NORTHERN ARIZONA UNIVERSITY

College of Engineering, Forestry & Natural Sciences

The Wonder Factory STEM Display
B – Team 15

Final Report

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DISCLAIMER

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EXECUTIVE SUMMARY

The team was tasked with creating an interactive educational STEM displays that would be used to enable users to employ critical thinking while solving science problems for fun. Therefore, the design was expected to be safe, durable, enjoyable, and exhibit critical thinking features. Moreover, the design was required to contain both visual and audio components that would engage users and make them feel creative while solving puzzles. Moreover, the team was expected to generate 100 concepts to obtain a single unique idea to implement. Notably, the team came up with all the essential concepts that were utilized to create an educational design consisting of three unique subsystems namely electronic, gearbox, and safety system. Specifically, the gearbox contained two sets of gears connected to a generator that was in turn attached to a puzzle circuit. Lastly, the circuit puzzles were attached to a race track. It should be pointed out that most of these components were fabricated in the workshop while other were ordered. In particular, the wooden parts were cut into shape and manufactured by team while components such as 3D printed gear were ordered. During its operation, the design required users to solve a puzzle concerning gear ratios and resulting speed for the car on the race track to operate. In particular, one was expected to creatively select gear whose ratio would give a higher speed to be attached to the gearbox so as to win the race. It is worth pointing out that once users crack the puzzle of obtaining the best gear ratio and win the race, they feel creative and value their engineering concepts employed. In addition, the gearbox was covered with transparent plastic that enabled users to observe the effects of their gear selection on the rotating gears besides hearing gear movements while racing. This enabled the design to be more interactive by acquiring audiovisual features that intrigue users. The four fabricated stations also enable multiple users to solve the puzzles individually and race simultaneously with other user enhancing fun and competitiveness of users. Subsequently, the project was designed to operate when the gearbox front cover is in closed position improving the safety of the device and further incorporating creativity. The overall puzzles, therefore, required users to adhere to safety requirements by closing gearbox front cover and solving the gear ratio puzzles before racing. The final design was also light and could be carried by one person comfortably since it weighed about 43lb. Most importantly, the design utilized simple tricks and puzzles that could be solved easily after reading the instructions attached next to the gearbox. Therefore, the final design was intriguing, enjoyable, and adaptive to users of all ages.

Figure 1: Final Solution

ACKNOWLEDGEMENTS

The team is greatly indebted and thankful for facilities, sponsors, and shops for the assistance they were accorded during the design and fabrication until the completion of the project. Specifically, we would like to convey our special thanks to our sponsors W. L. Gore & Associates for the timely support with extra funds that enabled us to complete four stations. Most importantly, special thanks go to our client The Wonder Factory, Inc who provided us with a golden opportunity to lead the next generation of creative minds to an extra level as creators, thinkers, and makers through hand on interactions with engineering and science by creating STEM display. We sincerely had the greatest opportunity to work on the project at the engineering fabrication shop to complete four stations. Lastly, we thank our faculty advisor David Willy for providing some ideas to improve the project and a special thank you our instructor Dr. Sarah Oman for assisting us to find right solutions for printing the gears from NAU RAPID Lab and makes sure all the stations are professional by taking her feedbacks. Thank you goes to the mechanical department to give this opportunity for our team to design a challenging project to improve team's skills and understand new techniques of manufacturing.

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1. BACKGROUND

This section provides information on the client, The Wonder Factory, and explains the company's goals for the local community. The client's project description is delivered along with how this project's objective will correspond with The Wonder Factory's aspiration for the community of Flagstaff, Arizona.

1.1 Introduction

The Wonder Factory is a learning center that integrates art into science, engineering, and technology and provides interactive experiences for the young and young at heart. The Wonder Factory STEM Display B – Team 15, which will be referenced as "the team", has the opportunity to generate learning through play. The Wonder Factory staff, along with the team, feel passionately that the next generation must be given opportunities to have hands-on, interactive experiences to take their positions as the thinkers, makers, and creators of the future. Northern Arizona University will be sponsoring the project and will offer financial support up to $1500. Once the team is finished with the project, there is a possibility that the project will be on display at The Wonder Factory, Inc. museum (TWF) in Flagstaff. Upon completion, children and students will have more incentive to visit TWF because the project will give them a safe, interactive, meaningful, and enjoyable experience. The frame of the project takes a complex scientific theory and breaks it down to a simple level. Because of this, the younger generation in Flagstaff, regardless of experience, will be able to enjoy and learn science in a way that they may not have been able to before.

1.2 Project Description

The following is the original project description provided by TWF:

> Your task is to generate lots of interactive display ideas and to ultimately design build and test one final display ready for public consumption. Your final design must:
>
> - 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 [1]

1.3 Original System

This project involved the design of a completely new interactive display. There was no original system when this project began.

2. REQUIREMENTS

The team analyzed the project description and met with the client to create the customer requirements (CRs). These CRs specify and clarify the overall project objectives and were given a weighting based on importance. The team determined the engineering requirements (ERs) needed to evaluate the potential designs and future final design. The ERs were designed to be verifiable with target values with tolerances with their respective justifications. Testing Procedures (TPs) and Design Links (DLs) were created to evaluate the engineering requirements and determine how they meet the targets and tolerances are explained.

2.1 Customer Requirements (CRs)

The CRs for this project included: portability, safety, ability to have multiple users, ability for users to project themselves into the role, aesthetics, and simplicity. Additionally, the project must have tactile, auditory, and visual aspects and must enable the users to "feel smart". These projects were meant to be used by children to learn scientific, technological, mathematical and engineering principles. Therefore, one of the paramount requirements was that the device should be safe. The safety aspect of the project was achieved by covering the moving parts. The customers expected the device to be portable by having wheels or being light. A light project could be obtained by using light materials, such as using aluminum instead of steel. The customers needed multiple users to be able to use the device. This required the project having features such as adjustable height. The customer also expected the device to be functional, in that children should use it effectively to learn scientific, technological, mathematical and engineering principles. The functionality of the device was achieved through features such as tactility, visibility, and auditory. The STEM projects were expected to be aesthetically pleasing. This feature motivated children to use the projects for their learning purposes. The last requirement by the customers was that the devices should be simple in construction and operation since they are meant to be used by children.
Each CR was given a weight based on importance. The most important requirements were given weights of 5 while the least important requirements were given weights of 1. The prioritized requirements were summarized in the House of Quality in Table 1 of Section 2.

2.2 Engineering Requirements (ERs)

The ERs were designed to provide a way to objectively measure specific parameters or conditions based on the CRs. Each ER was assigned a value along with a justifiable or rationale tolerance. In regards to portability, which has been gauged based on weight, fixtures, and durability of the components, a score of 5 shows that the designed object moves with ease, and the motion does not affect the functionality. Given that there is a range of area of portability, a score of 5 has been attained for an area of less than 200 ft^2. Here, tolerance reduces outside the stated area of 200 ft^2. Regarding safety, the precautions include weight, power, and exposed faces. Here, the highest score of 5 is attained when the weight is low and no sharp parts are exposed. Regarding usability by multiple individuals, a system that accommodates at least two users has been regarded as multi-user.

The highest score was given when more users can be served at the same time. Tactility was a measurement of the extent to which the product can be handled by human hands. In this case, the rating was based on the ergonomic aspect of the exposed parts as well as the power consumed. Also, the presence of sharp edges, which could injured the user, was a negative aspect thus would result in a lower rating. Regarding auditory and visual aspects, which majorly encompass the comfort of the user, based on how the product affect the hearing and the vision of the user, the rating depended on the power consumed and the higher the power consumed, the lower the above two aspects, given that there were audio and visual noises that affect the user negatively. The project attained high rating when it had an interactive display and offers an educational value during the use of the product. Finally, how smart the user felt and simplicity of use were two aspects regarded in this case too. In this case, the simplicity was determined by the display and educational aspect of the product.

2.3 Testing Procedures (TPs)

Testing of the designed product shall had been done per the set of parameters, which must comply with customer and engineering requirements. In this case, the system shall been tested for conformity, with a rating of each aspect derived from the initiated the HoQ measurements. Here, the testing procedures included the power rating of the system, system weight, combined operation of the parts, visual and ergonometric aspect of the prototypes and the final design. As such, each of the Engineering and customer requirements shall have been investigated, based on design links. The team had separated the project to seven parts to test if each part is working well.

1. Power Generator: The team would clamp the generator into a mill and tested the voltage and current output at various RPM with a multi-meter

2. Assembled Set and Racetrack: The team would weigh one assembled set and the racetrack by weighing one team member on a home scale without holding anything and again with the team member holding the assembled set or racetrack. The difference would be taken to calculate the weight of the assembled set and of the racetrack. Each assembled set would contain the crank arm, gears and gear mount, generator, and circuit puzzle

3. Design Size: The team would take an initial measurement with a student-owned tape measure using a full-size cardboard prototype. A second measurement would be taken of the operational, full-size prototype and of the final design.

4. Operation: With all stations being used, the slot car racetrack would be visually inspected for proper operation.

5. Gears: Test 3D printed gears by assembling the gearbox with rear gears attached. Connected a cordless drill to the end of the shaft connected to the larger gear. Measuring with a tachometer, run the shaft to create a 1300 output RPM (to generator) for five minutes. After the time was done, checked the gears for any wear.

6. Gear box: Test with plastic material, then check if we could use this material or not.

7. Visual Display: The plexiglass material must be made for a cover to assure that users can see how the gears rotate. The display must be visual.

8. Sharp Edges: We would touch all the areas and angles of the materials to make sure that the materials will not injure hands

9. Safety Mechanism: When safety mechanism was engaged, attempted to rotate shaft using crank arm. When safety mechanism was disengaged, shafts shall has been freely rotate

2.4 Design Links (DLs)

For this section, the team worked on how the design meets each Engineering Requirements. Voltage tests were conducted where the team decided to use a power generator, and test whether the system will adequately and safely operate using the grid power, rated 220V AC power from the mains. Weight and balance of forces tests entailed investigation of the total weight of the system and thus be compared to the set limits on the House of Quality (HoQ). Design size test entailed the overall surface area of the system. The system should operate simultaneously. Thus, the operation test was conducted. Gear box test was fundamental since the gears are made of plastic material, the applicability of this material to the set workload was also tested. Another test was the visual test which entails visibility of the operation process of the system, through the cover of the system. Finally, ergonometric of the system shall be tested to ensure the safety of the users.

1) Power and voltage requirement: If the power output is within the target with tolerance, no action is needed. If the output voltage is too low, the part will be returned and exchanged for a new generator.

2) Weight: If each assembled set/racetrack weigh less than 150lb, no further measurements will be made. If anything is over 150lb, the team will begin to research using plastics and/or ligher metals to reduce weight

3) Set-up Area: If the assembled design area is within the target with tolerances, no further action is necessary. If the design area is too big, the team will reduce the number of users to fit in the set-up area.

4) Simultaneous Operation: If all stations are not able to operate their individual slot car, ensure all connections are in the proper location. If still not operational, use a multimeter to check all connections between the generator and the slotcar track.

5) Reach 1000RPM: check which gear set can be reached 1000 RPM (+/- 200 RPM) when we give 70 RPM as an input.

6) Visual display added: The plexiglass material must be made for a cover to assure that users can see how the gears rotate. The display must be visual.

7) No exposed sharp edges: When we cut and designs all the parts together, we have to make sure the parts do not have sharp edges

2.5 The House of Quality (HoQ)

In this section, the House of Quality was completed by doing customers' requirements, engineering requirements, absolute technical importance, relative technical importance, targets, tolerances, testing procedures and design links. The main reason of doing the HoQ to assure all results of the design would meet the expectations of the all requirements. To start with creating the HoQ, the team had to list the customer requirements and rate the most important requirements. This allowed the team to focus on best requirement. After that, the team had to list the engineering requirement to rate the customer requirements that are related to the engineering requirements. Thus, the team could rate the engineering requirements using scale 1 to 10 to know what to select for targets with tolerances to assure the design would succeed all tests.

Table 1: The House of Quality (HoQ)

House of Quality (HoQ)

Customer Requirements (1 - 9):	Weight	Engineering Requirement	fits in set-up area	low total weight	low cost	meet power/voltage requirement	no exposed sharp edges	visual display added	multiple, simultaneous operation	educational level	meets required RPM
1. Portability	5	-	5	4				1	2		
2. Safety	5	-		4		3	4				4
3. Multiple users capable	3	-							5		
4. Tactility	3	-				2	4				
5. Auditory	2	-				2					
6. Visuality	3	-				2					3
7. Project into role	4	-						5		4	
8. Feel intelligent	4	-						4		5	2
9. Simplicity	5	-						3		5	2
Absolute Technical Importance (ATI)	-	-	25	40	0	31	32	56	25	61	47
Relative Technical Importance (RTI)	-	-	8	4	9	6	5	2	7	1	3
Targets; with Tolerances			100 ft^2 total; <200 ft^2 total	90lb/assembly; <150lb/assembly	$1200 total; <$2000 total	20V & 1A; +/- 2V & < 1.5A	1/8" radius; > 1/6" radius 1/16" chamfer; > 1/14"	1 display; 1-4 total	4 users; +/- 2 users	tailored to age 10; > 6 years old	1000RPM: +/- 200RPM
Testing Procedure (TP#)			3	2	5	1	7	6	4		
Design Link (DL#)			3	2		1	7	6	4		5

3. EXISTING DESIGNS

This section details the research conducted on the current processes used by other science centers and available interactive displays. The team evaluated several science museums/centers to gain information on what type of information was delivered to their visitors and how it was delivered. The team then went into further detail by examining interactive displays and how they communicate information to their users.

3.1 Design Research

With TWF being a learning center that provides interactive experiences using STEM integrated with art, the team researched other science museums and centers around the country. The team conducted this research by attending science events in Flagstaff where TWF was a participant and by investigating other centers of science utilizing their official websites. The team chose four science centers in the United States to evaluate and determine what kind of information was provided to their visitors, what type of exhibits were available, and how information to delivered to the visitors. At the subsystem level, the team found four different interactive displays or exhibits that were either currently operating in a science center or could potentially be an interactive exhibit. These four subsystems were assessed to establish a benchmark on what was currently being used in the industry and what information was provided through each exhibit.

3.2 System Level – Science Centers

The research conducted at the system level was aimed to find what type of information was provided by other centers and how they deliver it to their visitors. This allowed the team to understand some what kind of information was provided by science museums along with current methods used to communicate it. The team investigated four different science centers in the United States: the Oregon Museum of Science and Industry in Portland, the Pacific Science Center in Seattle, the Arizona Science Center in Phoenix, and the Exploratorium in San Francisco.

3.2.1 Existing Design #1: Oregon Museum of Science

Museums are known for educating the community by researching and collecting information. One of the most known museums that have followed this path of offering education to the community in the United States is Oregon Museum of Science and Industry [2]. Oregon Museum is found in Portland and aims at providing both engaging educational exhibits that focus on STEM. OMSI is the largest organization in the United States that provides education programs to families, children, adults, schools, etc. through presentations. The museum also offers financial assistance to students so that they can complete their scientific projects. The museum is about 219,000 square feet with about five halls that have numerous scientific exhibits and displays, a submarine display and a planetarium. The sections are the USS Blueback, the Featured Exhibit Hall, the Turbine Hall, the Life Sciences Hall, and the Science Playground

The USS Blueback is a submarine located in the museum and used to educate the public about propellers. This display offers daily tours and visitors how the option to sleep over. The Featured Exhibit Hall is used to display temporary exhibits. The exhibits may be produced by the museum personnel or may have been purchased from other institutions [2]. The exhibits found in the Turbine Hall are projects that apply the principles of engineering, physics, chemistry, and technology. The chemistry lab located in the turbine hall and has six stations that allow visitors to perform experiments that test nature of matter biochemistry, chemical reactions, etc. The hall also is equipped with a physics lab, Laser/Holography, and Vernier technology laboratory. In the physics lab, exhibits such as electrical circuits, magnetism, motion detectors, etc. are displayed. The Laser/Holography lab is used to generate holograms and is opened one hour in a day. In the Vernier laboratory, the visitors get to learn the effects of technology on the society by investigating various technologies such as communication technology, robotics, and biomedical technology among others [2].

The Life Sciences Hall is located on the second floor of the museum and is divided into Life science hall and Earth science hall. The life science hall allows the visitors to study a wide variety of animals. Also, there is an aging machine that enables visitors to create a picture of themselves as they age. The earth science hall displays the geology – orientations. The Earth science hall has a Watershed laboratory that allows the visitors to investigate on erosion cycle using a river model and the Paleontology Laboratory gives the visitors an opportunity to see the excavation process. The Science Playground is an area located on the second floor of the museum and serves children up to six years old. The science playground gives children security and allows them to learn scientific principle through play [2]. Examples of science exhibits found in these locations include; giant sandbox, reading area, etc. In the science playground, there is a discovery laboratory, which gives children an opportunity to develop their cognitive behavior. Other sections of the museum are the planetarium and an Auditorium. The planetarium is used for the purposes of astronomy shows while the auditorium used for holding events such a science fair.

3.2.2 Existing Design #2: Pacific Science Center

The Pacific Science Center in Seattle, WA, is a science museum that "brings science to life". The history of this science museum consists of very interesting milestones and dates. The Pacific Science Center began as the United States Science Pavilion during Seattle's World Fair during 1962. After millions of people had come to visit this place over the years, eventually the science pavilion was given a new life as a not-for-profit Pacific Science Center as we now know it today. This created history as it was the first U.S. museum founded as a science and technology center. Some interesting aspects of this science museum are that it contains programs for people of all ages, ranging from toddlers to adults, and exhibits for the everyday visitors [3].

Examples of some of the programs for the children and toddlers consist of many labs, camps, and clubs that they can join. Children can join anything from the "Preschool Family Play Lab" which gives the parents the tools to teach their young children some interesting science ideas through themes and songs, all the way to the "Scouts in the Wild" which gives children an after-school option to learn about badges, wilderness, and various other outside team building activities [3].

Some of the major exhibits that exist at the Pacific Science Center are "The International Exhibition of Sherlock Holmes", "The Studio". With "The International Exhibition of Sherlock Holmes", visitors are given the chance to discover how Sherlock Holmes used various observations and science techniques to solve crimes that were, at the time, considered impossible, and learn about how many of his techniques are still in use today. "The Studio" offers visitors the chance to observe and view current health related research that is occurring in the area [3].

3.2.3Existing Center #3: Arizona Science Center

The Arizona Science Center in Downtown Phoenix is a great example of science made fun. The science center is split up into permanent exhibits mixed in with an ever-changing cast of rotating educational science shows. Many of their exhibits are hands on and give people and kids a first-hand experience with the science being shown. The presentation of their exhibits is eye catching and hard to miss.

Their permanent exhibits are split up into nine different sections. Each section talks about a different aspect of science in a way people can understand. Their Nine exhibits are: All About Me, American

Airlines Flight Zone, Evans Family SkyCycle, Forces of Nature, Get Charged Up, Making Sense of Your Dollars and Cents, My Digital World, Solarville, and The W.O.N.D.E.R. Center. The All About Me Exhibit is a showing of how the human body works and shows things like surgeries and how they are done by professionals. The learning is not all just visual; people are also given the opportunity to hear and smell what it is like to digest food.

The Forces of Nature exhibit is a great meteorology learning experience. People can experience the “Magic Planet” Which allows you to see the last six weeks of weather patterns around the planet. You will also be able to see the cloud and air patterns that create major storms around the world [4]. Their non-permanent exhibits also look very interesting. One of them is called “Alien Worlds and Androids”. The exhibit asks if humans are alone in the universe and talks about A.I., Robots, and Aliens. This is a more interesting exhibit than it is educational, but it still has the science feel to it. Besides their exhibits, the Arizona Science Center also provides training and development courses for students and teachers. These courses are more STEM orientated and look like very good opportunities to learn STEM skills.

3.2.4 Existing Center #4: Exploratorium

The Exploratorium in San Francisco, California consists of six museum galleries which focus on different areas of exploration. All their exhibits are interactive and allow their visitors to touch, feel, and operate various displays. The six galleries are: South Gallery: Tinkering, East Gallery: Living Systems, Osher West Gallery: Human Phenomena, Bechtel Central Gallery: Seeing and Listening, North Gallery: Outdoor Exhibits, and Fisher Bay Observatory Gallery, Observing Landscapes.

The Tinkering Studio allows visitors to “think with their hands and explore your creativity” by using exhibits such as the marble machine, a non-electronic “tinkerer’s clock” that is full of chimes and a device that counts the rotating put into while you explore your own participation and patience [3.2.4]. Inside the Living Systems gallery, the visitors can learn about to learn about life around them such as the hourly height of the tidal of the San Francisco Bay, the various plankton in different parts of the ocean, and view different life forms under a microscope. The west gallery allows visitors to “experiment with thoughts, feelings, and social behavior” by discovering more about the science behind sharing, building an arch and exploring the science behind it, and walking through a completely dark dome where the visitors can explore their different senses [5].

The gallery of seeing and listening provides the visitors with options to experiment with light and sound through exhibits such as the monochromatic room that is colorless, standing in front of the “giant mirror” and by playing an instrument that the user can vary its pitch [5]. The outdoor exhibits of the north gallery allow visitors to “investigate forces shaping the City, Bay, and region” by observing how the wind and tide affect the exhibits. Some of the exhibits include a 27-foot tall harp that uses the wind to create sound and watching how the tide flows by watching arrows in the ocean change [5]. The Fisher Bay Observatory Gallery provided an opportunity to view the geography, history, and ecology of the San Francisco Bay area by having an exhibit that is a large-scale relief map of the area and seeing what kind of data is being collected by the environmental field station project.

The museum also hosts public events where exhibit designers and special guests talk about their contributions to the museum and current science events. The museum’s website also provides links and videos to events around the world such as solar eclipses and live deep-sea exploration. There are sections that give teachers opportunities to conduct in-class learning sessions, as well.

3.3 Subsystem Level

The team went into further detail by examining interactive displays and projects. We evaluated four designs: “my five senses”, a strandbeest, a radiation concentrator competition, and a marble machine. These designs are either currently used in science museums or are capable of being an interactive display. The goal was to gain an understanding of how a smaller system delivers information to its users and what the user can learn from them.

3.3.1 Existing Design #1: My Five Senses

OMSI plans events whose is to provide a platform for young students. In this case, the students are provided with hands-on, exiting and explorative activities. As such, the students manage to enjoy and develop the urge to engage in the scientific learning process. In this case, the projects are organized as events, where the scientific world is presented in a simplified manner, f or the young students to understand. Among the projects planned is “my five senses.” [2]

“My five senses” is a project whose aim is to provide students with an environment that enable them to learn the science behind the five human senses. These senses include hearing, sight, impulse, taste and smell. In this case, the organizers provide the scientific equipment, which can replicate our senses. As such, the students attain a scientific perspective towards the subject thereof.

Theoretical background of the design is the biology of human sensory organs. In this case, the parts of the sensory organs, how the organs function and their relationship to our daily activities are studied. Then, the theoretical aspect is redesigned and fabricated to present visual and audio presentations, which provide a more elaborate and comprehensive learning environment [2].

Having the project done by the students themselves provides the students with a platform for direct involvement in the systematic process of research[3]. As such, the students develop a positive attitude towards science and the practical nature of the subject. In addition, the students can engage with their instructors in a different environment, which breaks the monotony of theoretical lessons.

The five senses project provides also enables the students to relate the lessons they learn about human senses, to the scientific thinking and design process. The students are required to make the sense organs using the provided materials and organize them to serve the roles of the human organs. Here, the relation is derived from the systematic disassembling and assembling of the models of the human sensory organs. As such, the students manage to attain lessons that they can apply in other areas of study. Also, the students can ask questions, which is a critical step in STEM and overall, the scientific study and research process [2]. It is also noteworthy that the students also gain interest in following a systematic process in the study, which includes problem statement, statement of constraints, the definition of method of implementation, following a set procedure and finally analysis and presentation of results.

3.3.2 Existing Design #2: Strandbeest

There are so many different types of this product and this figure is one of the many works by Theo Jansen. This work does not use any motor or engine to function, but instead uses only the simple resource, wind, to power it.

Figure 2: Strandbeest Machine [6]

The basic concept of this product is getting energy from wind and changing it to linear and rotational motion, so it will move forever unless the wind stops. This product is showing a good example of the how legs will normally cycle when in motion.

3.3.3 Existing Design #3: Radiation Concentrator Competition

This design takes some inspiration from our heat transfer class and want to try to teach these kids about solar radiation. The systems would be small and the team would provide different materials for the kids to build their concentrator with. The goal would be to heat up a temperature sensor as fast as possible using only a source of heat radiation and many different types of materials. They could use the sun or try to capture as much of their radiation source as possible.

This project would let the kids think and design their own solar concentrator. This is the type of project that needs to be made for TWF. Not this exactly, but something that there is no one right answer for. Their only limitations should be their imagination and our materials.

Figure 3: Solar Concentrator Thermal Power Plant [7]

Something like this, but on a very small scale. Safety would be a key factor. There will be a sensor that will shut off the radiation source before unsafe temperatures are met.

3.3.4 Existing Design #4: Marble Machine

Inside the Exploratorium in the gallery called the Tinkering Studio, there is an exhibit called the marble machine. This studio is "an immersive, active, creative place where visitors can slow down, become deeply engaged in an investigation of scientific phenomena, and make something – a piece of a collaborative chain reaction – that fully represents their ideas and aesthetic" [5]. This area correlates closely with the goals of TWF in the sense that both places want to encourage their visitors to engage their minds and learn while having fun. Inside the Tinkering Studio is an exhibit called the marble machine.

Figure 4: Marble Machine [5]

The marble machine is a creative ball-run contraption, made from familiar materials, designed to send a rolling marble through tubes and funnels across tracks and bumpers until it reaches a catch at the end. This marble machine uses a peg board as a stand and allows the user to create and infinite number of possible runs while using problem solving skills combined with trial and error to get the marble from the top to the bottom. This machine engages the user's mind and gives them the freedom to use any of the parts any way they choose. The marble machine is an example of an interactive display that is fun, simple, and the complexity can be defined by the user.

3.4 Functional Decomposition

Functional decomposition is a diagrammatic representation of a process, which entails the components and how they interact to achieve a defined goal. In this project, functional decomposition has been employed to represent an engineer's pit race display. In this case, the aspects represented include the components involved, which include hand, circuit, gears and the CRT display.

Here, the hand-actuated the electric circuit, which activated the conversion of electric energy to kinetic energy, which could initiate the motion. Also, the hand activated the gear mechanism, which was recognized as human energy. Conversion of human energy is to potential energy and then to rotational energy. The combination of the two energy types initiated the motion of the hand, with some energy losses as heat and sound. All the processes could be displayed on a CRT display. Thus, the process could be monitored. The developed functional model is shown in Figure 5.

Given that the issue entails interaction of processes, the user's hand must be placed on the counter for the race to start. The functional model could help the members to visualize this interaction. Here, the energy is used to move the gears, which rotates to start the race. The losses of energy could also be visualized, and they included heat and sound.

Also, the developed functional model enabled the team to define the specific interaction of processes and components in an engineer's pit race design. Then, the energy transformations that took place in the process were also established. Also, the outcome of each process, as well as how it affected the overall system was determined. It can, therefore, be concluded that the functional model is a visual aid enabling the establishment and improvement of interacting processes and components in the engineer's pit race design.

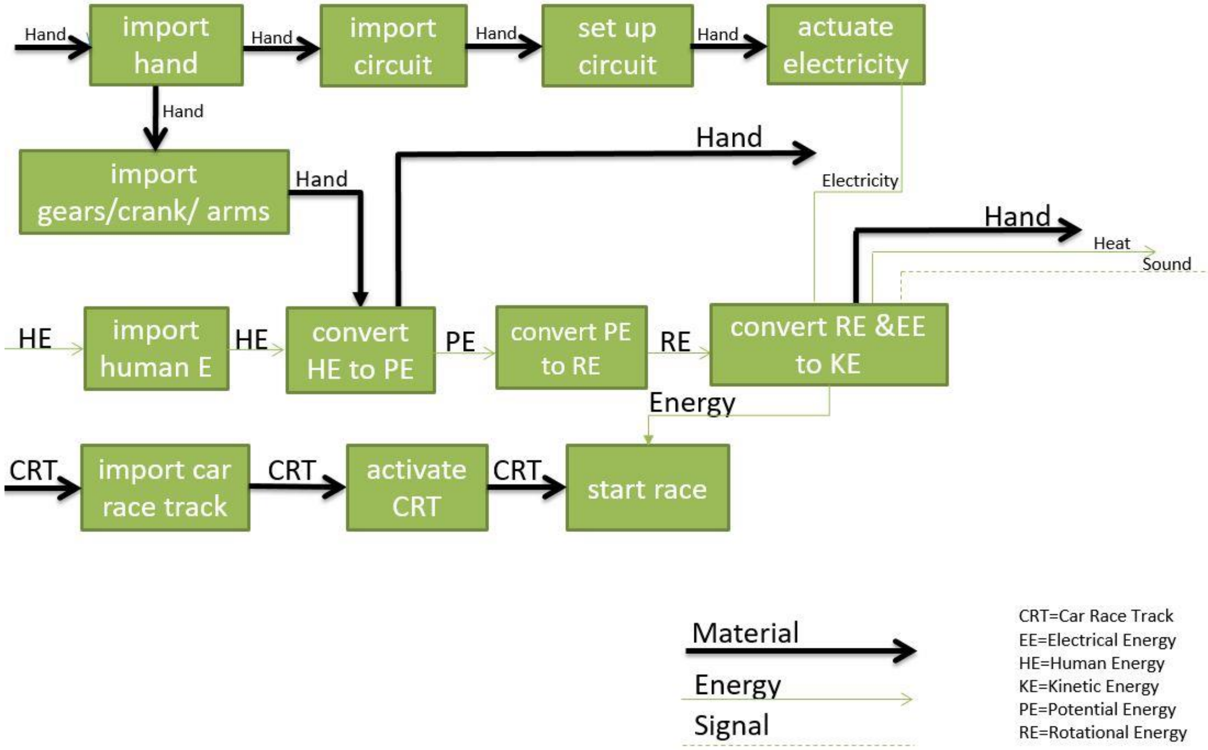

Figure 5: *Function Decomposition of "An Engineer's Pit Race"*

4. DESIGNS CONSIDERED

The initial designing phase of the project was difficult because of the amount of designs required from the group. The clients requested 100 ideas. The Wonder Factory wanted a large variety of ideas to pick from. For the beginnings of the design selections, our team used many different methods for creating designs. We incorporated the C-sketch, and the 4-1-2 methods. Throughout the process our group took inspiration from many things to help us come up with quality ideas. Eventually after coming up with many ideas together we went and each thought individually, and came up with the rest of the ideas individually. The engineering requirements were always kept in mind during design creation to help guide thinking. The pros and cons of the designs were decided based on the customer requirements.

4.1 Compressed Air Organ

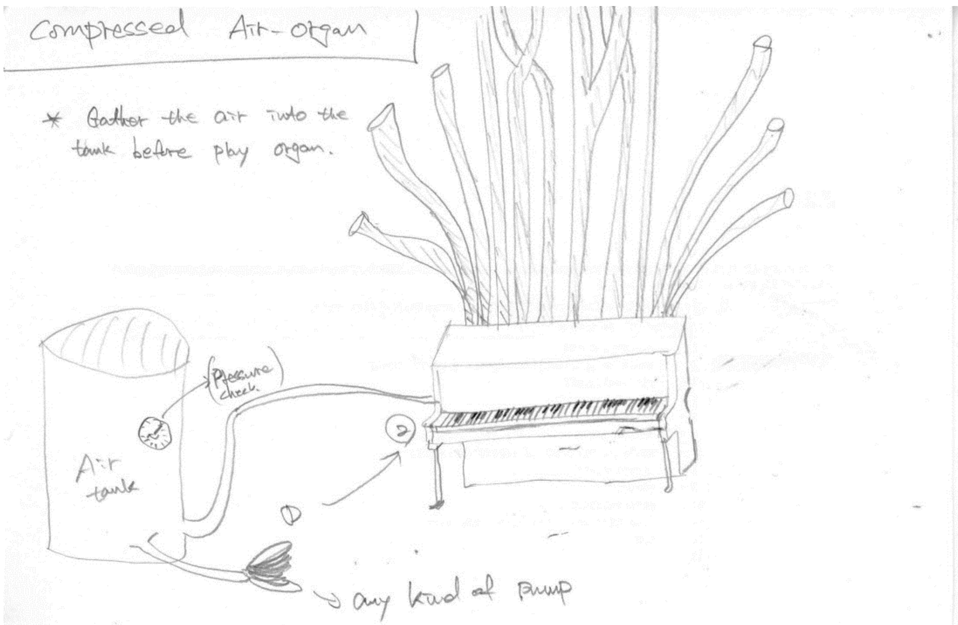

Figure 6: Compressed Air Organ Concept

The basic concept of this design is showing how air can make sound. Kids need to keep pressing air to play the organ while the kid play. In case there are more than two kids, another kid can compress the air for player.

Advantages

- Simple
- Safety
- Extremely Auditory

Disadvantages

- Not Very portable

4.2 Gear Powered Race

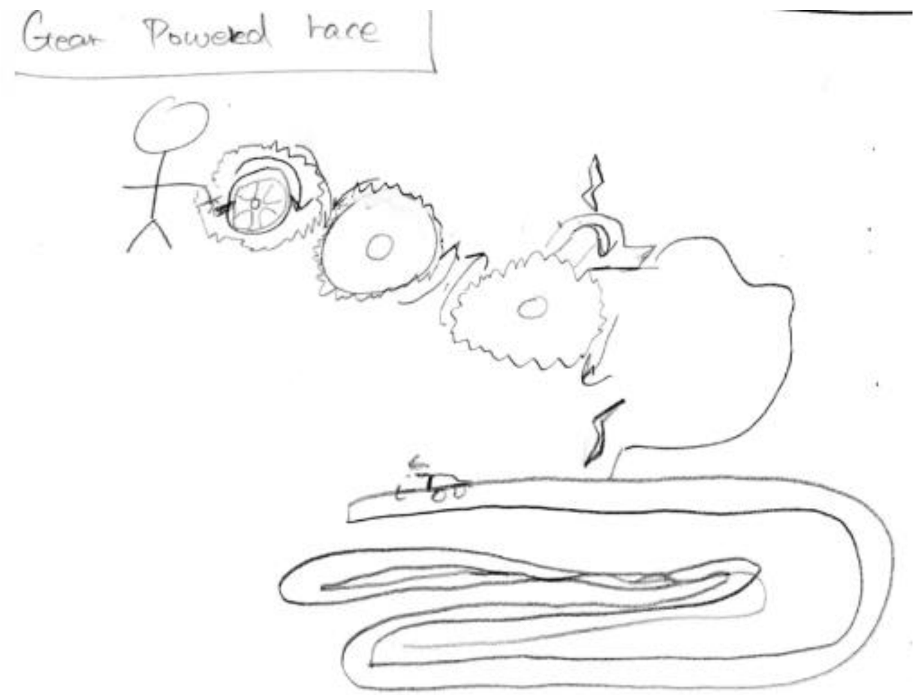

Figure 7: Gear Powered Race Concept

The concept of this design is how kids can generate power efficiently to race the car faster. In other words, if kids can generate more power by understanding how gears work, the racing car will go faster.

Advantages

- Simple
- Visual
- Project Into Role Easily

Disadvantages

- Not as Portable as others

4.3 Popsicle Stick House

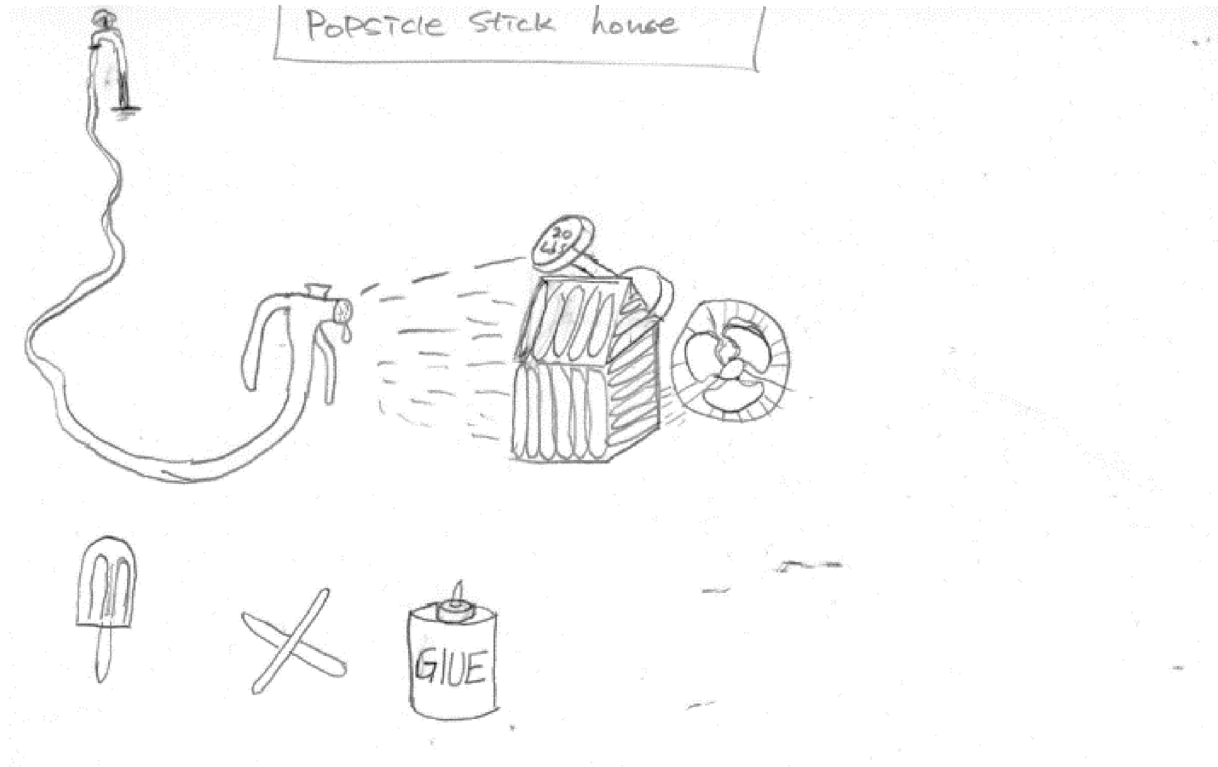

Figure 8: Popsicle Stick House Concept

This design asked kids to come up with their own design for a house that could withstand weight, water and air effects. The kids would get glue or some other form of adhesive and popsicle sticks for creating their homes. Depending on how well their houses did their name would be recorded and they would get a picture of themselves with the house they designed and built.

Advantages

- Project Into Role
- Safety

Disadvantages

- No Auditory element

4.4 Music Water Cups

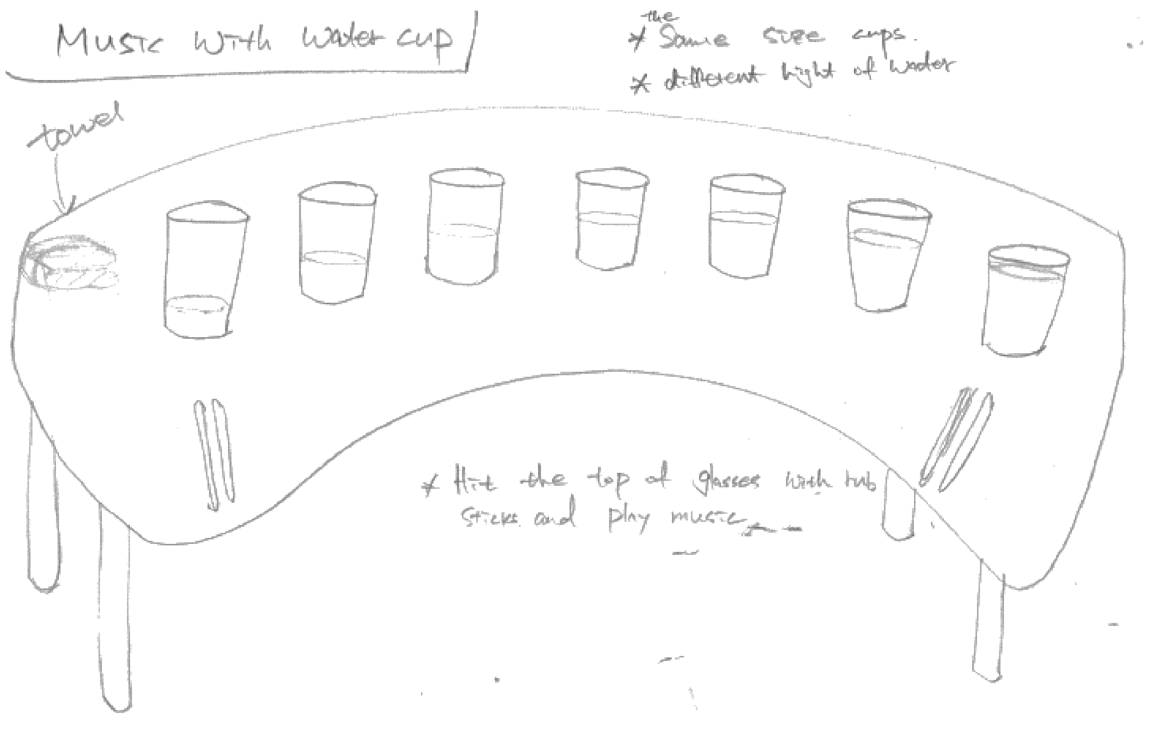

Figure 9: Music Water Cups Concept

This design will teach kids that the water filled in the cup can change its vibration frequency. Also, each cup has its own sound so that kids can play any music they want. There is measure line on the cup so kids can adjust the sound they want.

Advantages

- Simple
- Auditory

Disadvantages

- Not many users at once

4.5 Dam To Generate Power

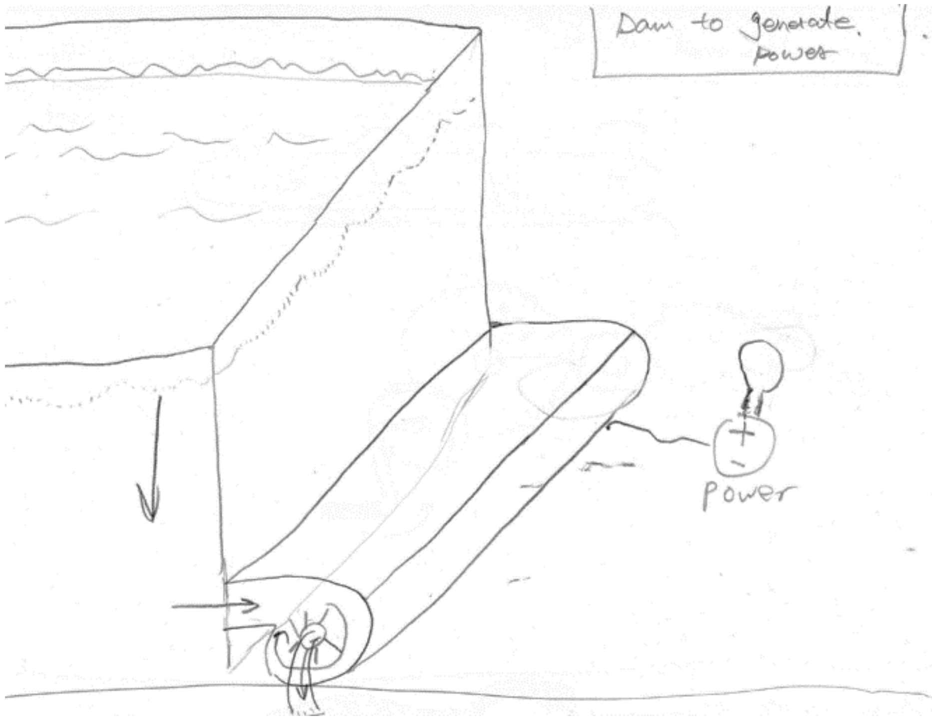

Figure 10: Dam to Generate Power Concept

This design was meant to show the kids how water from dams produce electricity. Using a big clear container full of water and a small hydro generator near the bottom of it, the machine would let water through the generator and produce electricity. The kids would be able to fill as it drained and see what happened if they add more or less water.

Advantages

- Simple
- Visual
- Multiple Users

Disadvantages

- Not Very Portable
- No Auditory Element

4.6 Plane In a box

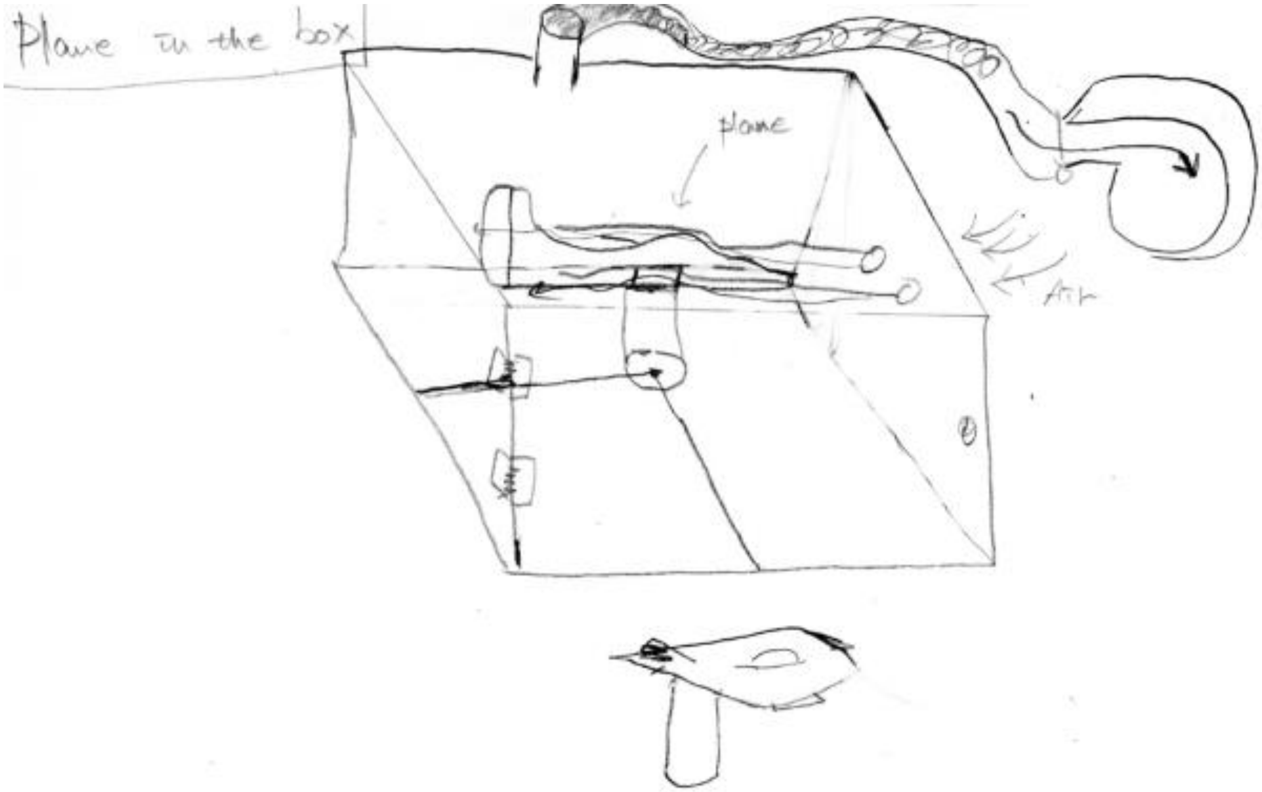

Figure 11: Plane in a Box Concept

This design is showing the force 'Lift' by wings in flowing air. The box would have some smoke lines that would flow over winds of some premade aircraft and if the kids wanted to they could design some of their own and see how the lines flow over their aircraft.

Advantages

- Visually Great

Disadvantages

- Not Very Simple and may be too complex

4.7 Gear Puzzle

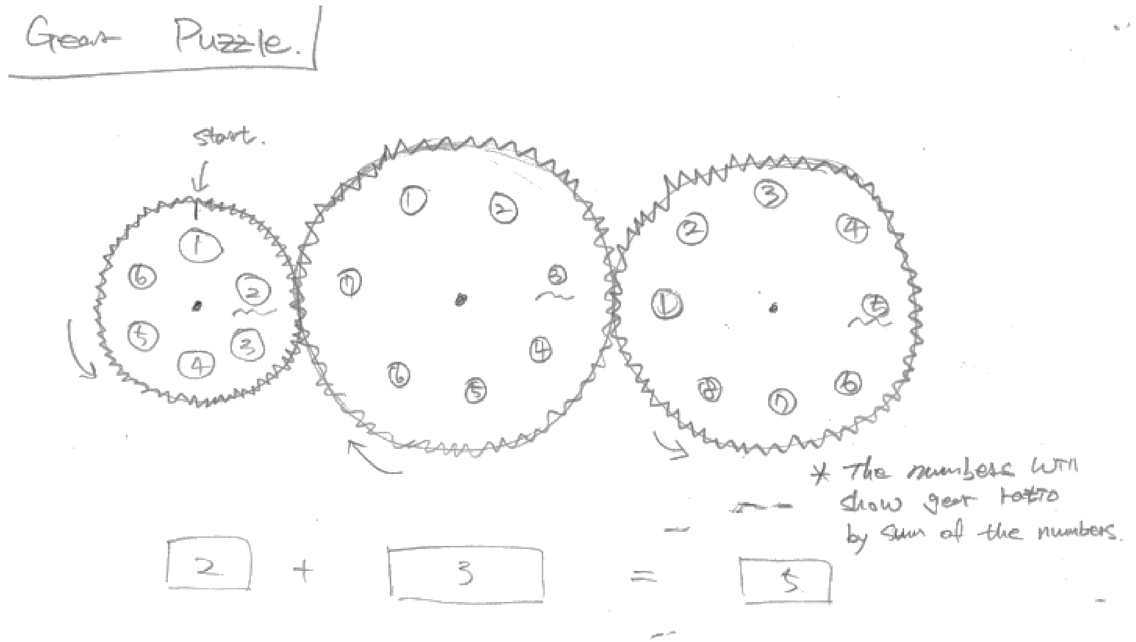

Figure 12: Gear Puzzle Concept

This design will be useful device to understand gear ratio. Basically, there is numbers on the gears, and it will show what final gear indicates a number. Kids are, also, able to change size of gear and it will help kids understand ratio more.

Advantages

- Portable
- Tactile

Disadvantages

- Not Very simple

4.8 Gear Powered lights

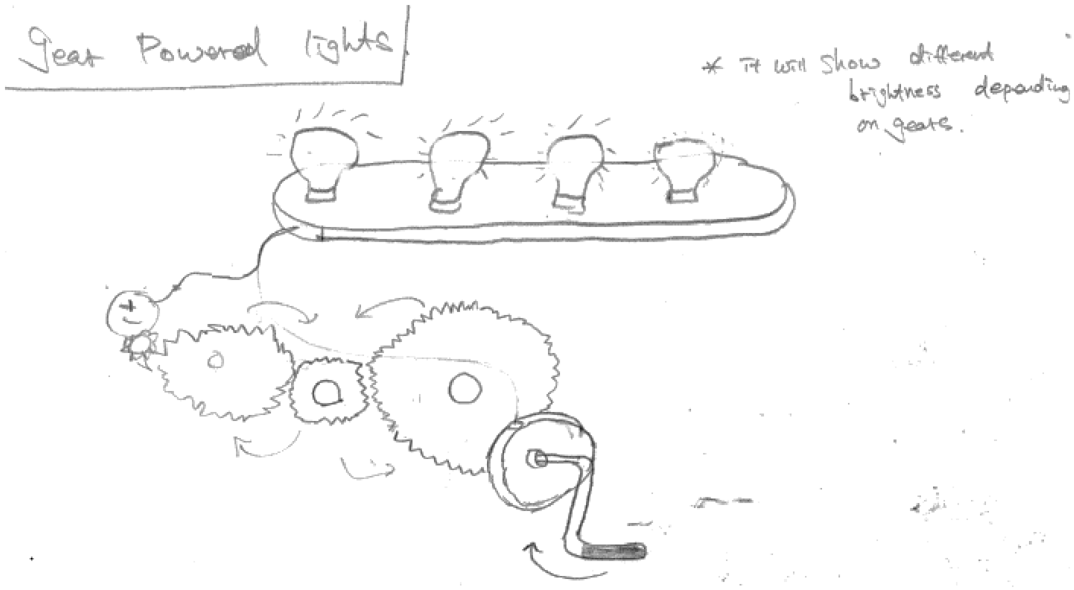

Figure 13: Gear Powered Lights Concept

This design is similar with gear powered race but this will show how much power generated directly with 4 bulbs. Kids can change size and order of gears, then they will figure out highest efficiency of gears. The faster they turn the crank the more lights that will turn on.

Advantages

- Simple
- Visual

Disadvantages

- Not as Safe as other ideas

4.9 Bridge Design and Build

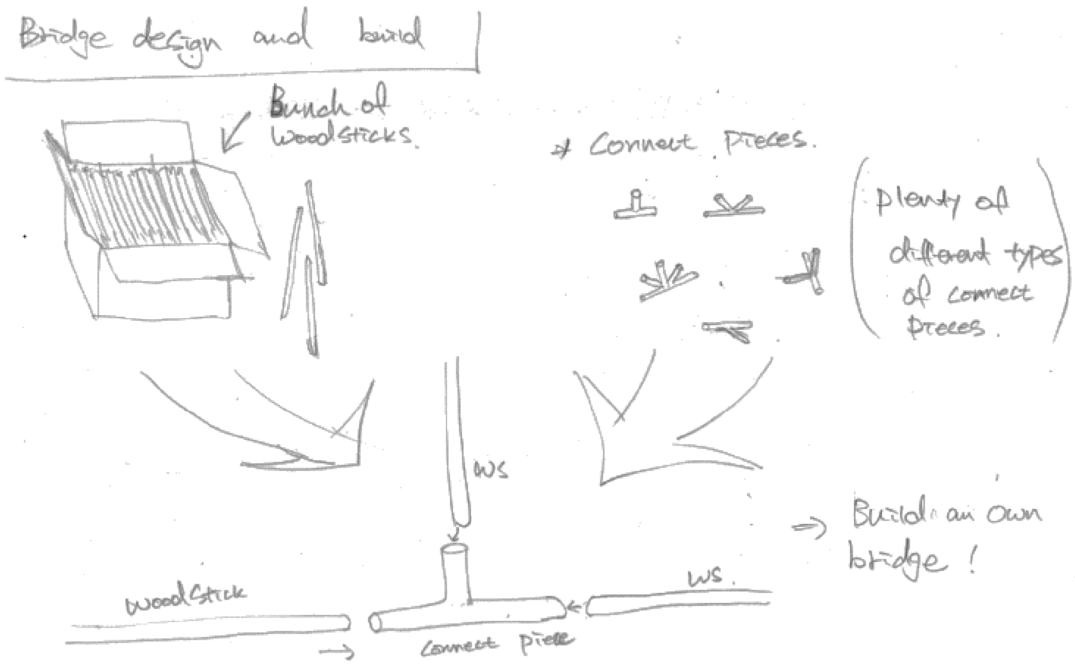

Figure 14: Bridge Design and Build Concept

Building bridge design will help kids to understand the theory of weight and the distribution of it. There are bunch of wood sticks and different shape of connecting pieces. By building their own bridge with these components, they will get which shape will be strongest.

Advantages

- Make the kids feel smart
- Project themselves into the role of civil engineer

Disadvantages

- No Auditory Element

4.10 Moment Machine

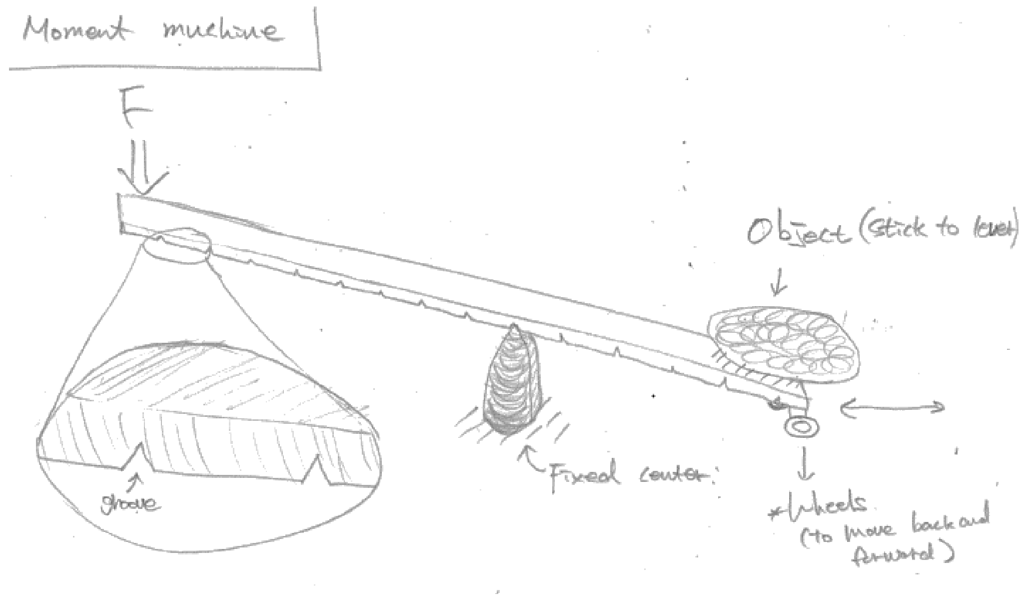

Figure 15: Moment Machine Concept

This design is lever basically. Kids can move the wood plate back and forward to experience that which distance between center and object is easy to lift.

Advantages

- Simple
- Tactile

Disadvantages

- Not Many Users

5. DESIGN SELECTED

Although the team developed 100 ideas, only 20 of the ideas were further evaluated. The team used a Pugh Chart to determine which ideas met most of the CRs. The team decided to critique the top four ideas and instead of choosing one of the four, the team created a new design.

5.1 Rationale for Design Selection

The team used a Pugh Chart to evaluate 20 designs that the team developed, which can be seen in Appendix B. The Pugh Chart uses a datum (an average idea) to compare the other ideas against it. Each idea was given a +1, 0, and -1 based on if the idea met the CR better, the same, or worse, respectively relative to the datum. The team assessed how many +1s, 0s, and -1s and total sum each design idea received. The team then took the top four ideas from the Pugh Chart and further evaluated each idea's strengths and weaknesses.

The team decided to create a new idea based on the strengths of these ideas that would meet all the CRs better than the datum. The new design developed is what the team is calling "an engineer's pit race". In this design, the users are counted down to start the race. Each user must determine which gears and crank arms they want to use based on how much power they want, how difficult the crank will be to turn the power generator, and which gears will mesh with each other. The users will then complete an electric circuit "puzzle" which will allow power to be transmitted from the generator to the racetrack. The users will finish by operating a racecar and competing against the other users to get to the finish line first.

This new design concept will meet all the CRs in the following ways:

- A setup that allows the client to disassemble the design for transport, without being bulky or having too many parts, will meet the portability requirement.

- Careful steps will be taken to make sure the design is safe to operate by not having any sharp edges, exposed electric components, or exposed crush or hinge points.

- The new design will allow at least two "players" to use it to compete against each other and this design could potentially have more than two players or teams. This satisfies the "multi-user" requirement.

- With this design, all the participants will be able to use their senses of touch, sight, and hearing while operating or observing this concept which will meet the tactile, auditory, and visual requirements.

- The users will be able to project themselves into the roles of the project through feeling like a manufacturer, engineer, and even a remote-controlled racecar driver while operating this concept.

- Lastly, this design will be simple enough to operate while also providing an exciting, interactive learning experience.

5.2 Design Description

This section provides the analytical analysis' completed for each subsection of the design. Each team member individually evaluated four separate sections of the proposed design to justify mathematically the viability of the project. Each report describes the size of each component, the materials used, and other specifications. The four subsystems evaluated were: cover and safety mechanism, gears and gear mount, power generator and overall mounting with wiring, and electrical circuit puzzle and slot car racetrack completed by Ali, Kevin, David, and Carlos, respectively. The SolidWorks drawing for the design can be found in Appendix C.

5.2.1 Cover and Safety Mechanism

Power transmission can be achieved through various methods, which include gears, wheels, and belts as well as other engineering components of a system. Given that power transmission will be determined by the intrinsic factors of the design, the factors considered during selection of the method thereof may vary [8]. Thus, it is prudent to document the factors considered during the design process in the 'engineer's pit race' project.

Power transmission method selected shall depend on the magnitude of the compression and bending forces expected, as the crankshaft is used to transmit the force from the arm of the user to the gear system [9]. As such, there is a system of measures to be considered too, which include safety, powering and achieved torque too. In this project, a detailed analysis of the factors that affect the selection and set up of the crank arm, selection and implementation of the crank arm, implementation of a covering mechanism as well as a system of implementation of user safety measures shall be discussed in details.

The system design entails a set of gears, whose motion is triggered by the manual application of force by the user [8]. As such, there needs to be a design that will facilitate the attainment of maximum torque, given that the users of the system are within a young age bracket [9]. As such, the selected crank arm mechanism shall also include a length that shall accommodate the maximum size of the expected hand of the users. Finally, the set of gear, attachment method shall be considered, with the safest system being selected. Type of crank selected shall be the L-crank, given the setup of gears and the configuration of the system.

Considering that there shall be another mechanism responsible for the motion of the gears, the timelines for the force application shall be short, as the motion of the gears shall trigger a secondary mechanism, which includes the connection of the electrical circuit [8]. The force required to move the gears is also affected by the material used. Thus, the same material for gears shall be used for the case of the crank arm [9]. In this case, the material used to make gears for the project shall be steel, given that the gears are not transmitting high torque. The handle shall be improvised. To improve the ergonomic and safety of the user. In this case, the handle shall be covered with rubber, which shall also serve to improve the grip.

Based on further evaluation of the difficulty and price of manufacturing the handles and cranks versus purchasing, the team decided to purchase the crank arms and handles from a local bicycle shop.
The crank mechanism entails moving parts. In this case, the gears, the arm of the crank and even other rotating parts may harm the user, if there is no coordination of events. Here, the major concern is the starting of rotation, where set up is connected and fixed to the right position. As such, there shall be a need to establish perfect fit points in the system, such that there shall be motion when the cover is in place [8]. In this case, this aspect has been attained by the introduction of a hollow, through which the arm of the crank must pass and lock in position, for the motion to be started [9]. At the same time, there is a need to ensure that the cover does not come out during the rotation. This aspect has been considered paramount, as the moving parts can cause a lot of harm, when the cover is disengaged during the actual motion. As such, the fixing of the lid in position, and the introduction of a groove shall serve to secure the user from harm as motion will only begin when the cover is locked in place.

In conclusion, the design outcome has considered a different aspect of the operation of a crank to drive the gears. At the same time, a system of measures meant to ensure the safety of the user has been considered. In this case, the crank has been designed to perfectly mesh with the gears and the material selected for the crank is the same as the open for the gears. As such, there shall be no wear due to friction [9]. Then, a cover which forms a perfect fit with the gear mechanism has been designed. The outcome depicts an adequate measure to ensure that the user will not be at risk of having the crank move without the cover. Regarding the ergonomic aspect, the user, who is required to apply force to the arm, to rotate the gears, shall hold on the rubber handle. Thus, the user shall be able to drive the rotor without compromise of their safety. It can, therefore, be concluded that the crank mechanism has attained the expected HoQ and ERs as stated in the earlier sections.

5.2.2 Gear and Gear Mount

This section is about the gear part converting input work to generator in certain rpm. The Wonder Factory project is showing scientific theories to kids in an easy way and let them try the devices by hand. This gear part is one of the main parts of our project to show kids how we can generate electricity efficiently. To choose appropriate gears, the team considered basic customer needs and engineering requirements which are safety cost efficiency, sound, wornness, and strength.

To choose the material, the team need to consider all basic customer needs and engineering requirements. This is because all those needs and requirements will change depending on the gear's material.

Safety: Since the team is going to use safety lock on the gear box cover, the team didn't really need to think about safety of gears. The only thing the team needed to care about safety was the mount clip for holding gear.

Cost efficiency: Since the team is not going to use most budget to gear, the team picked these materials that cost is relatively lower. Moreover, you can see other advantages of these materials.

Table 2: Various Metals

	Relative cost	Other advantage
Ferrous		
Cast irons	Low	
Cast steels	Low	
Alloy steels (400)	Medium	Highest strength and durability
Nonferrous		
Aluminum alloys	Medium	Noncorrosive, light weight
Brass alloys	Low	
Bronze alloys	Medium	Low friction, excellent machinability
Nonmetallic		
Delrin	Lower	Wear resistant, long life, low noise
Phenolic laminates	Lower	Quiet operation, highest strength plastic.

Strength: For the strength, we need to know how much force is influence on a gear. We didn't know minimum power to generate electricity but let's assume it is starting from 9.8N, which is holding a 1kg dumbbell, with 70RPM (=1.8326 m/s for 0.125m radius of gear). Also, the team assumed the shaft is 20cm long. Then, the torque (T = F * r * sinα, F-force, r-radius, α-(angle between F and r) will be 1.96Nm(J). this will be transferred to gear and stress on outside of gear will be 15.68N (radius of gear is 0.125m). it will rotate 70rpm, then it can generate 28.73 W which is enough to operate generator. There is an equation to figure out how much stress gear can handle.

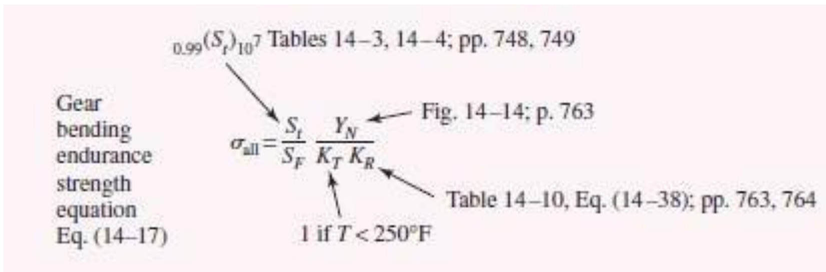

Figure 16: Gear bending endurance strength equation [10]

In addition, there is all equations to get factors in that textbook. However, our gear box's stress and momentum on the shaft and gear are small. Thus, we don't need to use that equation.

To figure out the number of teeth of gears, we can use the calculator. For the input, the team picked 25cm for center distance and 1:1, 1:2 for the gear ratio. For the ratio 1:2, the team got these values. First column is the number of teeth and second one is circular pitch.

Table 3: Number of Teeth [11]

# of teeth	**Circular pitch**
33 X 66	**CP= 0.625**
55 X 110	**CP= 0.375**
59 X 118	**CP= 0.349**
103 X 206	**CP= 0.200**
131 X 262	**CP= 0.157**

This is one of the examples of choosing appropriate the number of teeth. It will change depending on the gear ratio. To choose the best one, the team need to calculate efficiency of the gear. However, we can pick any of them because the stress on the gear is much smaller than its own elasticity. This is the most important part of gear box we are going to use. For operating our device, the generator must create 20-22V which is 700RPM-1100RPM at generator. Assume 70 RPM for input and we need 700 – 1100 RPM.

$$n_3 = \left| \frac{N_2}{N_3} n_2 \right| = \left| \frac{d_2}{d_3} n_2 \right|$$

where n = revolutions or rev/min

N = number of teeth

d = pitch diameter

Figure17: Finding Gear Ratio

In figure 2, n2 is starting gear's velocity. To get 700 RPM, the gear ratio should be 1:10 (10 for first gear). There is equation to get gear ratio based on velocity. For 1100 RPM, it will be 16:1. If these ratios of gears are hard to manufacture or do not work well, we will add another gear in gear box or right next to generator.

This is the final shape of gear box. Both shaft can be pulled out and kids can change gears while the cover open. The first shaft which has crank arm is input and second one will be connecting to generator.

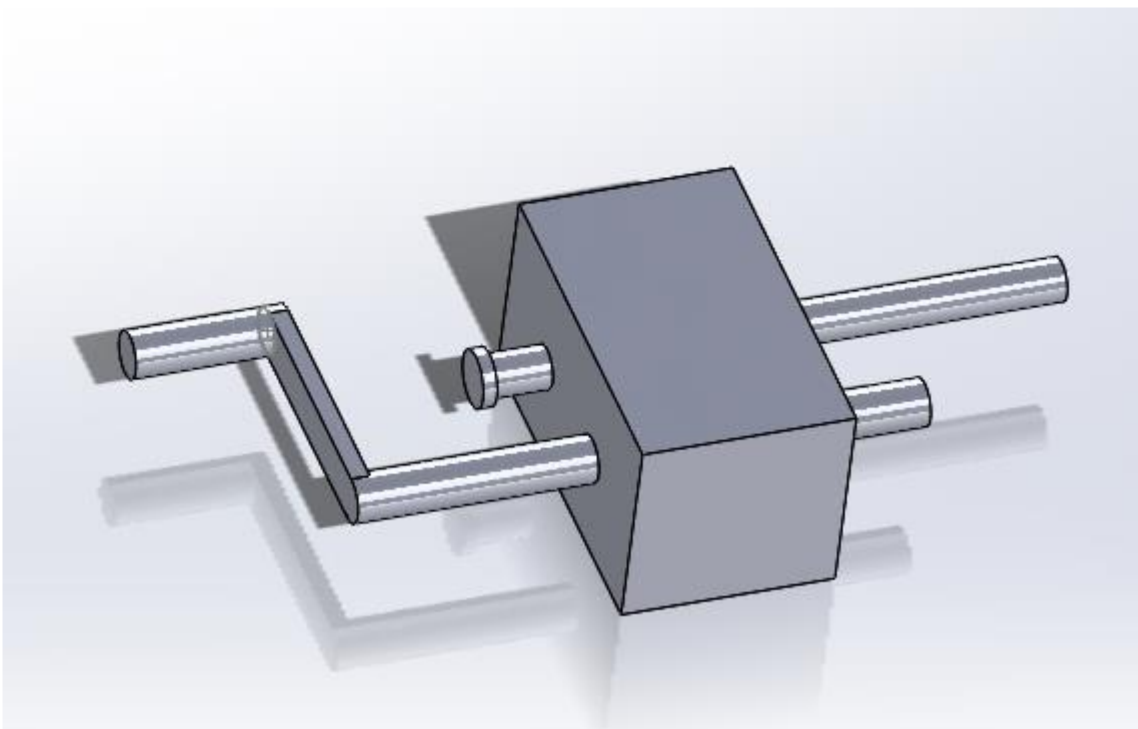

Figure 18: Final design of gear box

5.2.3 Power Generator and Overall Mount with Wiring

Flagstaff, Arizona is America's 1st STEM community that assists and collaborates with the 28 local schools to provide STEM education for young students in the area [12]. The Wonder Factory currently participates in several local events throughout the year that provide STEM education in a fun learning environment. The goal of The Wonder Factory 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" [13]. The Wonder Factory is presently a traveling science museum with plans to have a local facility in the future. Our project will allow The Wonder

Factory to provide another interactive display at STEM events and at their future facility. Part of our team's objective is to assist The Wonder Factory and Flagstaff STEM City in achieving their goal of integrating STEM into the community. In this memo, the team will report the progress of my team's design and present an analytical analysis of one of the subsystems.

The team will address the analytical analysis of the power generating subsystem. This analysis will provide information about what type of power generation system will be used. The team began by researching what kind of devices could produce power from rotational motion. Based on the input and output requirements for this subsystem, the team found two things that could be used in our project: an alternator and a generator.

The first idea for a power creation system is an alternator. An alternator would need a minimum of about 2100RPM input which is about 35 revolutions per second (Table 5) [14]. The team timed myself turning a fictional crank and determined that the user will rotate the crank arm at about 1 revolution per second or 60RPM (Table 5). Based on this test, the minimum gear ratio should be 1:35 since an alternator has a built-in output regulator. Alternators produce 12 VDC with an average RPM of 2100-10000RPM [14]. This would provide a constant voltage to the slot car track so each car would be set at the same speed. A concern with this concept is that it eliminates the competition component of the slot car race. Another downside the team found with alternators is that they need power to create power since they do not have permanent magnets [14]. This may pose a problem if The Wonder Factory is not able to provide power to the display or batteries may need to be inserted into the design which will require occasional maintenance. Additionally, every alternator the team found would require a base to be manufactured for our design since all of them were created to be mounted on an engine block.

Table 4: Revolutions per Minute to Revolutions per Second Conversion

RPM (revolutions per minute)	Conversion to revolutions per second
X [rev/min]	X * 1min/60sec = Y [rev/sec]

Next, the team considered utilizing a generator as the power system. A generator produces DC or AC voltage (depending on the model) but has permanent magnets. Therefore, it does not need an electrical input to create power [15]. The generators the team researched did not have an output regulator so the faster a generator is turned, the higher the output power (see Figure 17) [15]. This will allow the slot cars to go slower with less voltage and faster with higher voltage, creating more of an actual race. The output power will be based on the input rotational speed from the crank through the gears and to the generator. If the slot car track cannot handle low or excess voltage input, the generator output can still be regulated. The RPM requirement is also lower, so this design could use an approximately 1:15 ratio and power the slot car based on Figure 17. the team found generators that have integrated base mounts which would reduce labor time and material costs if a base needed to be manufactured specifically for the generator.

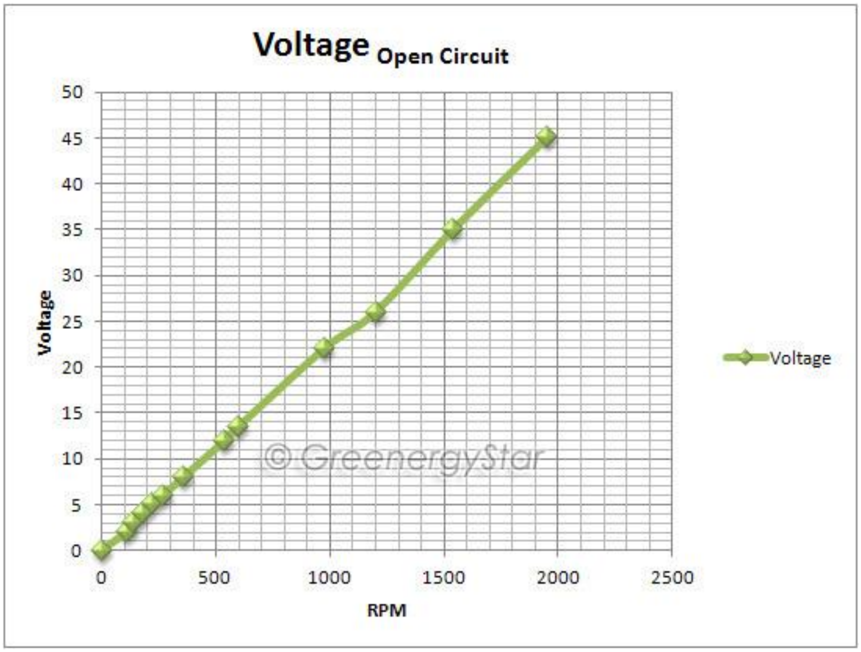

Figure 19: Generator RPM input vs Voltage Output [15]

Based on this research, a generator will be the best solution. The most significant obstacle is that they cost at least $150 where as an alternator can have a price as low as $35 [15, 16]. Although the price is higher relative to an alternator, our team decided that allowing the user to increase the speed of the slot car based on the input rotational speed was more important than budgeting for a higher priced part. Also, the total price of this choice will be reduced by not having to manufacture a mount for an alternator.

For the overall mount, a 10-gauge, hot-rolled steel plate (24" x 24") would be used to attach the gear mount, generator, and circuit puzzle. Using this material would be cost effective with a price of $14/sheet [17]. This mount would be elevated to allow the wires to run on the underside. For the gear mount, the generator has a threaded input shaft [15]. The final shaft that attaches to the generator will need to be a female threaded design. Further information on the shaft design will be discussed by my colleague in a separate memo. To wire each the power generator to the puzzle and to the racetrack, 12-guage wire will be used.

Based on my final results, the team am proposing to purchase the following items: WindZilla 12 V DC Permanent Magnet Alternator Wind Turbine Generator PMA Gearbox from Greenergy Star to create the electricity, plates of steel for the overall mount from Shapiro Alloys, wiring from Home Depot, and bolts and nuts from ACE HomeCo.

5.2.4 Electrical Circuit Puzzle and Slot Car Racetrack

One of the 2 problems assigned to me was picking a track that suited our needs. We needed a track that wouldn’t be too hard to power, was not too big, was not too expensive, and could run at most 4 different cars at the same time.

At first we thought we had found a track in phoenix that came with a really nice wooden stand that supported the whole thing. Unfortunately, by the time we contacted them they had already sold the track and were offering the track at the same price as getting a new track. We decided against buying from those venders and instead searching for a better deal.

The team started my search and found that www.rcsuperstore.com had some good deals compared to other retailers. The team searched through their selections and found many different 2 car tracks. the team proposed to the group that we get a 2 car track instead of a 4 car track to save some money. We decided that 4 would be better because we may end up just setting up 2 different stations, but that in the future the clients could add more with our instructions and money.

Once the team found some tracks the team started looking at the specifications that the tracks needed to run. It turns out that each car runs at around 20-22V and at 1 Amp. The team gave this info to David and Kevin so they could calculate rotational speeds and design gears for our generator. [18]

Once it was decided to get a 4 car track the team made a decision easily. We got the less expensive of the 4 car tracks. [19]

Once the track comes in we will be able to run calculations on it and be sure about what kind of current and volts we need in order to make sure it can run safely. 22V and 1 Amp may be good to run it, but we may need to lower either input to make it safe or to make the design easier and put less strain on gears and shafts.

6. PROPOSED DESIGN

For implementation of the porotype at the end of the first semester, the team worked on the four main sections of the project. 2 of the sections were worked on in tandem but the last parts needed the other 2 parts to be finished beforehand. A Gantt chart detailing the information below can be viewed in Appendix D. A Bill of Materials (BOM) can be viewed in Appendix E. Proposed design drawings and exploded views can be found in Appendix C.

6.1 Prototype Phase (Nov 26 - Nov 29)

A few gears will be created for the prototype. Either cardboard or 3D printing will be used to create some gears and a display that can showcase our whole project. The prototype will be a lite version of our final project and will show us the feasibility of the gearing setup that we have chosen. It will also be able to convey what exactly our project is to someone who looks at out project for the first time.

6.2 Gearbox Phase (Jan 15 - Feb 24)

Gearbox construction will begin at the beginning of the winter semester.
We will first create a box that will support our gears and make is so that once the box is opened nothing will be spinning and it will be safe for kids to try to change the gears. The outside of the box will also need to be made of a material that is clear so that the user will be able to see inside and watch the gears move

6.3 Electrical Puzzle (Jan 15 - Feb 24)

The Electrical puzzle will also need to worked on as soon as the semester begins. The base of the puzzle will be made of wood. The puzzle crosses will be either 3d printed or made of something that is easy to make and doesn’t transfer electricity well. Inside the puzzle crosses there will be a diode that will be connected to springs that will connect to ball bearings that will be connecting each piece.

6.4 Wiring Track (Feb 25 - March 1)

As soon as the other 2 are completed the track will be able to be wired up and tested to make sure that losses along the wires aren't too large. If losses end up being too big a battery connected at the end to supplement the power being generated should be enough to help power the system. If power is too large, then a few resisters can be added to help lower the current or voltage. We hope to have at least 2 stations made before March 6 so we can show it at the science fair and see what our clients think of it.

7. IMPLIMENTATION

The following section sheds light on the manufacturing processes of the first station for the an Engineer’s Pit Race. Generally speaking, the majority of the components that are used for the construction and implementation have been listed on the Bill of Materials, and they were mostly purchased from online vendors such as Amazon. For the budget, $2000 was set aside, but as it turned out, an addition of $77.26 was needed to meet the requirements. The lion’s share of this task involved the design and manufacture of gears and a gearbox to power the race track, and all precautions, prerequisites and additional information were taken into consideration as mentioned below. Further implementation was aided by determination the gears and crank arms that conformed to the power requirement of the electric generator. Power is to be transmitted to the racecar after successful completion of the of the electric circuit puzzle. First a clear description of the manufacturing of each part and a breakdown of all the parts that were used in the building process. Lastly there is a description of the tests done prior and during the building process, and a description of how these tests affected the building of the final result.

7.1 Design of Experiments(DoE)

Design of Experiments is a theory indicating minimum number of tests in order to develop a final model. This is for knowing how the design perform while using several variables at the same time. For Design of Experiments, the team tested each parts to determine the optimal design of the project. In theory of DoE, the team is supposed to test all three variables at the same time. However, most of parts were straightforward to use one variable, which is the time, for the test except for Circuit puzzle. Thus, the test was focused on the time instead of several variables.

Generator – The generator, 4 cube inch size, converts mechanical energy to electrical energy. Since the team is going to use this electrical energy in racetrack, the team tested this generator to figure out how many RPMs they needed in order to get around 21 volts. The testing proceeded 3 times for 5 minutes each and it showed that 840 RPMs were needed to get around 20 to 22 volts. With the output known team 15 could decide exact what gear ratios they would need and the shape of gearbox.
Durability of gears, shaft and keys – The gears convert input RPM to a certain output RPM. The shafts, which are aluminum rods, are connected to each gear and allow for rotation. Keys are used to connect the gears to shaft. The team needed to test the durability of the gears and keys because they are plastic and shaft and gear are connected by only one key. For this, the team rotated the handle 3 times for 5 minutes each with the output gears experiencing 1000RPMs, 1250 RPMs, and 1100RPMs. The results showed that there were no cracks, or wear on the keys and gears of each station. With these results the team kept 3D printing gears and using one key for each gear connection.
Circuit puzzle – For the circuit testing each connection was checked for continuity and for the correct voltage and resistance. The first components tested were the light and all the wire connectors for the puzzle. This was done by making sure each wire could turn on the light by itself. Each wire connector did its job and no changes were needed. The relay was also tested to make sure it closed the connection when the puzzle was completed and the light was turned on. The breaker was tested by pushing the switch and confirming that the circuit was not connected when the breaker indicated so. The breaker also performed well and no changes were needed. Each test was conducted 3 times with using different wires and there was no disconnection or not working. As a result, the team did not need to change anything of circuit puzzle.
Complete track test – The final test was making sure everything worked together harmoniously. The test was done by getting the 3 main components together and seeing if there were any hook ups while running them. When the group tested this for the first time it seemed to be working just fine. Further experimenting eventually revealed a small problem. It turned out that the relay was allowing negative current through the track no matter if the relay was closed or open. Prior tests didn't account for negative current and showed that the relay was working fine. This was fixed with a diode to prevent negative current and to ensure current was only allowed to flow 1 way. The gearbox worked fine and the track was moving the car pretty fast when we turned the crank arm. With the 1 problem found and fixed the track testing was finished.

7.2 Manufacturing

In this section, the manufacturing process of the gears and a full gearbox is described, coupled with a detailed description of the entire project, including the circuit puzzle and the DC generator. Because the racetrack was bought assembled, there was not much that could be explained about its fabrication. The materials that were ordered played their roles in ensuring the success of this project or picked up from Home Depot and HomCo. For example, the gearbox was made from gear frame and a wooden base plate, all fastened by screws, nuts and washers for bolts. Other items included a wall plate bearing, strap hinges, a power generator, to mention but a few. The full list of materials that were required is described in the Bill of Materials in Appendix E.

One of the best tool for designing the gears is the 3D printing. The design of gears necessitated an exceptional grasp of the following factors: type, power and speed of the prime mover, the overall ratio of the gearbox and the kind of the unit required, for which both parallel and angled drives were selected. Furthermore, the direction of rotation of the shafts was critical, coupled with operating conditions and space restriction. There were three concerns that were taken into account before calculating the nominal torque during design for all the gears for the project. First and foremost, the shafts were designed by lathe. Next, an electric generator was to be used, meaning it could develop twice as much full load torque on start up. The implication here is the resizing of the gearbox because the race track needs routine start/stop operations. Lastly, rigid couplings on the Bill of Materials transmits shocks quickly to the gearbox than a flexible gear type coupling, hence choosing had to be adjusted accordingly. Afterward, the gears, keys and arms were designed using SolidWorks software and 3D printed. The challenging part was in machining them.

Plastic was the best material choice for the gears as it is hardened to resist contact stresses and tooth breakage, and because it is relatively ductile to withstand shock loads on gears. Following the selection of plastic, it was treated by 3D printing to alleviate chances of distortion. Gear teeth were then cut into a gear blank and surface-hardened to maintain substantial ductility. The next step involved the assembly of the wooden gearbox, which included four general steps; construction of the shaft, preparation of the gearbox, installation of the plastic gears on the drives and last but not least, assembly and testing of the gearbox. The required tools included a wooden base plate, a gear frame, screws for assembly of the gearbox frame and those for mounting items on the base as well as shafts, bolts and washers. Checking the worm involved ascertaining the fit of the worm on the worm shaft, and it was a light press fit on the shaft. Afterward, the gearbox was prepared cleaning flashings as well as checking the bearing fit in the gearbox. On the wooden base plate, holes were drilled to secure the torque arm. This was followed by the installation of the plastic gear, after which everything was put together by placing the worm assembly with the washers and bearings on their side in the gearbox frame with the help of a wall plate bearing and a middle mount bearing. Notably, the plastic was lubricated, followed by the installation of the other gearbox half with secure screws.

The power generator was fastened on the wooden base plate with screws, and it was attached with banana wires and banana plugs. Connecting the power generator to the gearbox system was an aluminum round rod, and since the motion was already anticipated for the system, a bolt for bearing installation was included in the bill of materials to ease movement. It should be remembered that the gear system was hooked to pulleys for safety purposes. Another security measure involved closing the gearbox system with a glass top with a latch mechanism for easy access. Moreover, the connecting wires from the power generator to a source of energy were rolled from a 20ft 12-gauge hookup wire.

A schematic representation of the circuit puzzle frame was replicated on the wooden base plate with stain and seal paint, coupled with its circuitry and layout of connecting wires. At the same time, wires were restrained by hooks and wire clamps for safety and neatness. It should be remembered a solder fastened the connecting wires that passed through the circuitry of the puzzle and attachment to the power generator. Moreover, a resistor was added on wire connecting circuit puzzle to racetrack to prevent that the cars fly off from the track. After ensuring that every component was correctly assembly in its place, the four stations were laid as shown in Figure 20, 21, 22, 23,24 and 25. All in all, this was a successful implantation of the all stations for users.

Figure 20: Gearbox

Figure 21: Generator

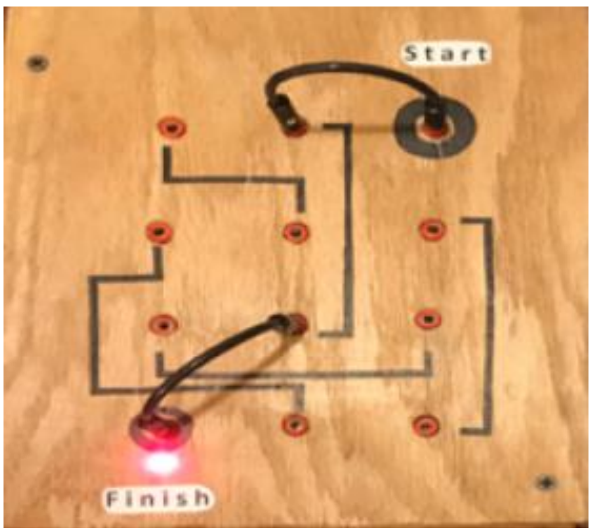

Figure 22: Circuit Puzzle

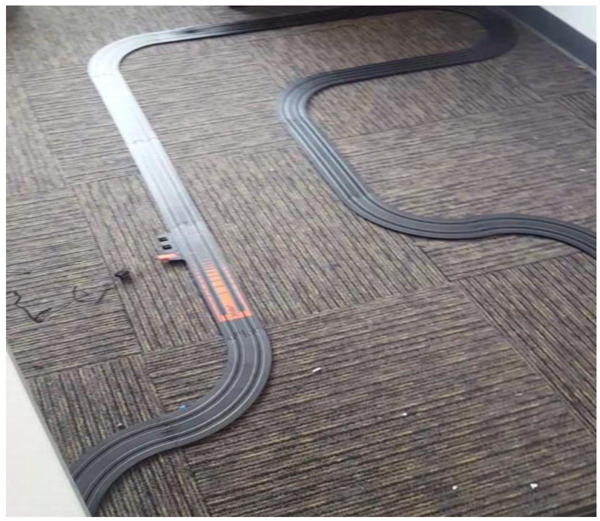

Figure 23: Race Track

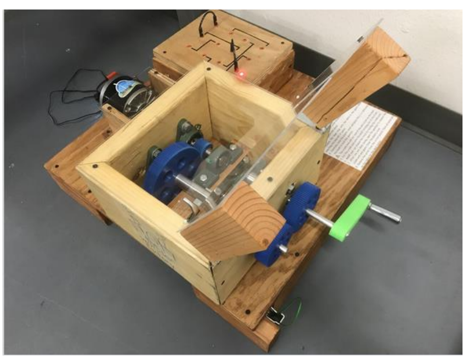

Figure 24: Final actual Design

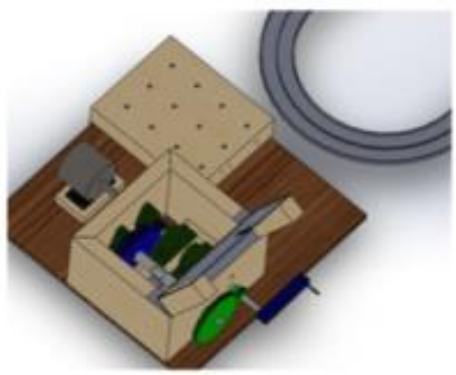

Figure 25: Final CAD Design

Figure 26: Four Completed Stations

8. Testing

From the design requirements, the design was expected to adhere to safety, ease of use, portability, simplicity, projecting into role, feel intelligent, simultaneous operation by multiple users, visual, audio and tactile aspects. The team had to test the project and determine the requirements met and that which were not achieved by testing. Notably, most of the requirements passed all tests.

8.1 Testing Results

Specifically, the safety feature incorporated into the design consisted of a gearbox front cover that would enable the user to solve the puzzle once it was closed. It should be noted that gearbox contained two sets of gear that would pose a danger if they were exposed to the user.

Additionally, the circuit puzzle was fitted with sufficient resistance to slow down the racing car preventing it from running off the track. These safety features were tested by trying to solve the puzzle without closing the gearbox front cover and by fitting the highest gear ratio, and their operation was efficient. As far as ease of use was concerned, an operation manual was simplified and attached on the front surface of the gearbox where every user would easily refer to while operating the device. Simplicity test was conducted by evaluating the incorporated technique utilized in solving gearbox puzzles and found to be adaptive and easily understood by most users. Eventually, projected into role test was conducted by examining the feel of the user after solving racetrack puzzles using the device and the resulting observation indicated that most users felt ingenious and creative and wanted to solve more of the same puzzles. The audio and visual aspects test were conducted by inspecting the clarity of gear rotation on the transparent cover, and it was noted that user was intrigued to see the actual operation of the gears they selected in the gearbox. Simultaneous operation test was conducted by inspecting the conformability of all the station to enable users to solve puzzles and race independently without interfering with other participants racing on other stations. Notably, the race track will only operate once the circuit puzzle is solved making the user feel smart. The gearbox consists of two different sets of gear ratio whereby the user is expected to select and attach them to the gearbox. The selected gear ratio provide different speeds when cranked and therefore require the use to figure out which gear ratio will provide higher rotational speed to win the race. This concept will make the user feel creative as an engineer once they find the best combination that will enable them to win the race. The team has also attached a resistance inside the circuit puzzle to make sure the car will not come off the track during high input rotation. The design exhibit great ease of use with little instructions that can be performed by following the instrctions on the station. For the portability, the weight that team has mentioned in testing procedure was 40lb. However, the tested weight was found to be 43lb indicating that the final design can be moved by one person. Moreover, the team used a plastic cover to house the gear box enabling the users to observe what is happening inside the gearbox while getting sounds from the rotating gears. Therefore, it can be noted that the design met visual, audio and tactile requirements. The design is also simple enough for users since its puzzles can be generated and solved easily after reading the instructions attached next to the gearbox. Finally, the team assembled four stations for multiple users operations, therefore, enabling four users to solve puzzles independently and race at the same time.

9. CONCLUSIONS

This section will contain the groups final thoughts on the project. It will talk about the contributors to success, and the areas for improvement of the project. It also talks about what the team learned and how they were able to overcome obstacles faced during the project.

9.1 Contributors to Project Success

In conclusion, we were able to complete and deliver our project to our clients while learning many things along the way. Our clients were very supportive along the way and always had very good input whenever we asked them for it. Thanks to them we were able to test our design at an event so we could see what was off and needed to be redesigned.
Besides our clients being a big factor to our success, there were many other tools and people that

helped us along the way. The machine shop ensured that we were able to have specialized tools and a place to work for large amounts of time throughout the week. The rapid labs and the library were able to make our 3D parts very quickly each time we ordered them. The ease of communication between the group and others helped to make sure we were on the right track. When we had questions our Professor was able to point us in the correct direction each time. The team was able to work together to solve many problems with our combined efforts. This greatly helped the project continue smoothly and made sure that when obstacles came up we were able to get past them with ease. The communication between the team was always good and this made it so time management was very good as well. We were always able to have an extra day to put things off just in case someone either had a test or if the team just needed a break. A few of the obstacles encountered by the team were the redesigning of gears and the implementation of a safety mechanism in the gearbox. These along with others were all tackled with ease and the team never faltered at a challenge.

9.2 Opportunities/Areas For Improvement

There are a few things that could have been improved. Since we realized too late that the gears were generating too much power the team had to eventually make the outside gears a 1:1 ratio which is effectively redundant. The team also could have spent money a little better as the projected costs went a little over budget. Some if the team ate these costs and that is how we didn't go over budget. Knowing what we do now the project would have been done in an easier and simpler way.

In the end the group was able to learn some valuable lessons. We learned how to be professional and interact with a client. We learned how to better interact within a group to get things done. We all received machine shop certification and some of us received specialized training on the lathe and mill machines. The design also required us to go back and relearn some things that we forgot and also learn some new concepts altogether. This project was an overall positive learning experience for our group.

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11. APPENDICES

11.1 Appendix A – Client Approvals

NORTHERN ARIZONA UNIVERSITY

David Rankin <dl555@nau.edu>

ME 476C Sect 2 - The Wonder Factory Stem Display B - Team 15

Jackee Alston <thewonderfactoryflagstaff@gmail.com> Fri, Sep 30, 2016 at 10:21 AM
To: David Rankin <dl555@nau.edu>
Cc: Ali Alkhaiyat <aa3363@nau.edu>, Yongseok Park <yp68@nau.edu>, Juan Shields <js2762@nau.edu>

Hi David,

This looks great to me. Thanks! Keep up the good work!

~ Jackee

On Wed, Sep 28, 2016 at 10:44 AM, David Rankin <dl555@nau.edu> wrote:

Hello Jackee,

We have put together your requirements along with our understandings of them and the relative weightings we thought were appropriate in the chart below. Would you be able to review them for approval, please? Feel free to make any adjustments that you deem necessary and we will make the changes.

#	Customer Requirements	Descriptions	Weight
1	Portable	Easy to move, setup, transport, etc.	5
2	Multiple users	Possible to have more than one user at a time	3
3	Project into role	User feels like an engineer, scientist, artist, etc.	4
4	Feel smart	Display allows user to learn from the experience	4
5	Tactile	Users are able to touch, move, and explore the display	3
6	Auditory	Display has integrated sounds for the user	2
7	Visual	Display is appealing and attracts visitors to use it	3
8	Simple	Not so complex that the user gets frustrated and quits	5
9	Safety	Anyone can use the display without injury	5

Scale is 0-5 with 5 being the highest importance. Please let me know if you have any questions or concern. I appreciate your assistance in this matter.

Figure 1: Client CRs and Weightings Approval Email

NORTHERN ARIZONA UNIVERSITY

David Rankin <dl555@nau.edu>

ME 476C Sect 2 - The Wonder Factory Stem Display B - Team 15

The Wonder Factory <thewonderfactoryflagstaff@gmail.com> Sun, Oct 30,
To: David Rankin <dl555@nau.edu>
Cc: Ali Alkhaiyat <aa3363@nau.edu>, Yongseok Park <yp68@nau.edu>, Juan Shields <js2762@nau.edu>

It looks great,
gentlemen. Thanks!

- Jackee

Sent from my iPhone

On Oct 28, 2016, at 1:11 PM, David Rankin <dl555@nau.edu> wrote:

Hello Jackee,

Thank you for the link! We are excited about the "Engineer's Pit Race" design concept and we are glad that you like it, too! We have made some changes to the engineering requirem
and targets with tolerances that are more tailored to this design. May we please get your approval on these?

House of Quality (HoQ)

Customer Requirements (1 - 9):	Weight	Engineering Requirement	fits in set-up area	low total weight	low cost	meet power/voltage potential	no exposed sharp edges	visual display added	multiple, simultaneous operation	educational level
1. Portable	5		5	4				1	2	
2. Safety	5			4		3	4			
3. Multiple User	3								5	
4. Tactile	3					2	4			
5. Auditory	2					2				
6. Visual	3					2				
7. Project into role	4							5		4
8. Feel smart	4							4		5
9. Simple	5							3		5
Absolute Technical Importance (ATI)			25	40	0	31	32	56	35	61
Relative Technical Importance (RTI)			7	3	8	6	5	2	4	1
Targets; with Tolerances			100 ft^2; <200 ft^2	90lb; <150lb	$1200; <$2000	16V; 14V> & >20V	1/8" corner radius; <1/6" 1/16" edge chamfer <1/8"	1 display; > 3 total	4 users; 2< & >6	tailored to age 10; 6<

Let me know if you have any questions or concerns.

Best Regards,
David Rankin

Figure 2: Client ERs Approval Email

11.2 Appendix B – Pugh Chart

Customer Requirements \ Design Ideas	air cannon	light shadow	smoke manipulation	mirror room	music with water cups	moment machine	clay car build and race	engineering puzzle	popsicle stick house	bridge design and build	gear powered race	compressed air organ	dam to generate power	plane in a box	treadmill candy machine	gear puzzle	gear powered lights	programming game	bicycle power video game	catapult game
Portable	0	-1	0	-1	0	-1	0		0	0	0	-1	-1	0	-1	1	0	0	-1	-1
Safety	-1	0	-1	0	0	-1	0		1	1	1	0	0	0	-1	0	0	0	0	-1
Mutiple Users	-1	0	-1	0	0	-1	1		0	1	1	1	1	1	0	1	0	0	0	1
Tactile	0	-1	1	-1	1	1	1	D	1	1	1	1	1	0	1	1	1	1	1	1
Auditory	1	-1	-1	-1	1	-1	-1	a	-1	-1	1	1	-1	0	-1	1	1	0	1	-1
Visual	1	1	1	1	1	1	1	t	1	1	1	1	1	1	1	1	1	1	1	1
Project into role	0	-1	0	-1	0	1	1	u	1	1	1	1	1	1	-1	0	1	1	-1	0
Feel smart	0	1	-1	0	1	1	0	m	0	1	0	1	0	0	0	1	0	1	0	0
Simple	1	1	1	1	1	1	-1		1	1	1	1	1	0	1	0	1	-1	1	1
Positives	3	3	3	2	5	5	4		5	7	7	7	5	3	3	6	5	4	4	4
Negatives	2	4	4	4	0	4	2		1	1	0	1	2	0	4	0	0	1	2	3
Same	4	2	2	3	4	0	3		3	1	2	1	2	6	2	3	4	4	3	2
Total	1	-1	-1	-2	5	1	2	0	4	6	7	6	3	3	-1	6	5	3	2	1

Figure 22: Pugh Chart (20 Ideas)

Customer Requirements	bridge design and build	gear powered race	compressed air organ	gear puzzle	New Design: An Engineer's Pit Race
Portable	0	0	-1	1	1
Safety	1	1	0	0	1
Mutiple Users	1	1	1	1	1
Tactile	1	1	1	1	1
Auditory	-1	1	1	1	1
Visual	1	1	1	1	1
Project into role	1	1	1	0	1
Feel smart	1	0	1	1	1
Simple	1	1	1	0	1
Positives	7	7	7	6	9
Negatives	1	0	1	0	0
Same	1	2	1	3	0
Total	**6**	**7**	**6**	**6**	**9**

Design Ideas

Users are counted down to start the race. Each user must determine which gears/crank arms to install based on how much power they want, how difficult the generator will be to turn, and which gears will mesh. Then, the user must complete an electric circuit to transfer power to the racetrack where users will race each other.

Figure 23: Pugh Chart (Top 4 Ideas and New Design Concept)

11.3 Appendix C – Design SolidWorks Drawings

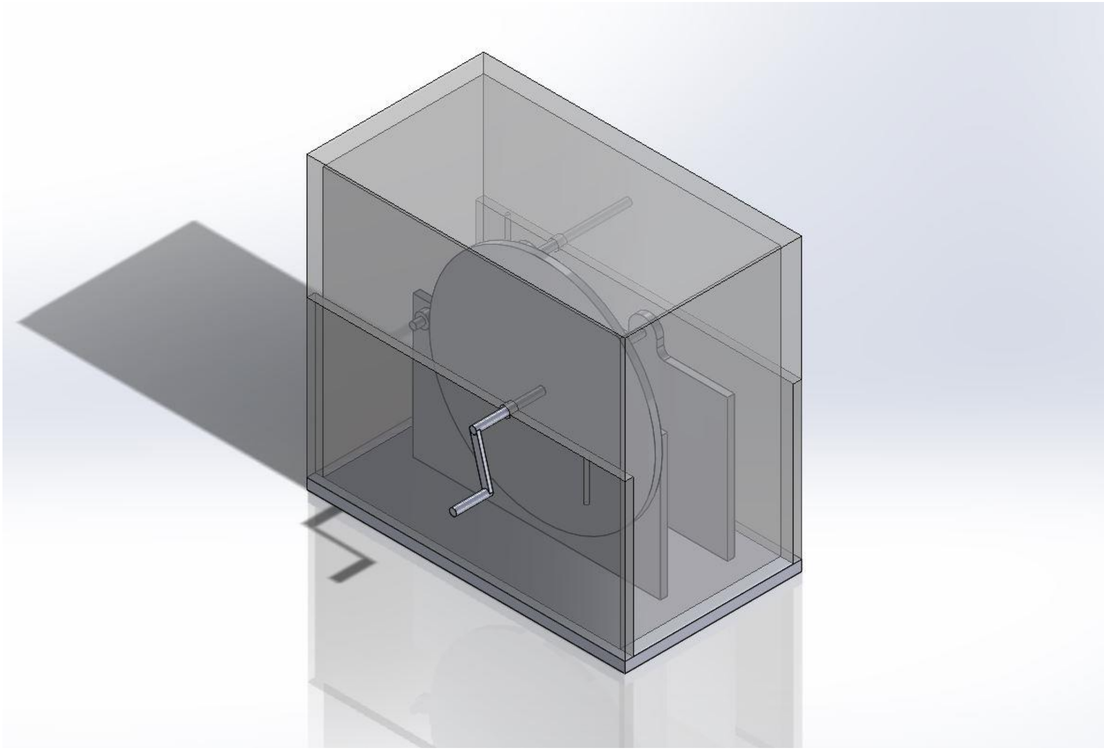

Figure 24: Gear Box Assembly

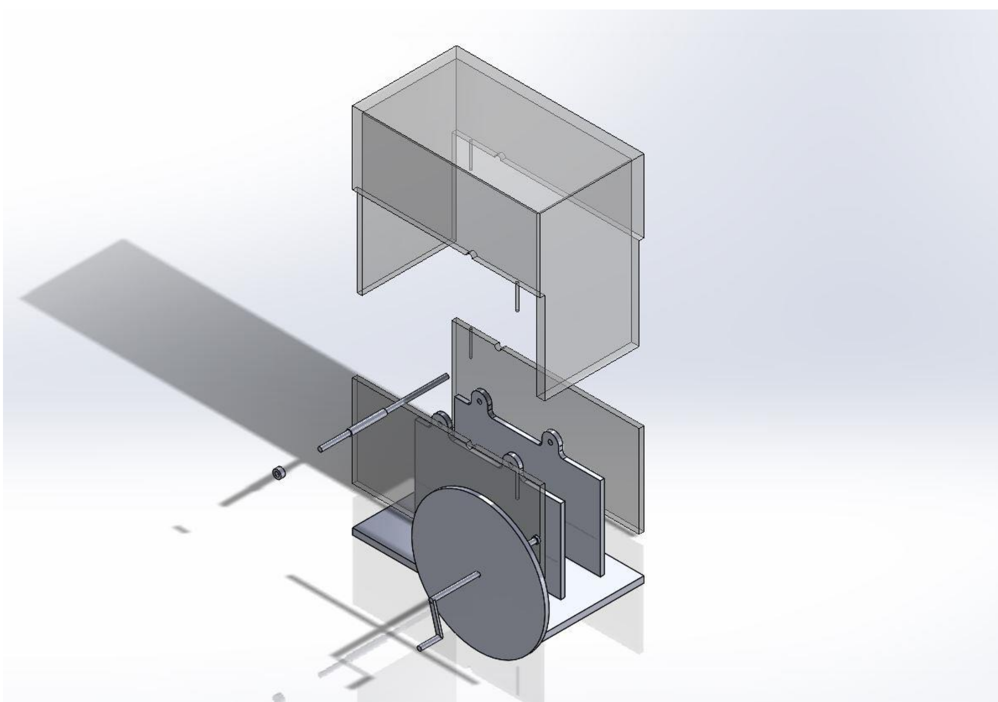

Figure 25: Exploded Gearbox View

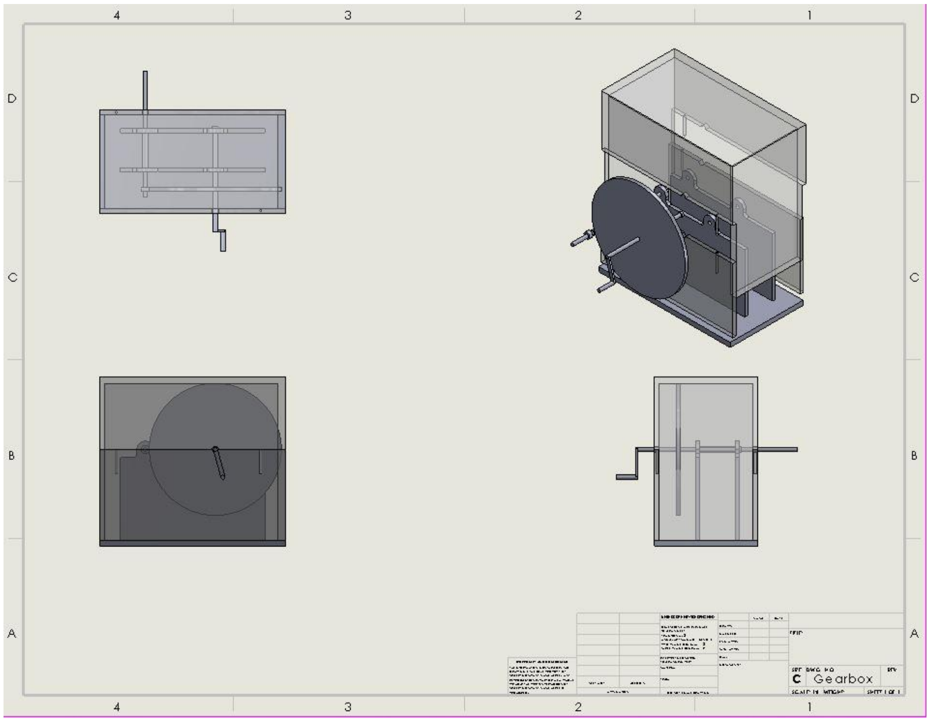

Figure 26: Gearbox Drawing

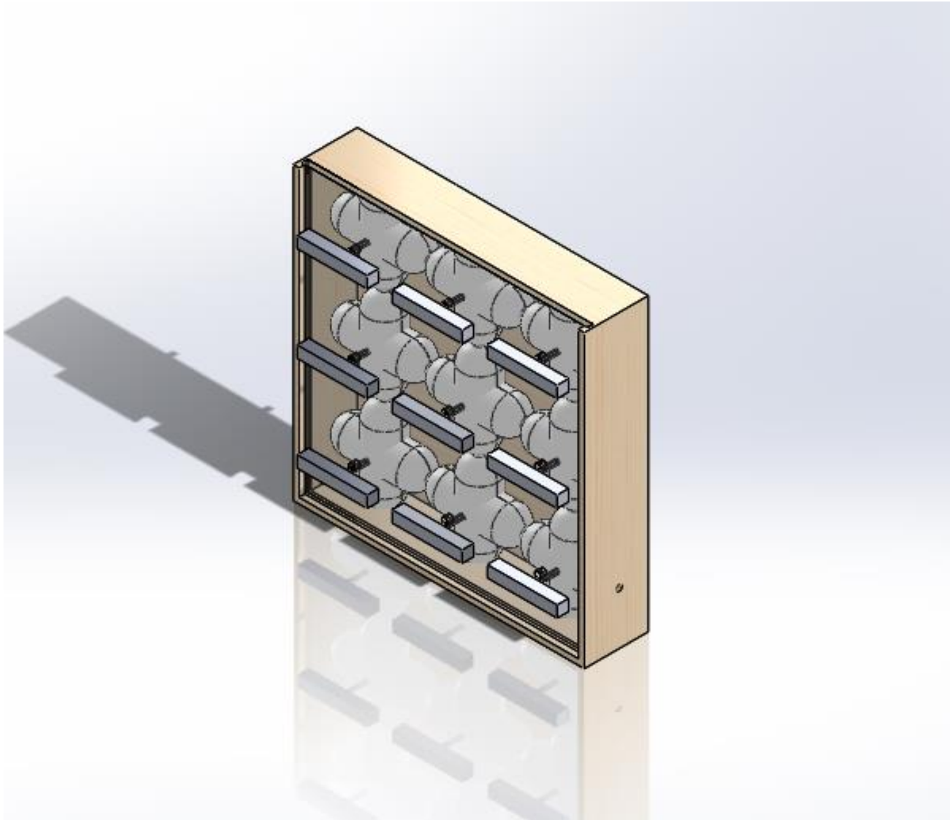

Figure 27: Electrical Circuit Puzzle Assembly

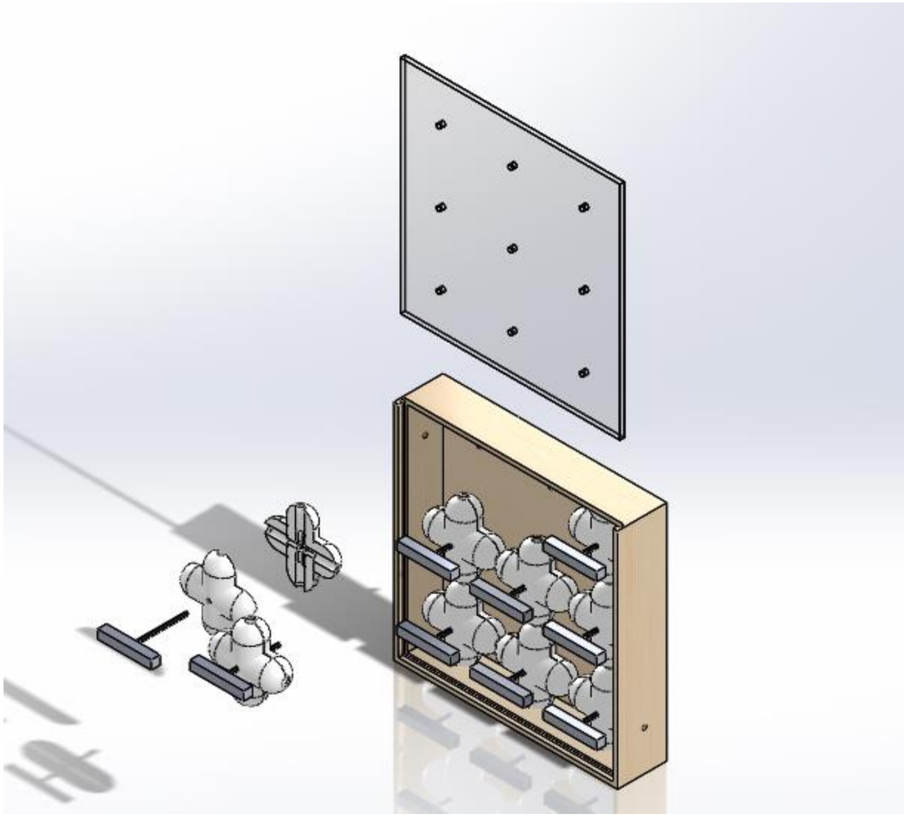

Figure 28: Exploded Circuit Puzzle View

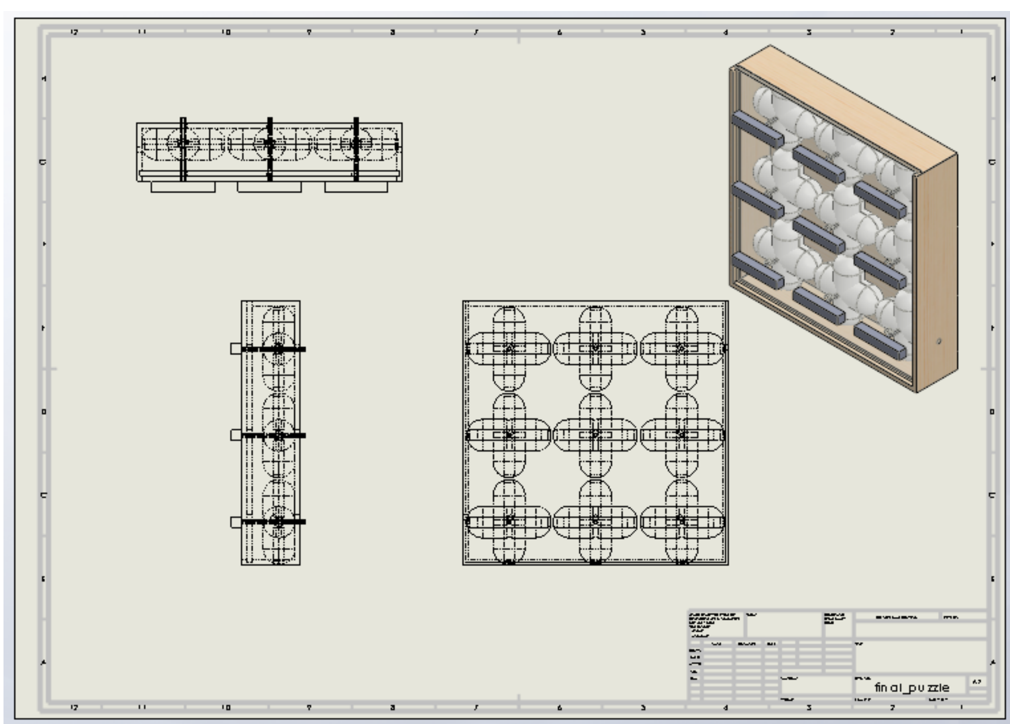

Figure 29: Circuit Puzzle Drawing

11.4 Appendix D – Gantt Chart

Table 5: Spring 2017 Gantt Chart

					Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16
	Start Date	End Date	Duration	Accountable	16-Jan	23-Jan	30-Jan	6-Feb	13-Feb	20-Feb	27-Feb	6-Mar	20-Mar	27-Mar	3-Apr	10-Apr	17-Apr	24-Apr	1-May	12-May
Team Meetings Week 1	16-Jan	16-Jan	1d	Team																
Staff Meetings Week 2	23-Jan	23-Jan	1d	Team																
Individual Post Mortem Week 2	23-Jan	23-Jan	1d	Team																
Manufacturing 1 Week 2	23-Jan	23-Jan	1d	Team																
Wonder Factory Meeting 1 Week 3	30-Jan	30-Jan	1d	Team																
Progress Presentations Week 3	30-Jan	30-Jan	1d	Team																
Manufacturing 2 Week 3	30-Jan	30-Jan	Id	Team																
Team Meetings Week 4	6-Feb	6-Feb	1d	Team																
Manufacturing 3 Week 4	6-Feb	6-Feb	1d	Team																
Manufacturing 3 Week 5	13-Feb	13-Feb	1d	Team																
First Station (Complated Design) Week 6	20-Feb	20-Feb	1d	Team																
Hardware Review 1 Week 6	20-Feb	20-Feb	1d	Team																
Staff Meetings Week 6	20-Feb	20-Feb	1d	Team																
Team Meetings Week 7	27-Feb	27-Feb	1d	Team																
Second Station (Complated Design) Week 7	27-Feb	27-Feb	1d	Team																
Midpoint Report Week 7	27-Feb	27-Feb	1d	Team																
Midpoint Review Presentations Week 8	6-Mar	6-Mar	1d	Team																
Hardware Review 2 Week 9	20-Mar	20-Mar	1d	Team																
Third Station (Complated Design) Week 9	20-Mar	20-Mar	1d	Team																
Team Meetings Week 10	27-Mar	27-Mar	1d	Team																
Fourth Station (Complated Design) Week 10	27-Mar	27-Mar	1d	Team																
Staff Meetings Week 11	3-Apr	3-Apr	1d	Team																
Draft of Poster Week 11	3-Apr	3-Apr	1d	Team																
Presentation walk-throughs Week 12	10-Apr	10-Apr	1d	Team																
Final Poster Week 12	10-Apr	10-Apr	1d	Team																
Final Product Testing Proof Week 13	17-Apr	17-Apr	1d	Team																
Draft of Operation/AssemblyManual Week 13	17-Apr	17-Apr	1d	Team																
UGRADS presentations Week 14	24-Apr	24-Apr	1d	Team																
Operation/AssemblyManual Week 14	24-Apr	24-Apr	1d	Team																
Team Meetings Week 15	1-May	1-May	1d	Team																
Final Report Week 15	1-May	1-May	1d	Team																
Final CAD Package	1-May	1-May	1d	Team																
Website	8-May	8-May	1d	Team																

Done
In progress

11.5 Appendix E – Bill of Materials (BOM)

Table 6: Bill of Materials

Bill of Materials (BOM) for The Wonder Factory STEM Display B -

Assembly Name :	An Engineer's Pit Race
Version :	3 (with additional funds and fundraising)
Assembly Revision :	2/25/2017
Number of Stations	4
Part Count :	283
Total Cost :	$2,077.26

Supplier	Name of Assembly	Seller Description	Qty	Units per station	Picture	Unit Cost	Notes	Cost
Home Depot	Wooden base plate	3/4 in. x 4 ft. x 8 ft. PureBond Red Oak Plywood	1	0.25		$ 49.98	pickup at store/ tax included	$ 49.98
Home Depot	Gearbox frame	2" x 8" x 8' #2 and Better Prime Douglas Fir Board	2	0.5		$ 6.37	pickup at store/ tax included	$ 12.74
Home Depot	Screws to assemble gearbox frame	#8 x 3 in. Philips Bugle-Head Coarse Thread Sharp Point Drywall Screws (1 lb.-Pack)	2	0.5		$ 4.89	pickup at store/ tax included	$ 9.78
Home Depot	Screws to mount items to base	#8 x 1 in. Philips Bugle-Head Coarse Thread Sharp Point Drywall Screws (1 lb.-Pack)	1	0.25		$ 4.89	pickup at store/ tax included	$ 4.89
Ace Home Co	Bolt to install bearings	3/8 in. - 16 tpi x 2-1/2 in. Zinc-Plated Grade-5 Hex Cap Screw (1 per Pack)	50	12		$ 18.62	pickup at store/ tax included	$ 18.62
Ace Home Co	Nut for bolts	3/8"-16 Zinc Finish Grade A Finished Hex Nut	48	12		$ 0.09	pickup at store/ tax included	$ 4.18
Ace Home Co	Washer for bolts	3/8" x 0.812" OD Low Carbon Zinc Finish Steel SAE General Purpose Flat Washer	1	24		$ 7.35	pickup at store/ tax included	$ 7.35
Amazon	Wall plate bearing	(Qty. 2) 5/8" UCFL202-10 Quality Pillow block bearing units ucfl 202 oval flange by JSB	8	2		$ 12.99	tax and shipping included	$ 109.91
Amazon	Middle mount bearing	1/2" UCP201-8 Self-Align UCP201 Pillow Block Bearing by ZSKL	8	2		$ 5.39	tax and shipping included	$ 47.61
Amazon	Aluminum Round Rod	2011 Unpolished (Mill) Finish, Cold Finished, T3 Temper, ASTM B211, 1" Diameter, 72" Length	2	0.5		$ 38.53	tax and shipping included	$ 80.51
RAPIDLab	Spur gear sets	1:2, 1:3, 1:4 ratio. 8 gears total	4	1		$ 76.26	tax included	$ 305.04
3D Print @ Cline Library	Keys	3D printed keys	16	4		$ 0.09	tax included	$ 1.40
Home Depot	Clear Acrylic Sheet	18 in. x 24 in. x 0.093 in. Clear Acrylic Sheet Glass Replacemen	4	1		$ 10.27	pickup at store/ tax included	$ 41.08
Home Depot	Black Hinge	3 in. x 3 in. Black Strap Surface Mount Hinge (2-Pack)	1	1		$ 3.83	pickup at store/ tax included	$ 3.83

Home Depot	Strap Hinges	3 in. Zinc-Plated Strap Hinge (2-Pack)	3	3.27		$ 3.83	pickup at store/ tax included	$ 11.49
3D Print @ Cline Library	Different size crank arm	3D printed crank arm. 8" long	4	1		$ 18.46	tax included	$ 73.84
3D Print @ Cline Library	Different size crank arm	3D printed crank arm. 5" long	4	1		$ 12.38	tax included	$ 49.52
Amazon	Revolving handle for crank arm	uxcell Universal 8mm M8 Male Thread Metal Revolving Handle Grip 2Pcs	8	2		$ 7.04	tax and shipping included	$ 56.32
Greenergy Star	Power Generator	WindZilla 12 V DC Permanent Magnet Alternator Wind Turbine Generator PMA	4	1		$ 155.00	tax and shipping included	$ 620.00
Home Depot	Pine Block	7/8 in. x 3-1/2 in. x 6 in. Pine Plinth Block	4	1		$ 3.97	tax and shipping included	$ 15.88
Amazon	Banana wires	HIGHROCK 20 Banana Speaker Wire Cable Screw Plugs Connectors 4mm	3	0.75		$ 7.75	tax and shipping included	$ 23.25
Amazon	Banana plugs - female	20 Pack CESS Universal Female Jack Socket For 4mm Banana Plug AWG 9 Gauge	3	0.75		$ 9.59	tax and shipping included	$ 28.77
Home Depot	Puzzle frame	2 in. x 4 in. x 92-5/8 in. Prime Whitewood Stud	4	1		$ 2.77	pickup at store/ tax included	$ 11.08
Rcsuperstore.com	Race Track	Product code: AFX21018 4 person race track, 22v 1A input	1	1		$ 229.95	tax and shipping included	$ 229.95
Home Depot	Southwire 12 Black Stranded	Southwire (By-the-Foot) 12 Black Stranded CU THHN Wire	60	15		$ 0.39	pickup at store/ tax included	$ 23.40
radio shack	LED light	RadioShack 5mm LED (Red)	4	1		$ 2.54	pickup at store/ tax included	$ 10.15
radio shack	solder	RadioShack High-Tech Rosin-Core Solder (1.5oz)	1	0.25		$ 9.70	pickup at store/ tax included	$ 9.70
radio shack	crimping wire connectors	RadioShack Shrink Butt Connectors	1	0.25		$ 2.44	pickup at store/ tax included	$ 2.44
radio shack	20ft 12 guage hook-up wire	RadioShack 20-Foot UL Hookup Wire 20AWG	1	0.25		$ 9.89	pickup at store/ tax included	$ 9.89
radio shack	100 ohm resisters	RadioShack 100-Ohm 1/4-Watt 5% Carbon Film Resistor (5-Pack)	2	0.5		$ 1.91	pickup at store/ tax included	$ 3.81
radio shack	velcrow	superlock and hook/loop fasten	1	0.25		$ 10.78	pickup at store/ tax included	$ 10.78
radio shack	aa holder	holds 1 aa and another that holds 2 aa	1	0.25		$ 6.35	pickup at store/ tax included	$ 6.35
radio shack	9 volt holder	RadioShack Heavy-Duty 9V Snap Connectors	3	0.75		$ 2.95	pickup at store/ tax included	$ 8.85
Ace Home Co	Pulleys for safety mechanism		4	4.4075		$ 8.82	pickup at store/ tax included	$ 35.26
Home Depot	Wire for safety mechanism	1/16 in. x 250 ft. Galvanized Vinyl-Coated Wire Rope	4	1		1.4	pickup at store/ tax included	$ 5.60
Home depot	Wire clamps for safety mechanism	1/16 WIRE ROPE CLAMP SET ZINC	3	0.75		$ 4.56	pickup at store/ tax included	$ 13.68
Home Depot	Hooks for safety mechanism	1.9 in. Matte Nickel Single Prong Robe Hook Value Pack (6-Pack)	1			$ 7.97	pickup at store/ tax included	$ 7.97
Ace Home Co	Spring for safety mechanism		4	1		$ 1.59	pickup at store/ tax included	$ 6.36
ME Fabrication Shop	Safety mechanism	Use scrap metal to create safety mechanism	4	1		Free		$ -
Home Depot	Spray paint	PAINTERS TOUCH 2X GLOSS BRILLIANT Blue	1	1		$ 3.87	pickup at store/ tax included	$ 3.87
Home Depot	Spray paint	PAINTERS TOUCH 2X SATIN EDEN Green	1	1		$ 3.87	pickup at store/ tax included	$ 3.87
3D Print @ Cline Library	Prototyping costs	Costs to create 3-D printed prototype	1	1		$ 98.27	tax included	$ 98.27
	Total		283					$ 2,077.26