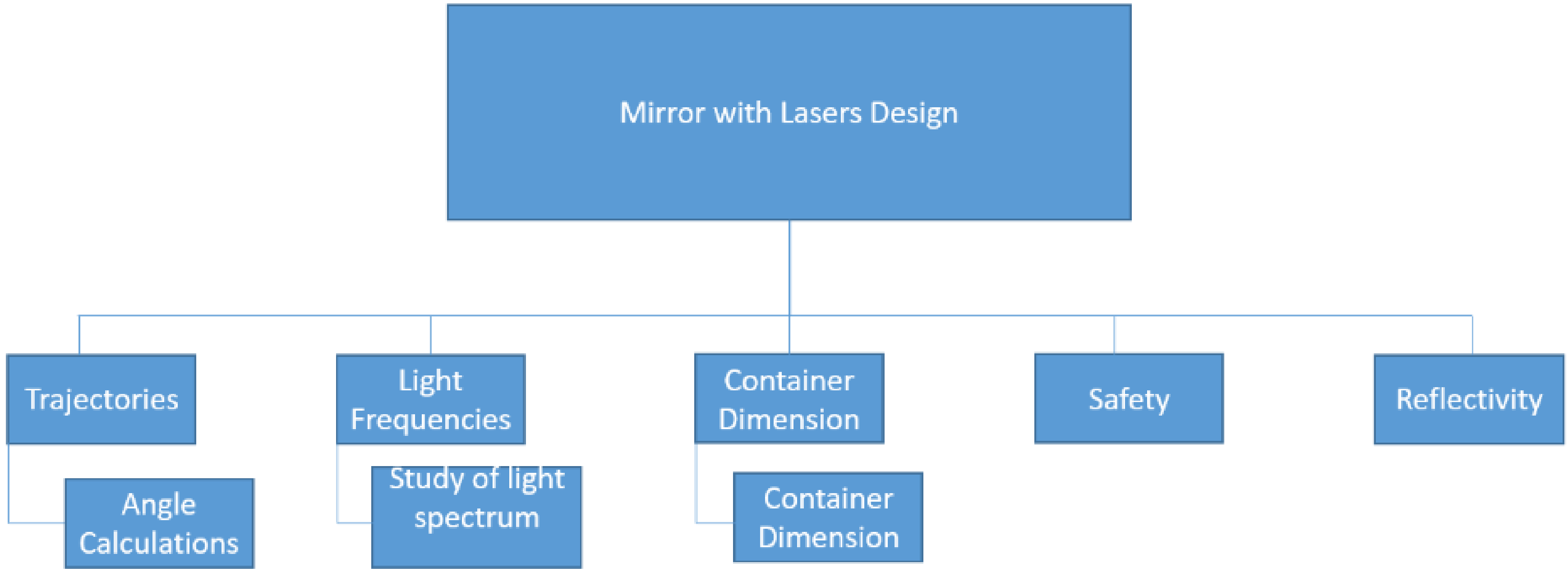
11 APPENDICES

11.1 Appendix A: House of Quality

Customer Requirement	Weight	Engineering Requirement	Total Weight	Laser Frequency	Cost of Production	Expected Life Span	Dimensions	Amount of Illumination in Device	Cost of Repair	Number of steps to complete device	Degrees of Freedom for the Rotatable Mirrors	Surprised Facial Expressions	Noise Loudness of device upon completion	Number of Devices	Time for set up	Solvabilty	Max Compressive Stress on Device Casing	Amount of time spent on Device	Number of surfaces reflected off of
1. Saftey	5	-	3	5	5		1				5		2				5		
2. WOW Factor	5	-			4			4		2		5	4	3		2		2	
3. Hands-On	5	-	3	2	3		2			3	4	2	3	5		4		3	
4. Integration of STEAM concepts	4	-		4						2						3			5
5. Simple Instructions	4	-								5						5		2	
6. Durability	4	-	1		4	4			2					3			5	2	
7. Visually appealing	3	-	3	3	4		4					3							
8. Narratives	3	-																	
9. Easy Assembly	2	-	2		3		2		1						5				
10. Multiple Visitor	2	-			1		2			2		1	2	5		4		3	
11. Mobility	1	-	5		3		5												
Absolute Technical Importance (ATI)			52	60	99	16	40	20	10	57	45	46	49	62	10	70	45	47	20
Relative Technical Importance (RTI)			6	4	1	15	12	14	17	5	10	9	7	3	16	2	11	8	13
Target(s)			40	650	300	2	3	60	40	3	1	N/A	70	2	8	2	500	5	10
Tolerance(s)			< 50	500< X < 700	X < 400	1 < X < 3	X < 5	20 < X < 100	X < 50	X < 5	X < 2	X < 1	60 < X < 90	1 < X < 4	5 < X < 10	1 < X < 3	400 < X < 1000	1 < X < 8	1 < X < 20
Units			Lbs	Nanometers	Dollars	Years	ft cubed	Lux	Dollars	Number	Degrees	Smiles	DeciBel	# of Devices	Minuets	Minuets	Newtons	Minuets	# of angle changes
Testing Procedure (TP#)			2.3.1	2.3.2	2.3.3	2.3.4	2.3.5	2.3.6	2.3.3	N/A	2.3.7	2.3.8	2.3.9	N/A	2.3.10	2.3.10	2.3.11	2.3.10	2.3.12
Design Link (DL#)			1	2	3	4	5	6	3	N/A	7	8	9	10	11	12	13	14	15

11.2 Appendix B: Functional Decomposition



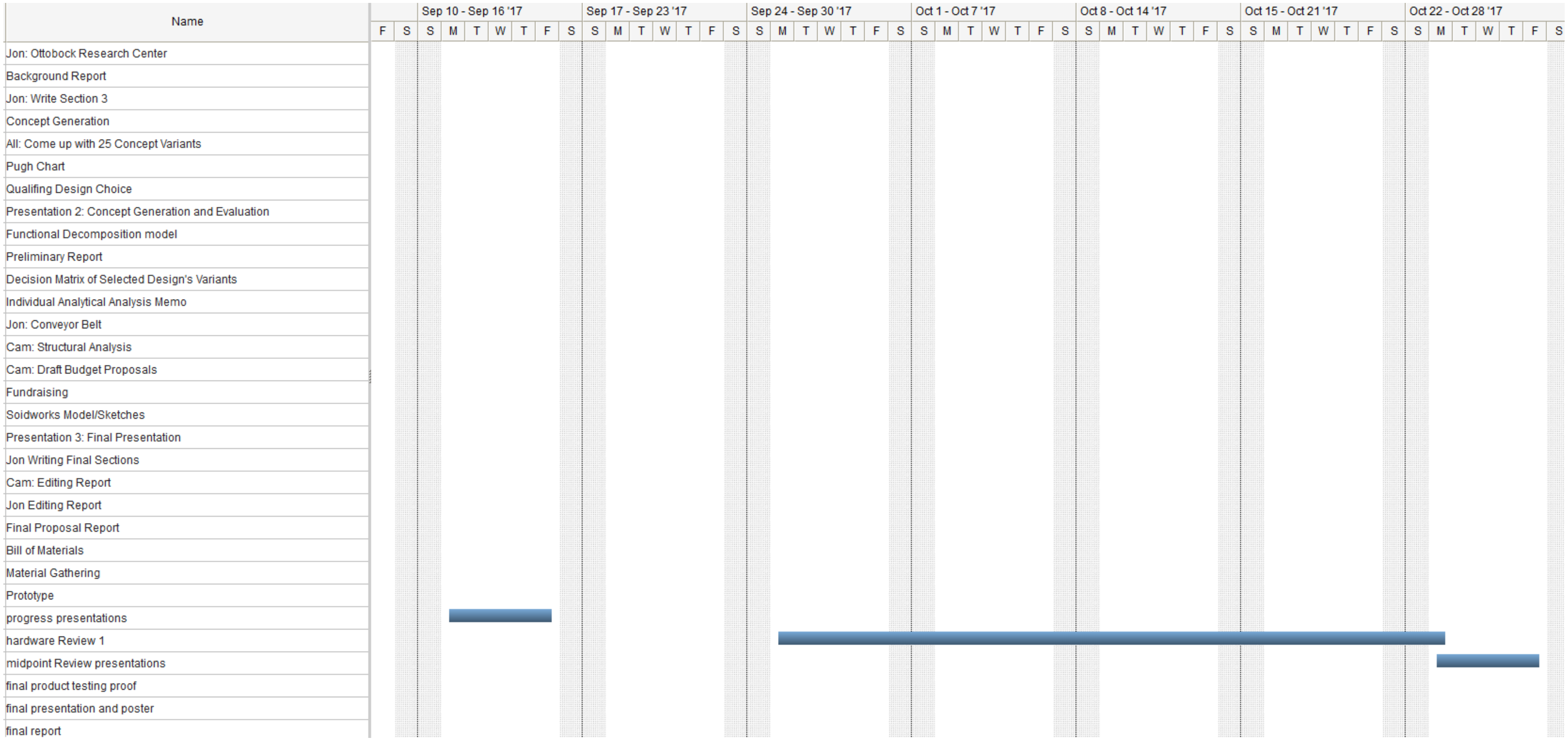
11.3 Appendix C: Pugh Chart

Concept Selection Legend
Better +
Same S
Worse -

Key Criteria	*Importance Rating*	Electric Car Generator	Group Game Matching Animal Weight	Greenwall Screen	Different Color Fire with metals	Peep Vacum	Dyed Roses with color lights	Graphite Circuits	Robotic Arm	Sphere Bot	New Material for Solar Panels	Vaporization (smoke pellots and Vacum)
Safe	**5**	NA	+	s	-	+	+	s	+	s	+	s
Wow Factor	**5**	NA	-	s	+	s	-	s	+	s	-	+
Hands-on	**5**	NA	-	+	-	-	-	+	s	s	-	s
Integration of STEAM concepts	**4**	NA	-	s	s	+	+	s	+	-	+	+
Simple instruction	**4**	NA	+	+	+	+	+	s	+	+	+	+
Durability	**4**	NA	s	+	-	+	+	s	-	+	+	s
Visually Appealing	**3**	NA	-	+	+	s	+	+	+	s	s	+
Narratives	**3**	NA	+	-	s	s	+	s	s	s	s	s
Easy Assembly	**2**	NA	+	-	+	-	-	s	-	+	-	-
Multiple Visitor	**2**	NA	s	+	+	+	+	+	+	+	+	+
Mobility	**1**	NA	+	+	+	s	-	s	+	+	+	+
Sum of Positives			5	6	6	5	7	3	7	5	6	6
Sum of Negatives			4	2	3	2	4	0	2	1	3	1
Sum of Sames			2	3	2	4	0	8	2	4	2	4
Weighted Sum of Positives			15	19	17	19	25	10	24	13	20	19
Weighted Sum of Negatives			17	5	14	7	13	0	6	4	12	2
TOTALS			**-2**	**14**	**3**	**12**	**12**	**10**	**18**	**9**	**8**	**17**

Key Criteria	Tonic Water and Blacklight	Balloon Powered light	Rail Gun	Generator and Resistor	Water Tracks Hydoelectric Dam	Modeling Car	Miniture Rankine Cycle	High Energy Laser balloon popping	Gliding Cape	Armor	Tesla Wire	Black body Radiation	Mirror Reflections	Wind Turbine
Safe	s	+	s	+		+	s	s	+	-	-	+		+
Wow Factor	s	-	+	-		+	-	+	s	+	+	s		s
Hands-on	-	-	-	s		-	-	+	-	+	-	-		-
Integration of STEAM concepts	-	-	s	s		s	+	s	-	s	s	+		+
Simple instruction	s	+	s	s		+	-	+	+	+	s	+		+
Durability	+	+	s	s		s	-	+	-	+	+	s		s
Visually Appealing	+	-	+	+		+	+	+	+	+	+	+		+
Narratives	s	s	s	s		+	+	s	s	s	+	s		+
Easy Assembly	-	+	s	s		-	-	s	+	-	s	-		s
Multiple Visitor	+	s	-	+		+	+	s	+	+	s	-		+
Mobility	+	+	+	-		-	-	-	+	+	+	+		+
Sum of Positives	4	5	3	3	0	6	4	5	6	7	5	5	0	7
Sum of Negatives	3	4	2	2	0	3	6	1	3	2	2	3	0	1
Sum of Sames	4	2	6	6	0	2	1	5	2	2	4	3	0	3
Weighted Sum of Positives	10	16	9	10	0	22	12	21	17	24	16	17	0	22
Weighted Sum of Negatives	11	17	7	6	0	8	21	1	13	7	10	9	0	5
TOTALS	**-1**	**-1**	**2**	**4**	**0**	**14**	**-9**	**20**	**4**	**17**	**6**	**8**	**0**	**17**

11.4 Appendix D: Gantt Chart



11.5 Appendix E: Overall Calculations

Casing

F = W = 302.5 N

L = 18 in = 0.4572 m

E_{wood} = 8.549*10^{9} Pa

I_{beam} = 4.44*10^{-6} m^{4}

$\sigma_{y,wood}$ = 33.09 mPa

$\sigma_{y,steel}$ = 370 mPa

r_{screw} = 0.002413 m

$$\delta = \frac{W \cdot L^3}{192 \cdot E \cdot I} \longrightarrow \frac{302.5N \cdot (0.4572m)^3}{192 \cdot 8.549 \cdot 10^9 Pa \cdot 4.44 \cdot 10^{-6} m^4} = 3.97\mu m$$

The top horizontal beams are reasonably rigid that the deflection is minor.

$$\sigma = \frac{\tau \cdot y}{I} \longrightarrow \sigma = \frac{\frac{F \cdot L}{2} \cdot y}{I} \longrightarrow \frac{302.5N \cdot \left(\frac{0.4572m}{2}\right) \cdot 0.1016m}{4.44 \cdot 10^{-6} Pa} = 1582.38kPa$$

$\sigma_{y,wood}$ is greater than 1582.38kPa thus the upper beams will not fail from bending.

$$\tau = \frac{F}{N \cdot A} \longrightarrow \frac{302.5N}{1 \cdot \Pi \cdot (2.413mm)^2} = 16.53mPa$$

There are 4 screws holding each beam up, the above caluclation shows that even if all stress was concentrated onto 1 screw it still would not fail since $\sigma_{y,steel}$ is greater than 16.53mPa. This makes testing for distributed weight over 4 screws redundant as the stress will decrease.

$$\sigma = \frac{F}{N \cdot A} \longrightarrow \frac{302.5N}{1 \cdot (0.0508m)^2} = 117.21kPa$$

There are 4 vertical beams holding up the top set of beams. The above equation shows that concentrating all stress onto only one vertical beam still leads to $\sigma_{y,wood}$ to be greater than 117.21kPa. It is also redundant to examine stress distributed over the 4 vertical beams as the stress will decrease.

Electronic Model Code

Code 1:

```
// these constants describe the pins. They won't change:
const int groundpin = 18;          // analog input pin 4 -- ground
const int powerpin = 19;           // analog input pin 5 -- voltage
const int xpin = A3;               // x-axis of the accelerometer
const int ypin = A2;               // y-axis
const int zpin = A1;               // z-axis (only on 3-axis models)

void setup() {
  // initialize the serial communications:
  Serial.begin(9600);

  // Provide ground and power by using the analog inputs as normal
  // digital pins.  This makes it possible to directly connect the
  // breakout board to the Arduino.  If you use the normal 5V and
  // GND pins on the Arduino, you can remove these lines.
  pinMode(groundpin, OUTPUT);
  pinMode(powerpin, OUTPUT);
  digitalWrite(groundpin, LOW);
  digitalWrite(powerpin, HIGH);
```

```
}

void loop() {
  // print the sensor values:
  Serial.print(analogRead(xpin));
  // print a tab between values:
  Serial.print("\t");
  Serial.print(analogRead(ypin));
  // print a tab between values:
  Serial.print("\t");
  Serial.print(analogRead(zpin));
  Serial.println();
  // delay before next reading:
  delay(100);
}
```

Code 2:

```
// these constants won't change:
const int ledPin = 13;      // led connected to digital pin 13
const int knockSensor = A0; // the piezo is connected to analog pin 0
const int threshold = 100;  // threshold value to decide when the detected sound is a knock or not


// these variables will change:
int sensorReading = 0;      // variable to store the value read from the sensor pin
int ledState = LOW;         // variable used to store the last LED status, to toggle the light

void setup() {
  pinMode(ledPin, OUTPUT); // declare the ledPin as as OUTPUT
  Serial.begin(9600);       // use the serial port
}
```

```
void loop() {
  // read the sensor and store it in the variable sensorReading:
  sensorReading = analogRead(knockSensor);

  // if the sensor reading is greater than the threshold:
  if (sensorReading >= threshold) {
    // toggle the status of the ledPin:
    ledState = !ledState;
    // update the LED pin itself:
    digitalWrite(ledPin, ledState);
    // send the string "Knock!" back to the computer, followed by newline
    Serial.println("Knock!");
  }
  delay(100);  // delay to avoid overloading the serial port buffer
}
```

11.6 *Appendix F: Bill of Materials*

Part #	Part Name	Description	Qty	Units	Supplier	Unit Cost	Cost	Link to price and/or info/picture
1	16 Tooth Sprocket	Bike Sprocket	1	N/A	Roller Chain	$ 5.14	$ 5.14	http://www.rollerchain4less.com/35A16-Type-A-Plate-Sprocket-12-Bore_p_2802.html
2	22 Tooth Sprocket	Bike Sprocket	1	N/A	Roller Chain	$ 6.09	$ 6.09	http://www.rollerchain4less.com/35A22-Type-A-Plate-Sprocket-12-Bore_p_2807.html
3	Pine Wood	Wood for Casing	3	2in X 4in X 10 ft	Home Depot	$ 3.52	$ 10.56	http://www.homedepot.com/p/2-in-x-4-in-x-10-ft-Standard-and-Better-Kiln-Dried-Heat-Treated-Spruce-Pine-Fir-Lumber-161659/100080482
4	Pine Plywood	Wood for Casing	1	1/4in X 4ft X 8ft	Home Depot	$ 21.02	$ 21.02	http://www.homedepot.com/p/1-4-in-x-4-ft-x-8-ft-BC-Sanded-Pine-Plywood-166014/100063669
5	Aluminum Axel	Aluminum for Axels	2	2.5in X 4in X 1in	Speedy Metals	$ 12.05	$ 24.10	http://www.speedymetals.com/pc-862-8350-2-12-x-4-2024-t3-aluminum.aspx
6	Aluminum Holders	Aluminum for Axle Holders	4	2in X 2in X 1in	Speedy Metals	$ 5.22	$ 20.88	http://www.speedymetals.com/pc-930-8377-2-sq-2024-t3-aluminum.aspx
7	Aluminum Billet	Crank to handle Base	1	1.25in X 1.25in X 1in	Speedy Metals	$ 2.73	$ 2.73	http://www.speedymetals.com/pc-928-8377-1-12-sq-2024-t3-aluminum.aspx
8	Aluminum Billet	Crank Handle	1	3in X 3in X 1in	Speedy Metals	$ 9.59	$ 9.59	http://www.speedymetals.com/pc-932-8377-3-sq-2024-t3-aluminum.aspx
9	Aluminum Billet	Axle to Mirrors	1	1in X 3in X 1in	Speedy Metals	$ 3.61	$ 3.61	http://www.speedymetals.com/pc-858-8350-1-x-3-2024-t3-aluminum.aspx
10	Aluminum Billet	Mirror Pegs	18	1.25in 2.5in X 1in	Speedy Metals	$ 3.67	$ 66.06	http://www.speedymetals.com/pc-849-8350-1-14-x-2-12-2024-t3-aluminum.aspx
11	ZINC Wooden Screws	Wooden Screws for casing	1	#10 X 4in	Copper State	$ 11.61	$ 11.61	https://www.copperstate.com/shop/320/wood-screws
12	Machine Screws	Screws for Assembly	1	TBD	Copper State	$ 12.00	$ 12.00	https://www.copperstate.com/shop/291/flat-head
13	Laser	Laser for Design	1	3.7 Volt	Amazon	$ 11.71	$ 11.71	N/A
14	Craft Mirrors	Reflective Surfaces (25 pack)	1	.5in X .5in	Consumer Crafts	$ 1.27	$ 1.27	https://www.consumercrafts.com/store/details/catalog/floral-square-mirrors/1613-60?gclid=CL-spO2P1dMCFUi2wAodQSoK_A
15	Acrylic Panel	Transparent Viewing Glass	4	12in X 24in X 1/8in	Amazon	$ 8.01	$ 32.04	https://www.amazon.com/Acrylic-Cast-Clear-Sheet-12/dp/B00FRUBXKO
16	Electronics	Additional Cost for electronics	1	TBD	TBD	$ 60.00	$ 60.00	N/A
	Total		**42**				**$298.41**	