The Wonder Factory

Preliminary Report

Team E

London Starlin

Abdullah Alshammari

Mohammed Kattan

2017

Project Sponsor:

Faculty Advisor: Jennifer Wade

Sponsor Mentor: Jackee Alston

Co-Faculty Advisor: Sarah Oman

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TABLE OF CONTENTS

Table of Contents

DISCLAIMER 2
TABLE OF CONTENTS 3
1 BACKGROUND 7
1.1 Project Description 7
1.2 The Wonder Factory 7
1.2.1 The Wonder Factory Structure 7
1.2.2 The Wonder Factory Operation 8
1.2.3 The Wonder Factory Performance 8
1.2.4 The Wonder Factory Deficiencies 9
2 REQUIREMENTS 9
2.1 Customer Requirements (CRs) 9
2.2 Engineering Requirements (ERs) 12
2.2.1 Safety & Simple Instruction 12
2.2.2 Hands-On & Wow Factor 13
2.2.3 Simple to Assemble & STEAM Learning Concepts 14
2.2.4 Narrative & Visual Appearance 15
2.2.5 Relatable & Durable 15
2.2.6 Educational & Mobile 16
2.2.7 Multiple Visitor & Cost 16
2.3 Testing Procedures (TPs) 17
2.3.1 Safety Tests #1 17
2.3.2 Preparation Test #2 18
2.3.3 Durability Test #3 18
2.3.4 Participant Test #4 19
2.3.5 Usability Test #5 19
2.3.6 Counting Test #6 19
2.3.7 Gravity Test #7 20
2.4 Design Links (DLs) 20
2.4.1 Design Links#1: Safety & Simple Instruction 20
2.4.2 Design Links #2: Hands-On & Wow Factor 21
2.4.3 Design Links #3: Simple to Assemble & STEAM Learning Concepts 22
2.4.4 Design Links #4: Narrative & Visual Appearance 22

2.4.5 Design Links #5: Relatable & Durable 23
2.4.6 Design Links #6: Educational & Mobile 23
2.4.7 Design Links #7: Multiple Visitor & Cost 23
2.5 House of Quality (HoQ) 24
2.6 Funding 24
3 EXISTING DESIGNS 24
3.1 Design Research 25
3.2 Existing Centers 25
3.2.1 Existing Center #1: Science Foundation Arizona 25
3.2.2 Existing Center #2: Amazement Square 25
3.2.3 Existing Center #3: Intrepid Sea, Air & Space Museum 26
3.2.4 Existing Center #3: The Discovery Cube, CA 26
3.3 Subsystem Level 26
3.3.1 Subsystem #1: Astrology 26
3.3.2 Subsystem #2: Environmental 27
3.3.3 Subsystem #3: Aerospace/Aeronautical 30
4 DESIGNS CONSIDERED 32
4.1 Design #1: Pendulum Wave 32
4.2 Design #2: Make Music with Water 33
4.3 Design #3: Hydraulic Lift 34
4.4 Design #4: Make a Bridge 35
4.5 Design #5: Ball Propeller 36
4.6 Design #6: Hill Climbing Racing 36
4.7 Design #7: Boat Sailing 37
4.8 Design #8: Handle Wind Power 38
4.9 Design #9: Ball Race 38
4.10 Design #10: Wind Shoot 39
4.11 Design #11: Weight Lifting 40
4.12 Design #12: Electric Train 41
4.13 Design #13: Hydraulic Chair 42
4.14 Design #14: Accordion Hydraulic Lift 43
4.15 Design #15: Platform Hydraulic Lift 44
4.16 Design #16: Hydraulic Arm 44
4.17 Modified Design #17: Ramp Lift 45

4.18 Modified Design #18: Railing 45
4.19 Modified Design #19: Hydraulic Forklift 46
5 DESIGN SELECTED 46
5.1 Rationale for Design Selection 47
5.2 House of Quality (HoQ) 47
5.3 Funding 48
5.4 EXISTING DESIGNS 48
5.5 Design Research 48
5.6 Existing Centers 49
5.6.1 Existing Center #1: Science Foundation Arizona 49
5.6.2 Existing Center #2: Amazement Square 49
5.6.3 Existing Center #3: Intrepid Sea, Air & Space Museum 49
5.6.4 Existing Center #3: The Discovery Cube, CA 49
5.7 Subsystem Level 50
5.7.1 Subsystem #1: Astrology 50
5.7.2 Subsystem #2: Environmental 51
5.7.3 Subsystem #3: Aerospace/Aeronautical 54
5.8 Design Description 56
5.8.1 Input Analysis 57
5.8.2 System Losses 58
6 PROPOSED DESIGN 58
6.1 Bill of Materials for Final Design 58
6.2 Budget 59
6.3 Prototype 59
7 IMPLEMENTATION 61
7.1.1 Cylindrical Support Analysis 61
7.2 Design Changes 64
7.21 Manufacture Process 64
7.2.2Lifting Platform 65
7.2.4Cylindrical Supports 66
7.2.5Ramp 67
7.2.6 Railing 68
9 REFERENCES 70
[4] HOW TELESCOPES WORK 70
[7] HOW TO MAKE A DRONE / UAV – LESSON 3: PROPULSION - ROBOTSHOP

BLOG.. 70
[8] THIS IS HOW DRONES WORK ("This Is How Drones Work") "This Is How Drones Work". Time.com. N.p., 2017. Web. 15 Feb. 2017. 70
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APPENDICES 73

1 BACKGROUND

Flagstaff, Arizona currently does not have a science center that enables the community to be involved with science, technology, engineering, art, and mathematics (STEAM) resources. Jackee and Steve Alston, have taken it upon themselves to develop a place where anyone can "learn through play." The Wonder Factory (TWF) is a science and engineering center that provides communities with opportunities to present classroom learning through interactive displays. These displays engage the user in performing tasks to understand underlying curriculum associated with STEAM.
The Wonder Factory has asked our Capstone team to develop a new display that will benefit the youth and young at heart. As a team, we are determined to design and construct an interactive display that educates the user about one or multiple STEAM concepts. The interactive display that our team selects to build will positively influence the Flagstaff community by getting their residents more aware and knowledgeable about STEAM. This report will outline the procedures and steps that will go into the process of defining which design meets customer satisfaction.

1.1 Project Description

Following is the original project description provided by the sponsor.

'Your task is to generate lots of interactive display ideas and to ultimately design, build and test one final display ready for public consumption.' - *[1, Pg. 1]*

1.2 The Wonder Factory

The Wonder Factory represents STEAM in all its concepts through interactive displays and learning modules. Originally, Jackee and Steve Alston decided to the forefront this operation because Northern Arizona does not have a center that gets the community interactive with STEAM. The main 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."

1.2.1 The Wonder Factory Structure

The Wonder Factory is currently a mobile exhibition that has different events year-round. Its existing exhibits are built and designed by Northern Arizona University students. Since the Wonder Factory is the first of its kind in Northern Arizona, it can be known as a pioneering science center for rural communities. This type of outreach is important because Jackee and Steve are doing what they originally set out to do; give the opportunity to communities that do not have access to STEAM education. This mobile unit provides a unique learning exhibition on wheels that will continue its outreach, even when a permanent place of operation is established. The Wonder Factory is in the progress of finding funding to get a permanent place of residence for their interactive displays. When they do have a place of "brick and mortar" there will be different rooms that focus on areas of STEAM.

These rooms are listed below:

Doctor's room
Scientists Lab
Engineer's corner

Geographer’s shop
Storyteller’s café
Naturalist’s Playground
Toddler space

There will be a Doctor’s room that will consist of conceptual learning of anatomy and anything health-related. The toddler space will entail simple learning modules that incorporate basic motor skill development, and concepts that require rudimentary knowledge. These rooms will be filled with interactive displays that present one or more STEAM concepts.

1.2.2 The Wonder Factory Operation

Daily operations can be translated into monthly events held by the Wonder Factory. In the future when they have a building this might change based upon types of special events or include daily operations. Most of the events are not continuous and are up to change based on demand.

These events include:

- GEE WHIZ TRIVIA NIGHTS
- Factory after hours
- Wonder ambassadors
- Toddler times
- Field trips
- Birthday parties
- Special events hosting
- Tech bash shark tanks.

1.2.3 The Wonder Factory Performance

The Wonder Factory is providing a service that was not initially met or recognized in Flagstaff and other regions of Northern Arizona. This service is bringing fun, interactive STEAM displays to the accessibility of communities that otherwise would not have them. The analysis below shows that there is a need of innovation of more interactive displays and extension of the preexisting TWF. As they progress in paving the way for a STEAM center in Flagstaff, TWF still needs more interactive displays because as shown in the survey below, 84% of the community is eager to participate and come to the center. In all cases, there is room for expansion in creating educational interactive displays that create learning through fun because 71% of the community think the attractions already in Flagstaff are not suitable for children to have fun and learn.

The community is eager to participate and come to the center, but the goal should be retaining the consumers and making them want to come back or buy a membership. For any non-profit organization to thrive, they need a relationship with the community to maintain the status of their structure and services.

Paid memberships will help sustain income and provide future development for expansion of The Wonder Factory.

The market analysis for the Wonder Factory includes these statistics:

- 71% of the people think that the attractions are not suitable for children to have fun and learn
- 84% of the people say that they would visit The Wonder Factory
- 58% of the people will go there once a month (these are people with memberships)
- 49% people say that they want interactive exhibits rather than visual ones
- 77% tourists spend 2.6 nights here, and 23% of them will travel with children *[2, Pg. 12]*

1.2.4 The Wonder Factory Deficiencies

When interviewing Jackee, she had mentioned they needed more interactive modules in a toddler-dedicated space. Since most capstones teams are focused on upper-level learning, such as projectiles and wind vortexes, TWF does not have a simplistic module for younger children. This could be a potential opportunity when trying to find unmet needs of The Wonder Factory. The current system in place is gaining momentum with the incoming interactive displays, but if the Wonder Factory is deficient in the toddler space, we want to investigate potential solutions or displays that would fill this need.

2 REQUIREMENTS

In this section, we will be explaining project requirements The Wonder Factory team should be considering. One of these requirements is safety. During the client meeting, this was stated as their top priority. We should be keeping this requirement in mind when we are generating multiple concept variants because users will be interacting with our design and we want to minimize any injury.

Before the completion of the project we must select, design, build, and test one final design. This display will be expected to be used every day; we should test accordingly and make sure the design will last and have no occurrence of mishap. The Wonder Factory team should be following these standards to maintain complete clientele satisfaction throughout this capstone project.

Throughout the duration of this project, team members must interact with the clients until the completion of this capstone sequence. This is a requirement because for our design to meet customer satisfaction we need to be well informed of their expectations. We also need to know if they approve of specifications and if there need to be any changes regarding our design or direction of the project.

2.1 Customer Requirements (CRs)

Through client interaction, we will be gathering customer requirements. We focused on keywords and expressed concerns about project specifics to deduce critical requirements the customer outlined. For example, if the customer mentioned they wanted a display that will be noticed and praised for how it made the operator feel or add to their, we would pull from this comment and make a customer requirement that best suited this statement. This account would be translated as the display having a “Wow Factor.” Customer requirements (CRs) are parameters that help engineers focus on the client’s vision and standards of the design. By following these CR’s, the project will have more detailed information so engineers can translate these CRs into engineering requirements (ERs).

Table 1.0: Customer Requirements

Customer Requirement	Weight (Rank)
1. Safe	5
2. Simple instruction	5
3. Hands-on	5
4. Wow factor	5
5. Simple to assemble	4
6. Integration of mult. STEAM concepts	4
7. Narrative	4
8. Visual appearance	4
9. Relatable	4
10. Durable	4
11. Educational	4
12. Mobile	3
13. Multiple visitor	3
14. Cost	3

2.1.1 Safe & Simple instruction

Safety came out to be our most important objective. By decreasing risk factor and taking the necessary steps to identify modes of failure, we can make the interactive display as safe as possible. We want to establish a level of reverence with the community who are going to be using this interactive display. Depending on the design of the project, we must account for safety since the customer rated this at a 5. It is not only in the engineering discipline to design with safety in mind, but it is important to the customer to have a safe product to avoid the risk of injury.

The customers expect the ideology of this design to be STEAM based concepts with the user interface of a "learning through play." The audience that will be interacting with our module will be assumed to have no foreknowledge of STEAM and will perceive the ideas as a student ready to learn. Thus, the design and display should be easy to operate and understand so that the consumer does not need to be guided on every step. This also implies that it will be engaging enough that they will not lose interest. The customer rated this as a five because in the initial interview they mentioned that displays that attribute complexity fail. For example, a user will become disinterested with determining how to derive a calculus equation because it requires upper-level skills of mathematics.

2.1.2 Hands-on & Wow factor

Hands on is a requirement that the design gets the user involved in their learning process. The customer requirements of hands on and education can relate to one another in this aspect. For instance, if the user is building a component they are applying what was taught to accomplish the task. If there is a requirement of a physical interaction, they are applying hands-on interface while learning. The customer rated this CR as five because many learning practices require hands-on experimentation and are proven to help grasp the subject matter.

Of these two customer requirements, the wow factor was rated at a 5. Jackee stressed this CR as important because it makes the interactor remember that display or learning module through amazement and wonder. Wow factor sets it apart from other interactive displays in a sense that it embodies something new and interesting. Wow factory is a measure of unexpected outcomes or the user.

2.1.3 Simple to assemble & STEAM Learning Concepts

A complex assembly that requires extensive knowledge is not suitable for The Wonder Factory. Because TWF exists as a mobile unit, the operators do not have time to set up an intricate display. We need to transform complexity into simplicity to make sure assembly methods are basic for future use. As

displayed in the house of quality in Appendix A, easy assembly is rated as a four which expresses their interests to have a display that can be set up within a reasonable amount of time. We also expect that we have fewer resources than other capstones with engineering laboratories, so we need to make sure our display doesn't need extensive assembly or use of high machining technology.
In the project description, we are asked to make an interactive display that deals with STEAM concepts. We decided this was essential to incorporate STEAM because it is the backbone of the project but we want to apply these learning concepts in one or more forms. Meaning there could be more than one STEAM concept in our design. This CR is rated as a four due to the freedom we have and since STEAM concepts tend to be interwoven into each other as expressed by the client.

2.1.4 Narrative & Visual appearance

Interactive displays with narratives can bring awareness to issues of daily life or around the world problems that need to be solved. The rating of 4 was given for this CR because narratives can prompt the user to construct feasible solutions or introduce them to real-world problems they didn't originally recognize. For example, a display about proactive recycling can have a long-standing impact on children that will bring this knowledge home for future implication.

The interactive display should have appealing visual characteristics so viewers are fascinated and intent in participating in curriculum based STEAM methods. The customer deemed this CR as a 4. Visual appearance is vital when designing. It has been known that consumers are more inclined to use a product that looks superior to competitor products.

2.1.5 Relatable & Durable

The experimental setup should be based on real concepts and relatable material. We want consumers to gain an attachment through resemblance. This customer requirement is rated at a four if you can truly relate to something you will associate yourself with that subject. If the user can put themselves into the shoes of an engineer, an artist, and achieve rather than just be visual amused, then we have accomplished our initial goal of getting the youth and young at heart educated and aware of STEAM.

When designing for something that will be used every day we need to account for long lasting and superior performance. Good quality raw material and mechanical components should be used to meet the requirement of durability.

2.1.6 Educational & Mobile

The educational feature will be incorporated into our design not only because it is a requirement but because it can positively impact the viewer. By gaining more knowledge, they can apply it to real world applications and leave The Wonder Factory gaining a sense of understanding and accomplishment. This CR was rated at a four because the consumer must acquire information through a fun, interactive element. As the equipment, will be handled by the everyday person, mobility must be contemplated. The interactive display should be easy to handle and required simple movements to shift the display easily. The design should have the provisions to be readjusted per floor spacing and number of consumers present at any time.

2.1.7 Multiple Visitor & Cost

When an interactive display can only interact with one person, the message is only received by one individual and the display is limited to collaboration. If we can get multiple participants interacting with the display, this inspires teamwork and gets a message to numerous people. The customer assessed this requirement at three because it may not be as important as other customer needs, such as safety.
The cost was also weighted as a three because the client did not want us to limit our imagination. Cost is still being considered for our project because while gathering information, we came upon a trending

factor. People get amazed at displays that can be home built, meaning material can be purchased at your local supplier for a reasonable price.

2.2 Engineering Requirements (ERs)

From gathered customer requirements, our team generated engineering requirements that outline specific, measurable needs our designs need to meet. These engineering requirements have parameters and tolerances. These are visible in the table below.

Table 2.0: Engineering Requirements

Engineering Requirement	Target	Tolerance
Success Rate	100%	90%
Center of Gravity	1ft(Off Ground)	1.5ft
Organized Components	Covered, Align	Within
Lift Cycle	Infinite	100 Lifts- 2 hrs
Corner Radius	11/16"	9/16"
Surface Temperature	70ºF	Below 78ºF
Skill Level	Novice	Moderate
Prompts User	2 Forms	1 Form
Operation Steps	5 Steps	6 Steps
Facial Features	4 People	3 People
Lift Weight	120kg	100kg
Design Preperation	1 People	3 People
Assembly Time	30 min	1 hr
Assembly Steps	3 Steps	10 Steps
Number of STEAM Concepts	3 Concepts	2 Concepts
Story Line	2	1
Attention of Audience	3 People	2 People
Comprehension of User	Full	Minimal
Connections	3	2
Yield Strength	250MPa	200MPa
Strength-Weight Ratio	46.4 kN*m/kg	76 kN*m/kg
Factors	2 Factors	1 Factor
Weight	150lbs	170lbs
Number of Inputs	2 People	3 People
Component Repair	$100	$130

2.2.1 Safety & Simple Instruction

Safety and simple instruction as explained in section 2.1.1, are the most important customer requirements of the design. The engineering requirements that pertain to safety and simple instruction are:

-Success Rate

The success rate has a target of 100% because the final design must be fully functional and ready for consumption. If our design has any mishaps, this could be a safety issue. Our tolerance was set to 90% due to the display being used multiple times throughout the year. We want to ensure it works and does not have any malfunctions. Users could be at risk if a component breaks and causes injury. If a part malfunctions over a certain period, then it must be rectified per use and replaced with another component that is better suited for that function.

-*Center of Gravity*

The center of gravity should be kept as low to the ground as possible for maximum stability. If the display is not structurally sound, then we will modify the design appropriately. The center of gravity must be no more than 1.5ft with a target of 1ft. If the center of gravity of the display is too high, wind, a user, or an unexpected force can tip the design over. The tipping point must be restrained.

-Organized Components

This is an important requirement because components must be well organized per the design. Any wiring or attachable parts must be covered or stored in an organized manner. The design must have all dangerous components covered to avoid injury. Components that are hazardous can be considered to pinch users or cause any harm. The tolerance of within refers to components organized within reason. If any wires are hanging out this can be overlooked if the component needs to be out and people are notified of its location.

-Lift cycle

Our interactive display will be used multiple times throughout the year at TWF events. If malfunctions occur, then the display will be inoperable. Stress limitations need to be known on the materials we use when finding major stress points in our design. Our tolerance lift cycle is 100 lifts in 2hrs without breakdown or signs of fatigue. This could be tested by stress cycles when applying our weight to our lift. We will be looking at fatigue strength of specific materials in use of our display. Ultimately, we want a high lift cycle or an infinite lift.

-Corner Radius

Corners radius of 11/16” will make the edges less sharp. If sharp edges are present, there is a risk of puncture or wound. These edges are necessary as children will be using the display and will be interacting with all components. Our tolerance for corners was determined to be 9/16” because it still outlines a curve that is less likely to be caught on clothing and flesh.

-Surface Temperature

The surface temperature in mechanical components must be controlled. If we notice that our design is generating heat over room temperature (70ºF), then an internal cooling system or heat sinks must be implemented. Since our components will be in constant use, meaning they will be moving and changing displacement, we need to account for components generating any heat from friction. Over 109.4ºF burns can happen, so for our tolerance, we are making sure temperatures of components stay below 78ºF.

-Skill Level

The skill level in regards to simple instruction has a measurement from novice learning application to moderate. We are assuming the users have no previous knowledge of how to operate the display. The skill level was targeted at novice so ages that span from 2-6 years of age can easily grasp what our display is asking for. The importance of basic skill level requires a growth of the user. As they operate the display, they gain understanding.

2.2.2 Hands-On & Wow Factor

As described in section 2.1.2, hands-on and wow factor is being both rated as 5. These CRs were translated into engineering requirements as follows:

- Prompts User

This engineering requirement incorporates the user taking on a direct role of initiating the action of the display. For instance, if there is an input that requires an action then the user will do this action. Our target is two forms of asking the user to perform an act on our display that will have a certain output. By prompting the user, we can get them directly involved with the inner workings of the display. They will put themselves directly into the role of an engineer, artist, etc.

-Operation Steps

The number of steps in operation should be kept at a minimum level so that the consumer can spend less time operating and more time learning. We have set the target at a maximum of five operation steps. This is an important factor to consider when dealing with hands-on learning. If there are a variety of steps to complete one task, people are less inclined to follow each step. For instance, if a recipe calls for over 20 steps and ingredients that can only be performed in a certain way or obtained from unique stores people will likely skip those steps or replace those items entirely to make a simpler meal. By minimizing the steps, we incorporate simple hands-on learning.

-Facial Features

For our project to succeed, we must have learned through play and have a wow factor. For our design to succeed, we will need a target of four people having amazed facial features. While observing a display at

TWF, they had an air gun that launched a rag into the air. When this happened, everyone would look up to watch it fall back to the ground. As displayed in Figure 1, these are the facial features of many observers. Although they were not directly interacting with the air gun, there was still excitement and a sense of "Wow."

Figure 1: Facial Expressions

-Lift Weight

This is also considered to meet the customer requirement of wow factor because we can execute a task of lifting a 120kg object or person with ease. If a child can lift that weight by using our display with minimal effort, they will be amazed because they are accomplishing something they originally could not do.

2.2.3 Simple to Assemble & STEAM Learning Concepts

This section referring to the CRs assembly, and STEAM concepts are deduced into engineering requirements below:

-Design Preparation

The number of people that initially setup the display should be one to three people. We must account for easy assembly because if our display is too complex and has multiple parts, the display will not be worth putting together. If three people cannot put the display together, then there is a possibility of missing parts, and overall functionality could be compromised by improper assembly.

-Assembly Time

The time required for assembly should be no more than one hour or less than 30 minutes. Set-up time is critical because many events TWF attends have people either ready to engage in the display or to come soon to the event. This period cannot be wasted because consumers are expected to use the display right away, and if the display is not set up, it will be disregarded.

-Assembly Steps

The number of steps in the assembly should be kept below ten, so the customer requirement of simple assembly is met. Our target number of steps to assemble is set at three. The reason why we want minimal procedures is that TWF is a mobile exhibit and they need to be able to set up displays with ease. If steps exceed 10, participants will likely miss important guidelines of setup.

-Number of STEAM Concepts

We decided to have a requirement of more than two STEAM concepts because we want users to gain as much knowledge as possible in a limited setting. These concepts are inter-related, to begin with, based upon benchmarking and customer interaction. For example, the helicopter ride at The Discovery Cube incorporates flight simulation and environmental sustainability. By incorporating different STEAM concepts, we will be maximizing visibility and absorption of multiple ideas, in a small-time frame.

2.2.4 Narrative & Visual Appearance

The narrative and visual appearance referenced in section 2.2.4 were translated into ERs which are listed below:

-Story Line

Storylines give the audience a sense of suspense leading up to events that impact the reader. The display will have a maximum of 1 storyline that will take on a narrative of our display. This narrative can be directly correlating to the use of the design or bringing awareness of technology most people don't fully understand. Our tolerance for this engineering requirement was zero because displays don't have to get a message across. They can simply show the user what is happening instead of setting a scene and building a narrative.

-Attention of Audience

If our design is not getting over three peoples' attention at face value, it will be over looked, and their interest will be lost. This engineering requirement will be measured by counting the number of people interested in our display. As a team, we decided it was paramount that there must be three people looking at or interacting with our display. This amount was determined based on previous benchmarking and viewing consumer interface. If a display could get many people intrigued it could achieve a level of popularity. We can account for the level of interest by incorporating visual and transparent elements of our prototype that allow the user to see what is happening in the interworking of the display. The users will be inclined to understand through visual representations about how the mechanical operations are being carried out and the concepts behind them by visually seeing what is going on and then engaging with the display.

-Comprehension of User

The comprehension of the user is vital because the user is interacting with something they have no previous knowledge of. They need to be able to fully grasp what task they need to accomplish for the display to work. The target of comprehension the user will gain through interaction will be the full understanding, and a tolerance of minimal will be set. If the display has complex components, users will not know what to do and move on. If users can approach a problem and leave knowing what happened, then they can be more prepared to complete similar tasks in the future.

2.2.5 Relatable & Durable

In this section regarding engineering requirements, we are focusing on relatable and durable. The ERs from these CRs are listed below:

- Connections

Connections are what we make to help us relate to objects or people. We might not understand something when first interacting with it, but we try to find interlaying similarities to help us connect. From this connection, we draw from preexisting ideas or experiences to help our minds better understand.
This can be used when first interacting with STEAM displays. Connections make objects or tasks relatable in the sense of drawing from previous experience or knowledge. If users can do this with our design, they will be more comfortable and inclined to interact. This engineering requirement requires the users to connect with three different parts of the design. Whether it be an emotional, intellectual, or practical connection.

-Yield Strength:

The raw materials and mechanical components used must have a high yield strength of 250MPa. Each component must be durable. The chosen tolerance for yield strength should be equal or over 200Mpa. We chose this because our display will be used regularly. This yield strength is around metal yield strength. We want to minimize part malfunctions. If our display is undergoing heavy loads, we want to account for it by using the high yielding material.

-Strength-Weight Ratio:

The strength should be at a maximum by keeping the weight to a minimum. This means that we want strong material that can be easily transportable. For light weight material with high strength benefits we might consider expensive metals like aluminum, titanium, or magnesium but these are costly. Steel can be easily attainable and inexpensive but is quite heavy. Our target for strength to weight ratio is found by tensile strength divided by the density of the material. Our target of specific strength is found by doing this calculation. With low carbon steel, our specific strength would be around 46.4kN*m/kg. The larger our specific strengths, the higher our breaking length. As a team, we decided the tolerance would be 76kN*m/kg.

2.2.6 Educational & Mobile

Educational and mobile are customer requirements stated in section 2.1.6. These two CRs were translated into engineering requirements below:

<u>-Factors:</u>

This engineering requirement is about teaching our audience about STEAM. This section focuses on the educational aspect of the display and how we are going to provide curriculum in an interactive demonstration. In an instance, if we were going to construct a closed system that cannot view the interworking of mechanical parts, we will provide a visual representation. This will help users see what is happening under the unseen components. The educational part must have two factors that pull from subjects that can teach our user something new or help develop current existing knowledge. By doing this, we are giving them the tools and motivations to further investigate into the STEAM industry by exposing them to education.

<u>-Weight:</u>

The weight of the whole interactive display should be no more than 170 pounds. Our target weight is 150 pounds because TWF needs to be able to move the display Due to the carrying capacity of the fluid and pipes, the applied weight must be in the design limit.

2.2.7 Multiple Visitor & Cost

The final engineering requirements that outline multiple user and cost are listed below:

- <u>Number of inputs:</u>
  The maximum number of users we want interacting with our display is three. This will give our display multiple interfaces and people engaging with the display. If one person is just interacting, then we are only impacting one user. By allowing three people to interact, we are increasing the type of experience users are having. This engineering requirement could also fall under relatable because it brings the community together. Our display is essentially bringing the consumer together with other people who are enjoying the same experience. ‘
- <u>Component Repair:</u>
  All components used in the construction of the display will be easily reparable or replaceable. If materials degrade over time, we want TWF to be able to find and purchase components effortlessly at local venders. If there is a component that needs to be custom made or manufactured and it becomes broken this could make our design useless and nonoperational for an extended period. We have decided to put a cap on the cost of a single component if the client needed to purchase a part to replace on display. The price tolerance is $130, and the target is equal to or below $100.

2.2.7 Multiple Visitor & Cost

The final engineering requirements that outline multiple user and cost are listed below:

- <u>Number of inputs:</u>
  The maximum number of users we want interacting with our display is three. This will give our display multiple interfaces and people engaging with the display. If one person is just interacting, then we are only impacting one user. By allowing three people to interact, we are increasing the

type of experience users are having. This engineering requirement could also fall under relatable because it brings the community together. Our display is essentially bringing the consumer together with other people who are enjoying the same experience.

- Component Repair:
  All components used in the construction of the display will be easily reparable or replaceable. If materials degrade over time, we want TWF to be able to find and purchase components effortlessly at local venders. If there is a component that needs to be custom made or manufactured and it becomes broken this could make our design useless and nonoperational for an extended period. We have decided to put a cap on the cost of a single component if the client needed to purchase a part to replace on display. The price tolerance is $130, and the target is equal to or below $100.

2.3 Testing Procedures (TPs)

The testing procedures measure the listed engineering requirements above. This could be in the form of actual tests we are performing on specific components or what standards parts of the design need to be met in the construction process to pass the ERs.

2.3.1 Safety Tests #1

Safety tests are performed to ensure the safety of the user. If safety tests are not performed on the design, there is potential for liability of the client and the engineer. Without inspection and verification, the design cannot be approved for consumer consumption because if these standards are not met injury may occur.

- *Organized Components:*

  Since we want components to be organized, we want to ensure users are not tripping over loose wiring or having difficulty navigating components. If there are disorganized components users will not want to interact and see our display as more of a hazard than a learning tool. This safety test will include making sure all parts are in appropriate sections of the display. For instance, the 6' hose connecting the ram to the piston hand pump will placed in a neat and orderly fashion to prevent any injury.

- *Corner Radius:*

  Corner degrees' radiuses that do not meet our requirement of 11/16" must be modified to ensure safety of our design. This ER will be examined by the sharp edge test. To perform this test, we will rub the edge with a polytetrafluoroethylene (PTEFE) tape. If the corner leaves a scratch on the (PTFE) tape, the edge will need to be rounded further.

- *Surface Temperature:*

  To test for surface temperature, we will be making sure the surface temperature is constant with room temperature. By doing this we could use an infrared laser thermometer that can be checked out of one of the thermodynamics labs, or simply exam the area where friction is occurring and see if there is a temperature variation. In our design, temperature will be occurring when the lifting platform is moving and the plunger from the ram is extending. This plunger is in direct contact with a parallel surface. When these components move, they create friction. While this platform is in use, we will be checking the surface temperature of this area where friction is occurring.

- *Success Rate:*

  The success rate will be tested by continually interfacing with our design to make sure the desired output is accomplished. The output of our design will be to successfully lift a person up, using the fundamentals of hydraulics. If we can successfully perform this task, every time, our design will be safe by checking all moving parts are working accordingly. This ER is a measure of safety because the client expects the design to work every time without a chance of injury.

2.3.2 Preparation Test #2

The preparation test will make sure all aspects of assembly are up to customer standards and account for any mishaps. Listed below are how the ERs will be measured using the preparation test:

- Design Preparation:
  Design preparation will be measured by the number of people required to assemble the display. This will help us determine if there are adjustments in the design we need to make to have a more proficient plan of action for set-up.
- Assembly Time:
  Assembly time will be measured by keeping track of the period of preparation. Team E will calculate the exact time it takes to set-up the display. If the display needs to be set-up within 30 minutes then we need to account for that time by designing for limited set-up stage. The assembly time should not be more than one hr. Assembly time will also include checking the validity of the components.
- Assembly Steps:
  Assembly steps will be tested based upon the number of steps it takes to fully assemble the display. This will be practiced and documented to ensure all steps are present. It is essential to know the number of steps it takes to assemble each component because preparation time might be limited.

2.3.3 Durability Test #3

A durability test is essential to make sure all components of the design will last long and can withstand any forces being introduced to the system. The following ERs will call under this test:

- Lift cycle:
  The life cycles will be verified by constantly lifting for 2 hours. Until we reach 100 lifts. After reaching that targeted goal, we will be recording any areas where we have calculated maximum stresses to be occurring and if any part malfunction is found. Since we are using steel, we know the fatigue strength to be for the A36 hot rolled mild steel used for the frame 250-270MPa. The location of max stress will be happening near our cylindrical support and the output ram while lifting is transpiring. This stress that will be acting on the ram and a cylindrical inner tube. This was calculated estimating a force of 300lb acting on this point.
- Component Repair:
  The display will be tested to lift 120 kg. The component repair can be measured regarding the frequency of repair and if fatigue is happening to high-stress areas. Components will be required to have a lifespan of 6-10 years. If there are smaller components that do not meet this, a repair log will be developed, and the components will be cataloged and prompt the client to replace before its life span is reached.
- Yield Strength:
  The yield strength of our material will not be measured by preforming a tension test but using gathered data on the material we use. By inspection, we will make sure all materials are manufactured properly. By inspecting the framing steel, we can make sure parts are not deformed. The material will be used in our design can handle a yield strength of 250MPa.

2.3.4 Participant Test #4

The participant test will measure the participant's experience. Further explanation of how we are going to utilize this test is listed below in by the two ERs:

- Attention of Audience:
  The attention of audience will be measured by seeing what the users are experiencing when first being introduced to our design. If they are actively engaged or if they are watching this will be noted, and the active or standby participation will be recorded.
- Facial Features:
  To measure facial features, we will be recording facial expressions and determine what kinds of feelings are present while the interface is occurring. If there is confusion, we will need to improve the understanding and how the required task is conveyed to users. If facial expressions exude detachment from the display, we must alter the display to make it more exciting. By doing this, we can adequately get the consumer's attention, therefore, get them more interested in STEAM.

2.3.5 Usability Test #5

The usability test will consist of users directly interacting with the design. This test will include different approaches of usability through understanding, education, relevance, and interaction.

- Comprehension of User:
  For comprehension of the user, we will be implementing usability testing. This test will be an observation of the operators interacting with the display. We will be documenting how they figure out what tasks needs to be accomplished and if the task was completed. If the user can easily learn and understand the phenomenon at the end, then we have completed our initial goal which was getting the youth more inclined to learn about STEAM concepts.
- Skill Level:
  Testing the skill level of the display will include people at different ages interacting with the display and determining which ages better understand what needs to be done to complete one lift. Our display requires basic motor skills of pushing vertically down on a handle. This will help us adequately determine who can interact with our display proficiently.
- Operation Steps:
  Operation steps will be measured how the user follows each step. If it is a step-by-step process or if any steps are skipped during the interaction. The number of operation steps will be counted as an audience member is using the device.
- Prompts User:
  This will be measured by what the user does first when engaging with the display. Specifically, what interfaces they approach and why they chose them first.
- Factors:
  Factors will be measured by asking users what they learned. By asking this, we can see if they learned about the educational aspects of our design. If they can walk away with more information and knowledge, then we have achieved our objective.
- Connections:
  When interaction with users is occurring, certain phrases or statements will be recorded to determine if connections are being made with our display. For instance, if an audience member talks about how they have used hydraulics with mowing lawns, on a merry-go-round, or rode an elevator they can better relate to our display.

2.3.6 Counting Test #6

The counting test will involve counting the ERs as they occur. This is outlined below:

- Number of STEAM Concepts:
  STEAM concepts will be measured based on what areas of the design fit each concept and

counting those numbers that fit. For example, if the display deals with fluid power this is both engineering and technology because it is dealing with technological advancements that help lift heavy objects and the engineering or such technologies. This is a total of two STEAM concepts that could meet our display.

- Number of inputs:
  A number of inputs will be counted by observing the interface and how each component is being used. By determining the number of people at different sections of the display, we can count the number of inputs.
- Story Line:
  The story line will be measured by counting a number of story lines the user noticed while interacting with the display. Story lines present a narrative that intrigues the listener. This will provoke the user to get emotionally invested and will inspire further investigation into that STEAM storyline.

2.3.7 Gravity Test #7

- Weight:
  Weight will be measured by requiring a certain poundage per section. This will ensure parts can be easily moved to a location whether is moved on a trolley or need additional lifting support. Since we are using steel, weight distribution will need to be kept in check. If the section is heavy, then the client cannot transport the display without extensive equipment. We will be testing this by weighing each section.
- Center of Gravity:
  We will be testing the center of gravity by either finding the balance point or using a plumb line. This will ensure the tipping point in never reached. We will be learning the display against a wall and attach a plumb line to multiple spots and take not of the lines created from the plumb line. After doing this, we can find a point of intersection for all the lines. The point found it that sections moment of inertia. A plumb line is easily obtainable and can be borrowed or made.
- Lift Weight:
  Our design will be required to lift a certain amount of weight of 120kg. This goal will be tested by adding weights to the platform that is being elevated. The weights we will be using will be heavy objects we can find to put on the lifting platform. Since we know specific dimensions and restrictions, we can determine what max load will cause buckling. The maximum loading that the ram can withstand is 8,000lbs. We want to test the structure to ensure we are not over loading the display.
- Strength-Weight Ratio:
  The strength-weight ratio will be tested based on looking at the material's properties of pounds/ft and their strength. We will be able to see a material's efficiency on holding up to loads while being light weight. If we cannot find a material that upholds a strength-weight ratio within 46.4 kN*m/kg, then we should determine ways to make the display more transportable. This could involve cutting the display into sections that are foldable and can fit within transportable spaces.

2.4 Design Links (DLs)

Design links explain how our design will meet the ER targets and tolerances. Design links are organized per the HOQ.

2.4.1 Design Links#1: Safety & Simple Instruction

The subsystems of our project will justify how we are going to meet the targets and tolerances.

- Organized Components:

To ensure all components are organized, our design will have minimal tubing showing. Our design might be detachable, but all parts will combine into a frame that coincides with each other. All components will be within parameters and tubing will be tightly fit and within sections of the design.

- Success Rate:
  The success rate is determined at a target of 100% and a tolerance of 90%. The design will meet a target of 100% by making sure all moving parts are functioning properly. The cylindrical support below the lifting platform safeguards the integrity and security of the platform. It makes sure the lifting zone will stay in place when lifting occurs, even if something happens it will guide the platform back into place.
- Yield Strength:
  As discussed in section 2.3.3, our design will be utilizing A36 steel which has a high yield strength of 250MPa. This material can withstand heavy loads. This material is used for high durability, the strength of the material to withstand environmental effects, wear, and damage.
- Center of Gravity:
  Our design as a whole has a 15" vertical rise and has a right triangular ramp leading to a square lifting zone. With the ramp and lifting platform together the height of the center of gravity is 1ft. This has met our target of the center of gravity no more than 1ft off the ground based on the general shape and size of our display.
- Lift cycle:
  To account for lift cycle in our display, we will have an extra cylindrical support, a 4 Ton Porto-Power, and ram. Inside this initial support will be an inner cylindrical tube and the ram. The ram will be extended, and the lifting platform will rise. When the ram starts to extend so will the inner cylindrical support. By having this design, it will meet our tolerance of 100 lifts in 2hrs by giving additional help with lifting the weight of the user and the lifting zone.
- Corner Radius:
  By making sure there are no sharp edges, we can maintain the customer requirement of safety. Our design will make sure to grind down sharp surfaces to the target of 11/16" if any are present. The design requires the only interaction to occur with the hand pump and the user to walk up the ramp and open a gate to the lifting platform. This will minimize any contact with sharp corners.
- Surface Temperature:
  The area of friction between the two cylinders will be sanded down and smoothed. Another preventative our design will have will be lubrication for the contact surfaces. These two design ideas will help with the reduction of surface temperature rising above room temperature.
- Skill Level:
  The skill level will be targeted to a novice audience and will have a tolerance of moderate. We are incorporating basic motor skills and the fundamentals of fluid power. Our design only requires the user to do a vertical push on a handle to work the display. Due to the complexity of Pascal's Law, it will be displayed in a very simple format, so the users will understand the concept without having any previous knowledge of the subject.

2.4.2 Design Links #2: Hands-On & Wow Factor

The following ERs describe specific design components that fulfill the targets and tolerances:

- Prompts User:
  The user will be prompted through a visual appearance of a handle. By looking at the handle on the piston hand pump, you can adequately guess that it is a tool to make the display work. Another point of interaction that prompts the user to do something would be the ramp. The ramp is leading the user to the lifting platform. Another design we will be explaining how to interact with the release valve on the piston pump to get the lifting platform back down. The initial target

for the ER.

- Operation Steps:
  For the display to work, there are only a few operation steps. The design will have arrows leading the user up the ramp to get started. Then the pump to move the platform will be visible so that users know that is what causes the platform to lift. There will be visual instruction for users who cannot initially figure out what to do.
- Facial Features:
  The interactive display will have subsystems that will influence users to have certain facial features. The lifting platform will be able to show how much a user has lifted. This aspect will create multiple reactions of awe because the user will feel like they have accomplished something. The targeted number of facial reactions is four people, to get stand-buyers reactions the design will incorporate lights when a lift is performed.
- Lift Weight:
  The design must lift a 120kg person. The ram component and piston hand pump acting as the hydraulic system will be able to perform lifts to 8,000lb. The lifting capacity will be met and lift more than 120kgs.

2.4.3 Design Links #3: Simple to Assemble & STEAM Learning Concepts

Listed below are ERs meeting tolerances and targets through specific design components of the display:

- Design Preparation:
  The display will be in different sections making sure design preparation will be only using minimal effort. Bolts will be used to secure parts together. This is a simple way to join each section because it will be simple seeing what parts go together in the succession of the ramp to the platform. This approach will ensure preparation only requires one-three people to set up. This is accomplished by not having many complicated parts that require specialized persons to put together.
- Assembly Time:
  Assembly time has been targeted to take 30 minutes with a tolerance of one hour. This will be accomplished by the simplicity of the sections. Each part will be able to identify where it goes and how it fits and bolts into the next. This will cut down on assembly time because the person does not have to worry about an extensive list of parts to put together.
- Assembly Steps:
  The assembly steps have a tolerance of ten steps and a target of three steps. The design guarantees time effectiveness with the overall design of the ramp and lifting platform. Each section will have a detailed step-by-step process on how to set up the interactive display.
- Number of STEAM Concepts:
  The display will have multiple STEAM concepts by illustrating different subsystems of the display. Users will be learning the fundamentals of hydraulics from using human energy to move the lifting platform.

2.4.4 Design Links #4: Narrative & Visual Appearance

Narrative and visual appearance are ERs that both justify the design and will be described how the design meets tolerances and targets below:

- Story Line:
  We will be making sure all possible story lines are being understood by the user through our design by presenting objectives. By creating an object through the display, we can incentivize the user into wanting to complete the task. This task will be part of a storyline that can be followed. The display will have a storyline that is not only directed at hydraulics being used in society today, but the ramp will allow persons with disabilities to interact with the display. This aspect will allow them to be empowered to be able to do something anybody else can, which would be

to get lifted using hydraulics.

- Attention of Audience:
  Our design will incorporate lights and an objective to complete. By achieving one lift, lights will go off, and users will be shown how much weight they lifted. More than three people will be interested in our design because we will be creating a visual appeal through flashing lights. We can catch the viewers' attention by including a personal achievement that would cause excitement. This achievement would have a child complete one or multiple lifts. Since there must be more than one participant, people will be more inclined to pay attention since other people are interacting with the display.
- Comprehension of User:
  The comprehension of the user will be obtained by showing a visual representation of our system. This will include transparent tubing and syringes as the actual lifting is performed by our final product. By seeing the liquid travel through the clear tubing, they will get a better idea of what is happening under the cylindrical support as they use the piston hand pump.

2.4.5 Design Links #5: Relatable & Durable

- Connections:
  The design will have an ADA ramp. Users could make a connection with either being disabled themselves or having a friend/family member that is also disabled. This type of connection is an emotional one. Users could make the connection with the piston hand pump like a water pump.
- Strength-Weight Ratio:
  The lifting platform will be made from steel having high strength but will have a greater weight. The approximate weight of the steel square tubing used as framing will be 5.41 pounds per feet. The total feet used for this platform will be around 30 feet. This means that the weight will come out to around 162.3 pounds. Since this is such a large weight, we must consider using a lightweight or designing a collapsible ramp so the client can take this display to different events through the year.

2.4.6 Design Links #6: Educational & Mobile

- *Weight:*

  Our design will be made up of two sections so that each part is easily transportable. The lifting platform will be one and the second will be a ramp.

2.4.7 Design Links #7: Multiple Visitor & Cost

- Number of inputs:
  In our design, we have two points where users can interact. One will be applying forces to the piston pump to make the lifting platform do a vertical extension. Another point of interaction will be the user standing or sitting on the lifting platform.
- Component Repair:
  The component repair and replacement should not be difficult because this can cause the display to be discontinued for the certain period. The components used in the system are all readily available from the market, and the repair will not be required for several months at the least. The frictional losses in the display are not causing wear and tear in the components as operated, so the system is durable.

2.5 House of Quality (HoQ)

The House of Quality (HoQ) in Appendix A correlates customer needs to engineering requirements. We determined customer requirements through an initial interview with the client. These were then rated, five being most important and one, least. Appendix A also contains verification that both Jackee and Steve Alston rated these requirements and approved them. By gathering this information from the client, we can define important standards that must be incorporated into our design and then translate them into engineering requirements.

Engineering requirements were weighted on a 0,1,3,9 scale of how they correlate to customer needs. The top ER came out to be attention of audience. This ER outlines how the consumer is relating to the actual display. By meeting this requirement, we can establish a connection with the user and the display. Therefore making it stand out when compared to other displays.

2.6 Funding

The capstone team is required to raise funds before the construction of the interactive display. There was not a given budget for the design so we were given freedom to choose our budget. With the help of the platform GoFundMe, we have raised $600 which is displayed below in Figure 2. After withdrawing there is a platform fee and tax which brought our campaign funding to $551.40. With the Northern Arizona University funding match, we added $500 to our original budget which will bring us to a total of $1,051.4 raised.

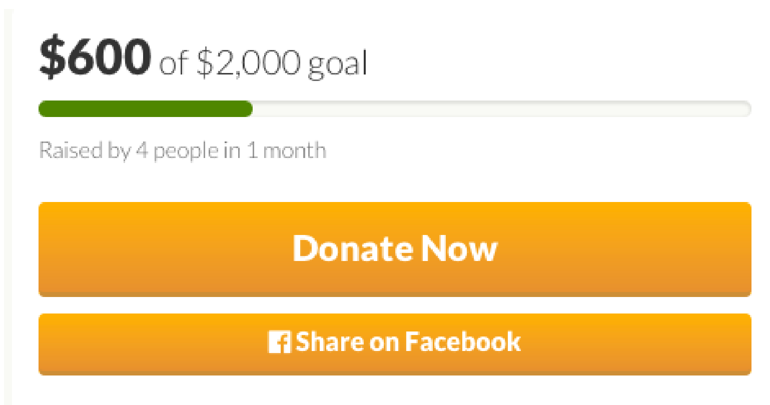


Figure 2: GoFundMe Campaign

https://www.gofundme.com/the-wonder-factory-capstone-team

3 EXISTING DESIGNS

Northern Arizona University capstone teams, over the past years, have contributed largely to The Wonder Factory by designing and constructing interactive displays with STEAM concepts. This has allowed The Wonder Factory to expand its exhibits and give more opportunities to the youth and young at heart through fun interactive learning tools. Listed below are some of the existing designs already in place at The Wonder Factory.

Existing designs at the Wonder Factory
Catapult
Wind Tunnel

Vortex Cannon	
Rocket Launcher	
Buoyancy Demo	
Fog Machine	

3.1 Design Research

The team researched existing interactive displays and centers where these displays were presented. The goal for this task was to find different science centers and how they inform the community about the concepts of the displays.

Members of the team had to answer why people were drawn to the displays in the first place, what the user was acquiring from this display, how they were absorbing the information, and the teaching style the center was exercising. The point of these questions is to get a better understanding of what is happening in the underlying methods of teaching users STEAM concepts. Most research was preformed through looking at the science center's website and going through exhibits. Yelp reviews of the science centers indicated the popularity of different displays and revealed details about how each concept was presented.

3.2 Existing Centers

At the state and national level there are many places where all kinds of people can get introduced to STEAM. In this chapter, we will be describing these places and how they interact with consumers, what techniques they use, and how they correlate to our customer requirements. By identifying these requirements in different centers, we can see trends that will help our team identify what works when trying to design an interactive display.

3.2.1 Existing Center #1: Science Foundation Arizona

The Science Foundation Arizona focusses on STEAM education. Its mission is to diversify Arizona's economy, link the industry needs with university research, and ensure the education system that creates 21st century workforce. This center has a wide network were students work on robotics. Projects require participants to be hands on and interactive like the customer requirements we determined earlier.

Students not only develop electronic, mechanical, drawing, software, and programming skills, but also teamwork and project management techniques. Students can participate in local and statewide competitions that motivate the individual to proceed in STEAM occupational fields. Recently the students made a clever robot that can perform many technical tasks such as: pass a ball, catch it, run down a field and launch the ball. This center makes connections and establishes fun and exciting new experiences with hands on opportunities which helps its community.

3.2.2 Existing Center #2: Amazement Square

The Amazement Square has the possibilities of learning more about structures and buildings and there is the usual experimentation that is also present for hands on practices. They have a separate section for the Harry Potter fandom which includes specific fan foods as well the best restaurants in town. The basic learning is centered for toddlers and children. It is open interaction and multiple members can accomplish a task. The visual scheme is very appealing especially the harry potter section. This science center is more related to science than engineering and it does not have moving mechanical machines. Many members want to come back because of the scientific laboratories that give them access to

3.2.3 Existing Center #3: Intrepid Sea, Air & Space Museum

This museum is unique in the aspect that it is located on an aircraft carrier base. It has hands-on-displays of items used in everyday life. There are views of the lower living quarters, and an outdoor flight deck with an assortment of fighter jets and helicopters. This center places ordinary people in WWII veteran's lives. Users leave with an extended knowledge of aviation and aerospace. There is a mix of hands on and informational teachings.

3.2.4 Existing Center #3: The Discovery Cube, CA

Similarly, to The Wonder Factory, The Discovery Cube is meeting a need for a specific region of Los Angeles (LA), California. While southern LA has many science centers, there are smaller communities within LA that do not have access to large science facilities. The Discovery Cube satisfies this need in the San Fernando Valley. The Discovery Cube is 71,000 square feet but when compared to other science centers it is small. For instance, the California Science Center has over 200,000 square feet. When visiting this center, there were many interactive displays that correlate to what is happening in California, such as, water and energy preservation, the science behind The Kings hockey team, smart shopping, and technology integration with youths. These displays are all engaging the user to learn and develop strategies to think when it comes to daily problems in life. The exhibit that pertained to hockey gave children the opportunity to put themselves into the role as a hockey player and learn about friction on a puck, the force behind shooting a puck into a goal, and blocking an incoming puck. This exhibit also had displays for multiple users to compete in racing games and promote teamwork through getting a puck past a simulated goalie. Other displays incorporated proper ways to recycle, smart shopping strategies when faced with different styles of packaging, and concepts to better sustain the environment.

3.3 Subsystem Level

The Wonder Factory team had to complete an analysis of components of displays, how they functioned, and which ones were popular. This section will consist of how team members determined why these individual displays are popular based on consumer interface. We will also analyze how the center demonstrates the educational aspect and how the displays correlate to customer requirements.

Each subsystem has a theme: astrology, environmental, and aeronautical. Existing designs under these subsystems are similar in the aspect of what they are educating individuals on but different in how they relay or display this information. This will be essential in determining trends between different displays.

3.3.1 Subsystem #1: Astrology

Since we live in a vast universe, astrology is forever expanding. There are several ways interactive displays can educate a community on our planetary system and other aspects of the universe. The following existing designs are different learning modules from centers that demonstrate many aspects of astrology.

3.3.1.1 Existing Design #1: Star Parties: Hands on Optics & Astronomy

The purpose of the hands-on display below (Figure 3) is to help students learn STEAM through astronomy by putting telescopes in the hands of middle class students. Just before the sunset or 2-3 hours later, students can observe the universe through a telescope. They are instructed on how to use the telescope, and the origin of the telescope.

Figure 3: Telescopes

The telescope is an invention to explore the universe. While commercial grade telescopes are bulky, the ones provided to these students are scaled down. Smaller telescopes are useful for understanding the importance of exploration at a more direct and portable teaching tool. These students look at distant objects to have a better understanding of space and to put the universe into perspective. Users are educated about how telescopes must have two properties, how well it can collect light and how well it can magnify the image. By visually showing these students constellations and providing a hands-on approach when using the telescope, they can travel further into the universe and explore astrology.

3.3.1.2 Existing Design #2: Planetarium

The Adventure Science Center has a 63 feet dome called the planetarium consortium. It projects stars in the sky and gives audio presentations of past stories related to constellations. This center has research and experimentation facilities that involve multiple individuals into collaboration with one another involving any aspect of astrology or exploration. This center is delivering information through visual projection of astronomy by showing the galaxy we are living in as seen below in Figure 4. The ocular presentation is exceptional and the pleasant environment makes people relaxed. The space rides and the stories told here make a very constructive impression in the minds of the participants and they leave with concepts related to astronomy along with visual amusement.

Figure 4: Planetarium

3.3.2 Subsystem #2: Environmental

This subsystem focuses on displays that engage the user with renewable energy, and environmental disasters or phenomenon.

Mostly the nature has been described in this section. The earthquakes, flash floods, wind energy and tornados. These subsystems able learners to learn about nature by simulating the effects, displaying a visually engaging media and by simulating the events in physical world at small scale.

3.3.2.1 Existing Design #1: Catching the Wind

This display has users see what goes into converting wind energy into usable electric energy. The display ties into actual wind turbines and shows the user how energy is converted by having them not only view, but interact in the steps leading up to actual energy use. This display, as shown below in Figure 5, educates the user of renewables and fossil fuel energies. Multiple users can be at different stages of the conversion of renewable energy.

Figure 5: Wind Station

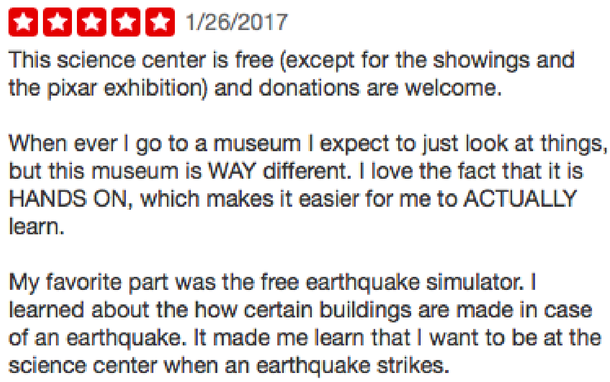
Users are so drawn to this display because energy is essential to everyone’s daily life, we use it everywhere. It also informs of essential placement of wind turbines, boundary layers, etc.
Through the exhibit’s live data tracking, visitors see which of the museum's own turbines are currently producing electricity and hear about why and how they installed them.

3.3.2.2 Existing Design #2: Flash Floods

There is an exhibit in the Smithsonian that takes the user down a dark hallway that has rain storm sounds. Users read lit up facts surrounding the canyon like walls that give information of flash floods and how fast they can occur. When you walk into the open area that are two Plexiglas walls in the surrounding area and then water suddenly fills up the outer walls. This exhibit surprises users by showing them how fast flash floods occur and educating them of natural disasters. This is a popular display because it has that “Wow” factor and element of surprise. It makes the user think and gain a knowledge beforehand when the action takes place. They leave with a level of understanding from both informative and visual aspects. Since it is a walk through multiple users can go through at once all being surprised. The small space out of the safety from the user is water tight and filled with water by pumps.

3.3.2.3 Existing Design #3: Earthquake Simulator

At the California Science Center, there is an Earthquake simulator. This is a popular attraction due to the element of surprise that occurs when consumers engage in this display. This simulator not only shows how earthquakes feel but also informs them about certain buildings and how structural analysis can protect people from natural disasters. Illustrated below in Figure 6, is a review of someone’s experience at this center. As you can see the interface communicates what makes buildings structurally enhanced to survive an earthquake. This is conveyed by allowing the user to reenact a scaled down version of an earthquake. Users step onto an area where the simulation takes place and get surprised by the vibrations made by a suspension system. When activated it



1/26/2017

This science center is free (except for the showings and the pixar exhibition) and donations are welcome.

When ever I go to a museum I expect to just look at things, but this museum is WAY different. I love the fact that it is HANDS ON, which makes it easier for me to ACTUALLY learn.

My favorite part was the free earthquake simulator. I learned about the how certain buildings are made in case of an earthquake. It made me learn that I want to be at the science center when an earthquake strikes.

Figure 6: Yelp Review

3.3.2.4 Existing Design #4: Tornado Vortex

The Tornado Vortex, Figure 7, at The Discovery Cube has a panel that controls different settings of a giant tornado vortex machine. You can essentially control the speed, color, and amount of fog it gives off. The intake fan is located at the top of the ceiling which draws vapor up made from a fog machine. Users have total control of how the vortex is created. The interface system can be used by multiple persons but there is usually just one person in control.

The educational aspect of this display is showing airflow and the science behind vortexes which can be seen in nature. Vortexes can hold lots of energy and they interact with gravity to create its form. Users liked to watch this phenomenon in a controlled space. It contained this wow factor because of the size and how fast you could make the actual vortex spin.

Figure 7: Tornado Vortex

3.3.2.5 Existing Design #5: Home Section

This interactive display had users travel around a scaled down home and learn about different utilities that are in everyday life. This exhibit presented house hold items and how they use energy or different types of resources. For instance, pictured below in Figure 8, is cylindrical container measuring how much gallons of water someone uses in a time span of taking a shower. This can get users more aware of how water is wasted when simply taking a shower.

Figure 8: Water Usage

3.3.3 Subsystem #3: Aerospace/Aeronautical

This section focuses on aerospace or aeronautical concepts.

3.3.3.1 Existing Design #1: Flight Simulation

From reviews of the Intrepid Sea, Air & Space Museum it was discovered that the flight simulator is a popular exhibit that excites users by giving the illusion they are flying. This advanced technology makes users believe that they are in a virtual simulation. The review below in figure 9 wrote that it “puts you into the action.”

This interactive display has a hydraulic system that suspends the user in a virtual reality box. There are electrical/mechanical components that tie to software of the flight simulator. This learning technique makes the user not feel like they are learning because it requires the user to play a game.

3.3.3.2 Existing Design #2: Drones

The current focus of Science foundation Arizona is Aerospace & Defense Initiative. This center helps users design commercial unmanned aerial systems (UAS) and associated protocols for safe integration into national airspace.

Unmanned aerial systems are most commonly known as drones. This is an aircraft under remote control by a human or onboard computers. There are many types of drones as pictured below in figures 9 and 10. Drones are used for different purposes like surveillance, aerial photography, and military applications that are dangerous for human beings.

Figure 10: Commercial Drone

Figure 11: Drone

During flight drones usually require a controller. It is like what pilots use to navigate commercial planes for takeoff, and landing. Controllers communicate with drones using radio waves and are controlled by skilled individuals. This center provides hands-on training and experience in designing and aviation navigation. This is popular because it directly involves the users in implementing advanced technology while giving them experience of simulated flight and structural knowledge of these flight systems. Users leave this compound proficient in aeronautical awareness.

3.3.3.3 Existing Design #4: Helicopter ride

This ride is featured at The Discovery Cube in Los Angeles. When you enter the helicopter like door (Figure 12) you walk into a small room that has two sets of three rows that face a white screen. When the presentation starts, it projects you into a role as a pilot. The room is setup to look like the helicopter cockpit and you get to fly around the Los Angeles area. While the presentation progresses, you learn about water resources and how you can limit your water use to help the current drought in California. It informs the user about water ways and how water can be recycled through a water treatment plant. While this interactive display is mostly visual, there is a part where the video makes you feel like you’re crashing which is exciting and gives the illusion of danger. People leave the display more aware of the limiting water resources and a sense of accomplishment from surviving a crash.

Figure 12: Helicopter Tours

4 DESIGNS CONSIDERED

After benchmarking different centers and interactive displays team members came up with concept variants that had ranging topics of STEAM. These designs were compared to a datum in a Pugh chart that is in Appendix B. Each design will be compared to customer requirements to indicate which one the team will pursue.

As can be seen from the Pugh charts, first there were 12 designs including the design at the datum whose title was Lifting Jack using Gears. 4 of them are selected on the basis of highest total points. These four designs are then compared with the design in consideration, that is, Hydraulic Lift. It has total of 6 points that easily overcome each of the four designs. The design is considered to be most reliable and feasible.

4.1 Design #1: Pendulum Wave

This life-sized pendulum can illustrate the concept of energy transformation. Instead of same length weights hanging from the wires, each ball would be staggered slightly below the one before to make a diagonal decent. Users pull the weights to a certain height and let go of them at the same time to make a pendulum wave. This would educate the user on the fundamentals of gravitational pull, potential to kinetic energy, and teamwork. Pendulums are normally used to showcase how energy can be transmitted from one object to another. This is defined from Newton's 2nd law, each action creates an opposite and equal reaction. This design would be scaled up and create a wow factor from its visual performance when users let go of the multiple weights. (Figure 13) shows this design. While this is a great technique to show how gravity works there would be an issue with safety. This model would require it to be bolted down because we want a secure display that will not tip. Since the balls are staggered it would have a center of gravity that would make it likely tip.

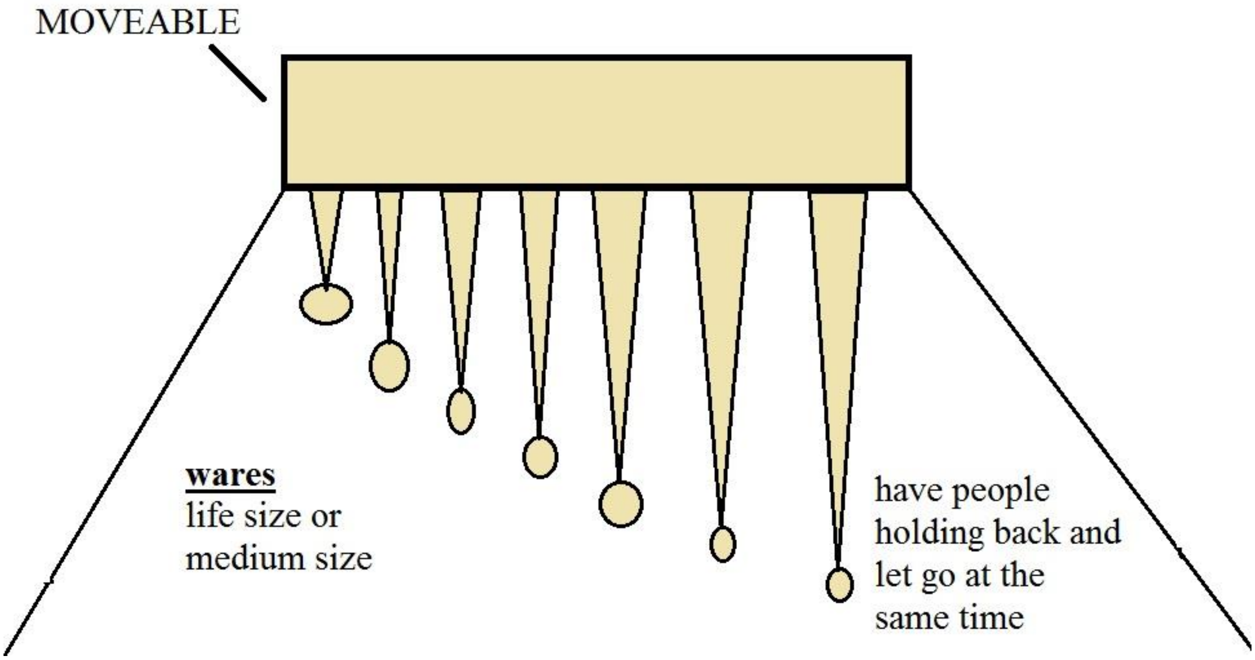


Figure 13: Pendulum Wave

4.2 Design #2: Make Music with Water

Making music with water would entail having large cylindrical glasses (Figure 14) filled with certain levels of water. These cylindrical glasses would then be hit with rounded wooden hammers to create sounds. How this happens is that when force is applied to the glass, vibrations are made through the water resulting in a tone. These vibrations or sound waves are heard at different pitches depending on the level of fluid in these glasses. For instance, if it is a high pitch it would be associated with the glass filled to a smaller level because of the fewer vibrations traveling through the water.

Multiple users could be interacting with display making music and playing with different pitches of sound while learning about sound waves and vibrations. This model could not meet the requirement of durability because over time users would hit this display and eventually it could collapse resulting in a safety issue. Glass is a brittle material which is hard to exactly determine when it will shatter when compared to ductile material that display deformations.

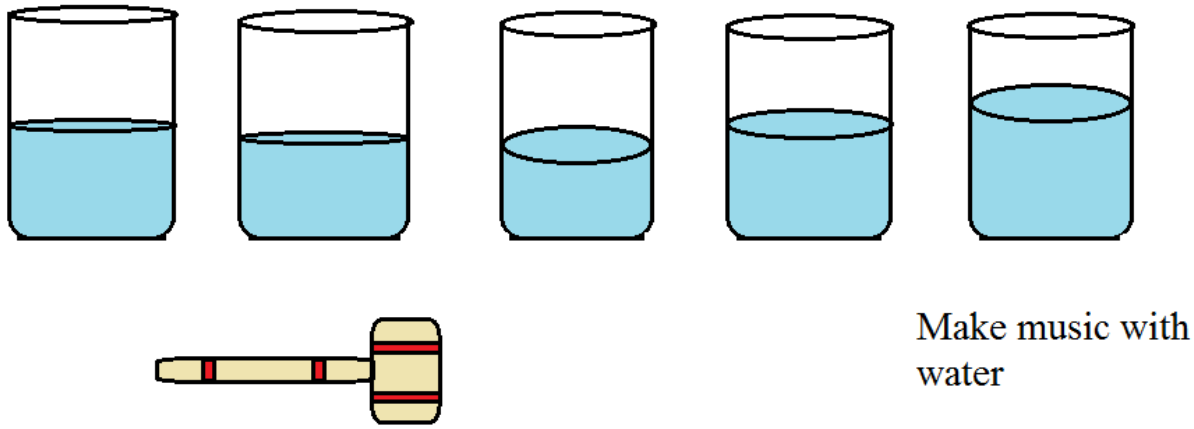


Figure 14: Make Music with Water

4.3 Design #3: Hydraulic Lift

This hydraulic design would be built by using two syringes connected to each other using plastic tubes as shown in Figure 15. A two-way valve would act as a free way allowing water to be transferred from a bucket (reservoir) to one syringe that would simulate a water pump. This pump would push water to a larger syringe using a certain amount of pressure to lift a weight. These concepts are the fundamentals of a hydraulic system. A hydraulic system must have a water reservoir, a pump that can output a certain amount of force measured in pounds per square inch (psi), two pistons that are proportional in diameter, a two-way valve, a certain amount of surface area and volume, and a system that contains the fluid (incompressible fluid). When a child can simulate a pump pushing water using the small syringe and filling another larger syringe with water to lift his/her parents they will be amazed they can do this task. Normally their parents can lift them up and carry them with ease but if they were to try to simply lift their parents in return they would not be able to.

When the two-way valve is open, it allows the water to run back through the tubes and into the bucket. This would allow multiple simulations of the display. When users pump the water, they are essentially multiplying their force to the larger syringe. While this has a great educational aspect of hydraulic systems, water is needed to do the heavy lifting. The amount of pressure applied when moving the fluid needs to be accountable because if there is not enough (psi) the object cannot be lifted. Another precaution would be over loading this hydraulic system and making sure leaks do not occur. If there are leaks in this system, it will not work because the water will not be incompressible and energy and work put into the system will be lost.

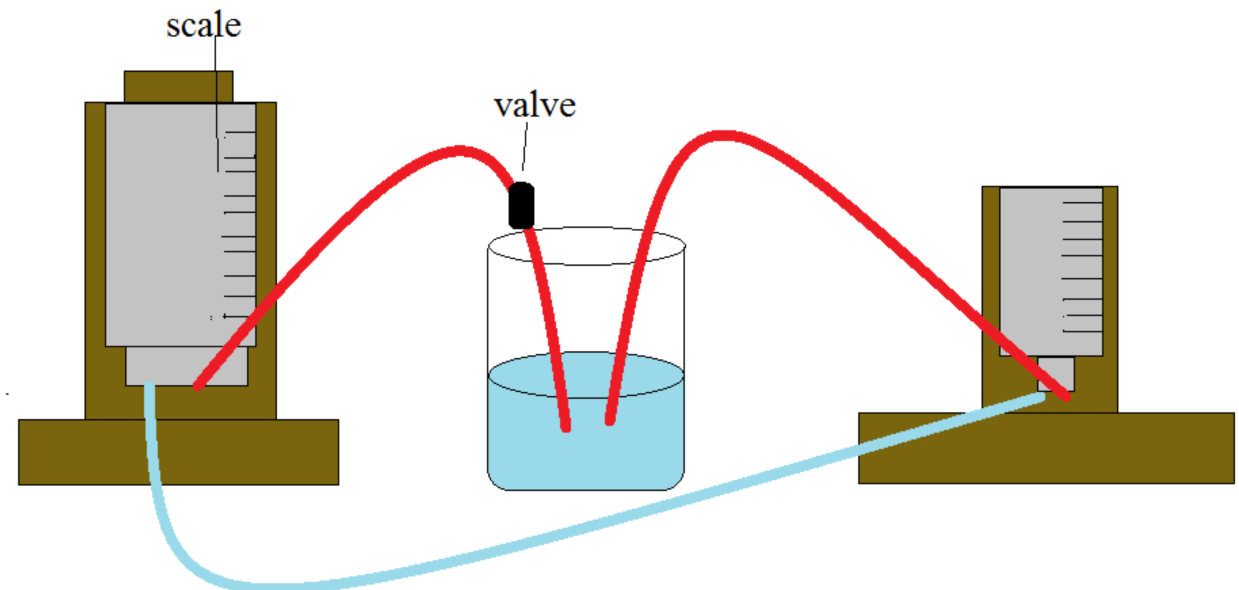


Figure 15: Hydraulic Lift

4.4 Design #4: Make a Bridge

This design has the compatibility with both making a suspension bridge and truss bridge. The provision is provided with detachable parts made of non-metallic materials which have no sharp edges. The design includes customer requirements that include safety, easy assemble and multiple users. This design has the element of creativity as the customers must construct a bridge themselves and then check if it holds the required weight or not. Minimum number of removable trusses should be used and at the end with hands-on experimentation the customers will learn about the load distribution and failure of bridges in daily life. The customers however require some pre-learning about the usage of pieces in construction.

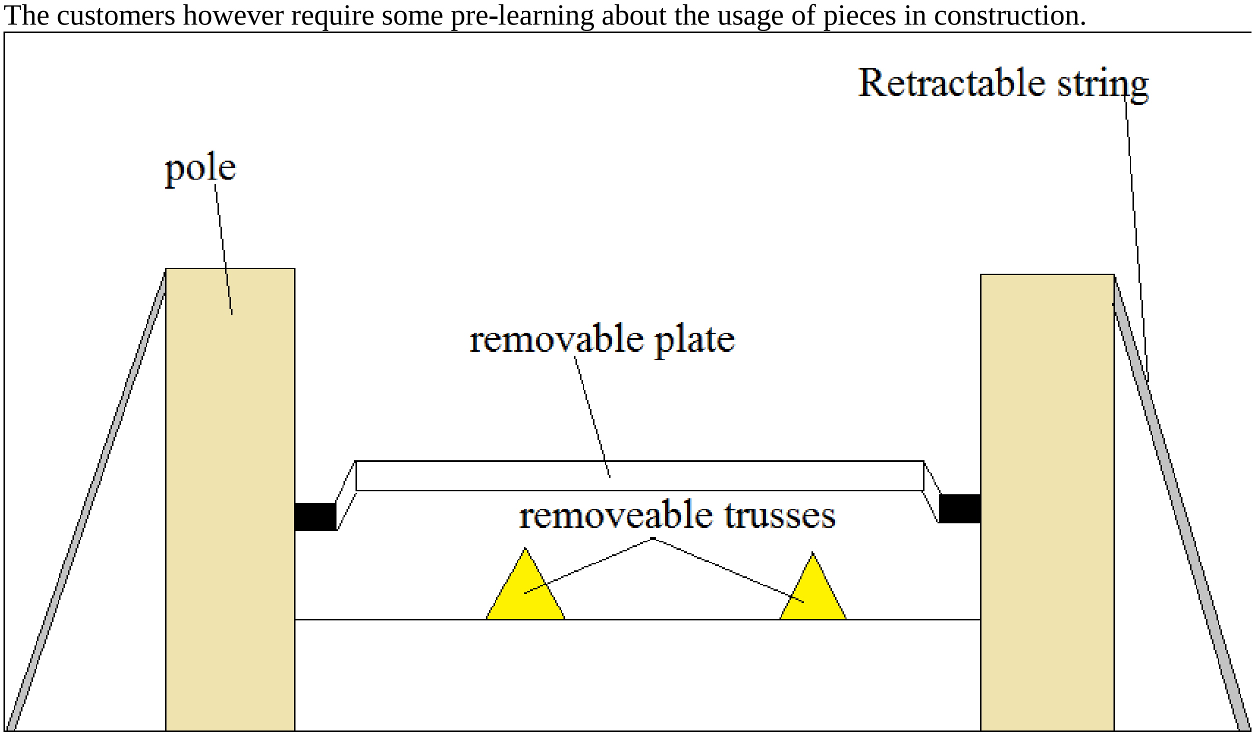


Figure 16: Make a Bridge

4.5 Design #5: Ball Propeller

This design has a hollow pipe and rubber ball which can be kicked into the pipe tunnel, with a fan in the pipe bend that will send the ball in the air and back to the person kicking it. The true angle of projection can be made adjustable as well for extensive learning. This design is safe to use but only one person can use it at an instance. It also has a factor of amazement because the fan will be invisible to the customer and they might wonder how the ball comes back to them. The basic concept learned in this experiment is the wind power which can be used to carry out mechanical operations. The second concept is the projectile motion of an object which is thrown at a specific angle and its landing point with respect to the projection angle.

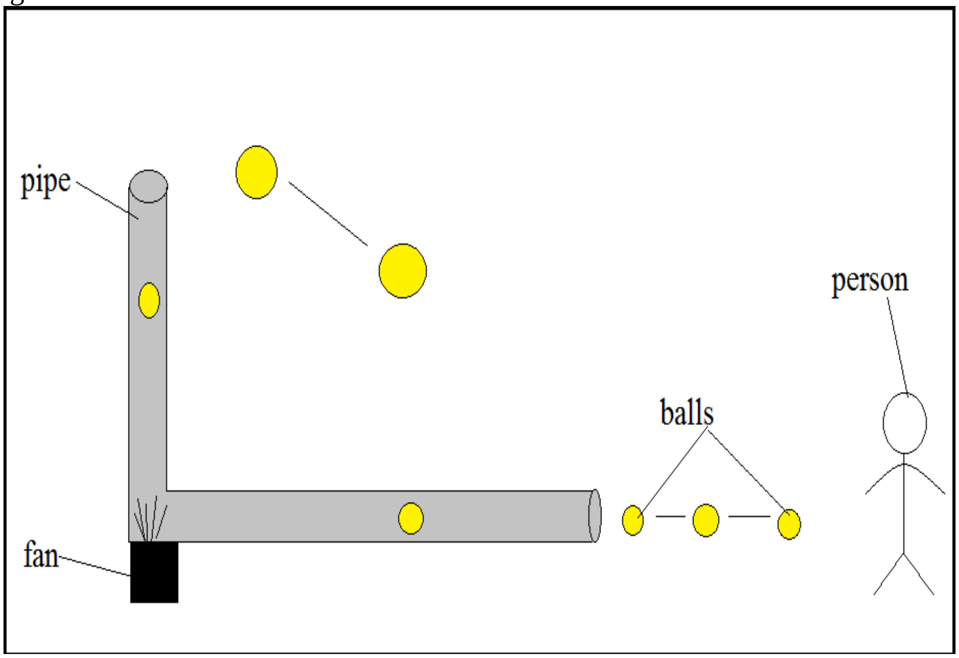


Figure 17: Ball Propeller

4.6 Design #6: Hill Climbing Racing

The facility has a race track made of plastic and a small vehicle with detachable magnets on its top. There is an electromagnet controlled with switch in the start. When we switch on the electromagnet is activated and the momentum is generated in the car to take it forward till the end. The basic concept learned in this experiment is the power of electromagnet and the use of momentum in scientific applications. The electromagnets is of specific power and detachable magnet has different sizes. Only one size will make the vehicle go till the end due to momentum. The design is very safe to use and electric supply used is of low voltage and it includes very important scientific concepts learned by easy experimentation.

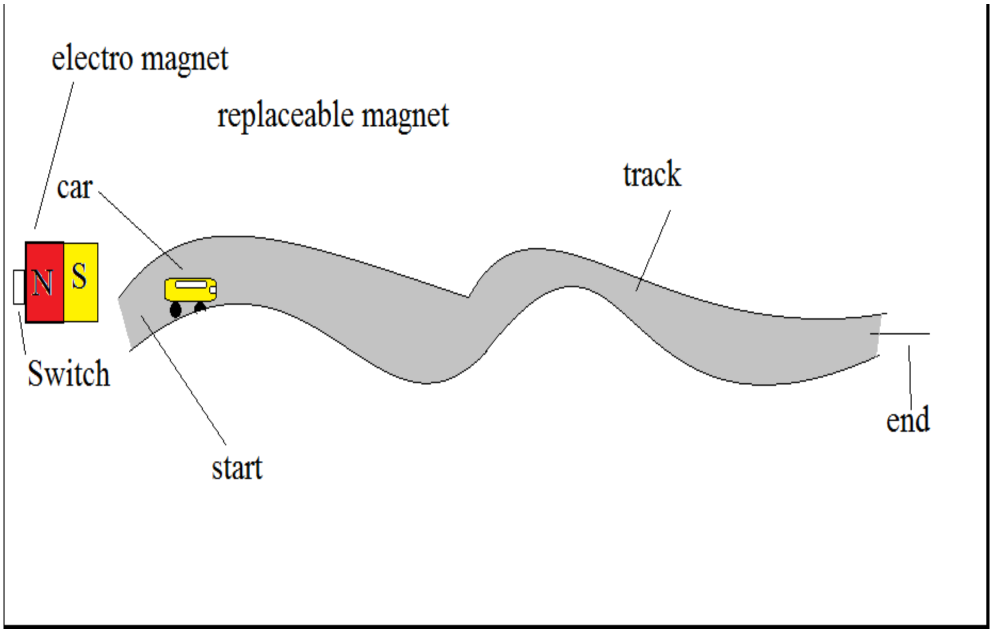


Figure 18: Hill Climbing Race

4.7 Design #7: Boat Sailing

The facility shown in the figure has a water tank with water supply through a pump. Detachable nozzles are present for mounting at the end. The water level will be adjusted in an order that only one tank is to be used. This experiment is safe to use and there is no involvement of electricity on front end as well. The experiment is based on the principle of fluid energy and its uses with an additional aspect of learning about the different nozzle designs and their ranges when fluid is thrown out of them. The nozzles will be available in different opening sizes and only one of them will make the boat reach the other end exactly. If a customer uses other nozzles, then the boat will not reach at the end.

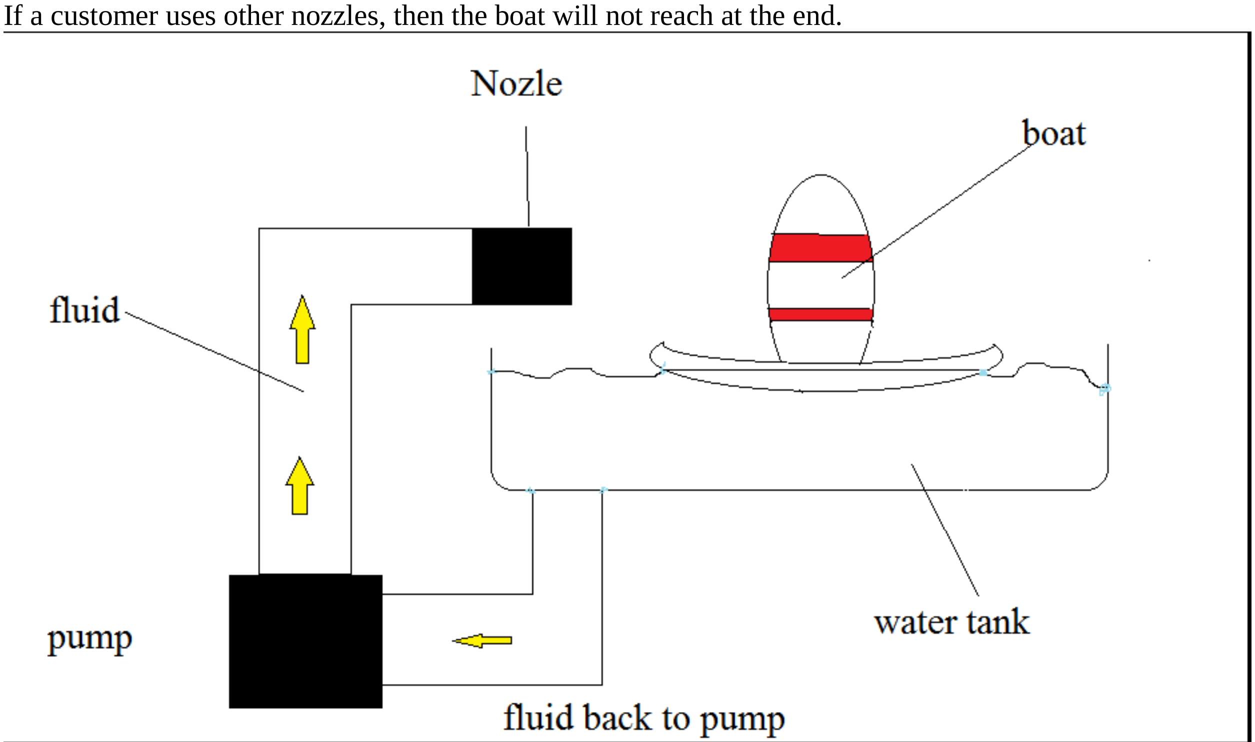


Figure 19: Boat Sailing

4.8 Design #8: Handle Wind Power

The main idea of this design is to build a wind turbine using gears and a handle shaft connected to plastic fan blades. The device should be built based on gear type and gear ratio to find out torque and how much power the fan will produce. The user can rotate the handle to transfer human energy into rotational energy. The blades will simulate wind energy when the actual energy is human. This design covers the concept of gears and teaches the user how the rotation of gears produces usable energy. Although, this idea is not safe for the consumer because if the blades were rotating too fast a child could be struck and the energy could be transferred into the child instead of the generator. The design also needs complicated machined blades which we cannot do. Another aspect to consider is that this design is only one user compatible.

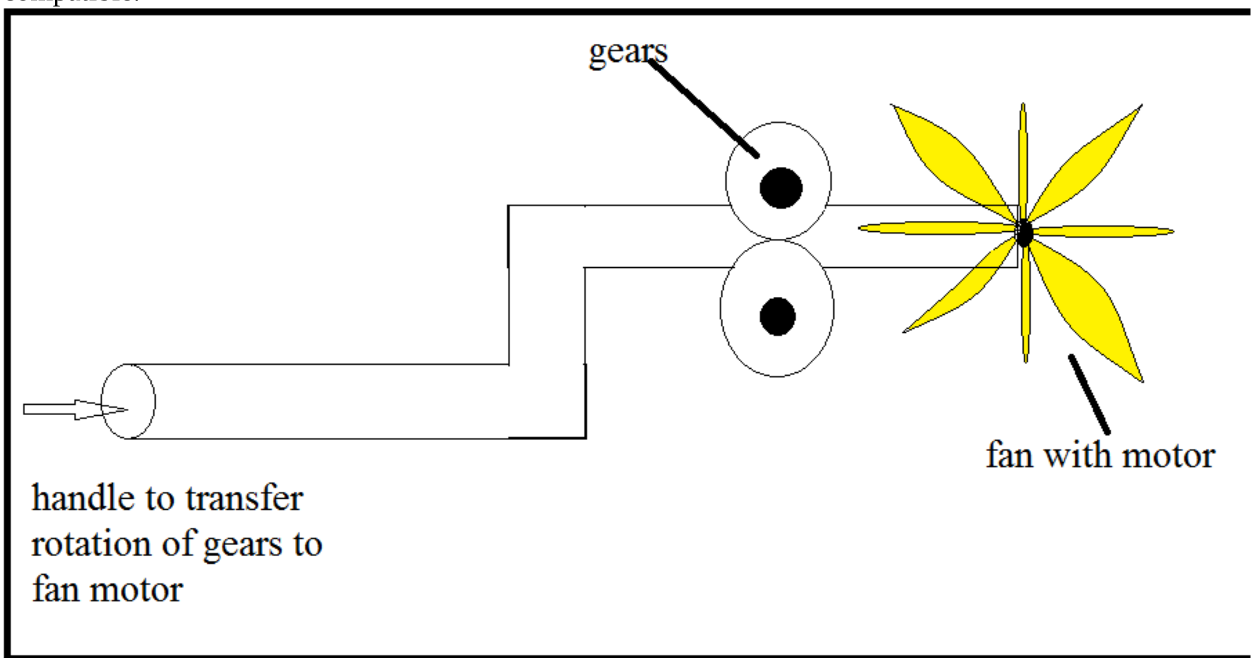


Figure 20: Handle Wind Power

4.9 Design #9: Ball Race

This design focuses on expanding the toddler space. It is essentially foam pieces that can be put together to make a ball track. This design (Figure 21) is simplistic and requires competition in racing different colored balls down the constructed track. The foam pieces are light weight and can be handled by children. This would challenge rational thinking skills in constructing the best race track but since it is such a simplistic design it does not have a wow factor. Children will not be as interested in this because it is such a simple concept.

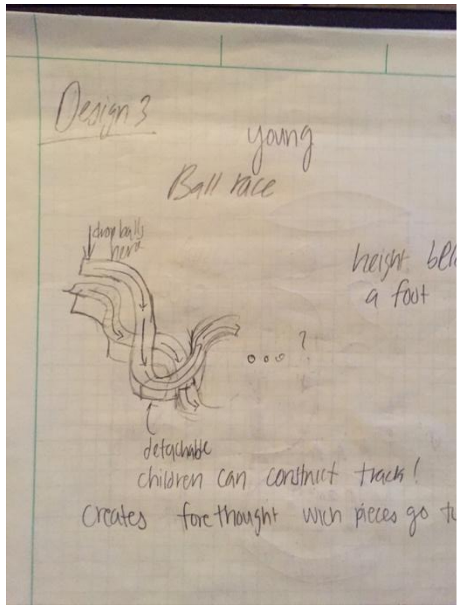


Figure 21: Ball Race

4.10 Design #10: Wind Shoot

The wind tunnel displayed below in Figure 22 depicts a capsule that can hold up to three people. When the user steps into this cylindrical container they push a button and the internal fans below the bottom start up. The fans intake air and push it past the users to get up to 70 mph wind speeds. This display shows the user how fast wind currents are and can even elaborate on the internal speeds in a tornado. This would be an expensive display that has electrical components and hard to manufacture materials.

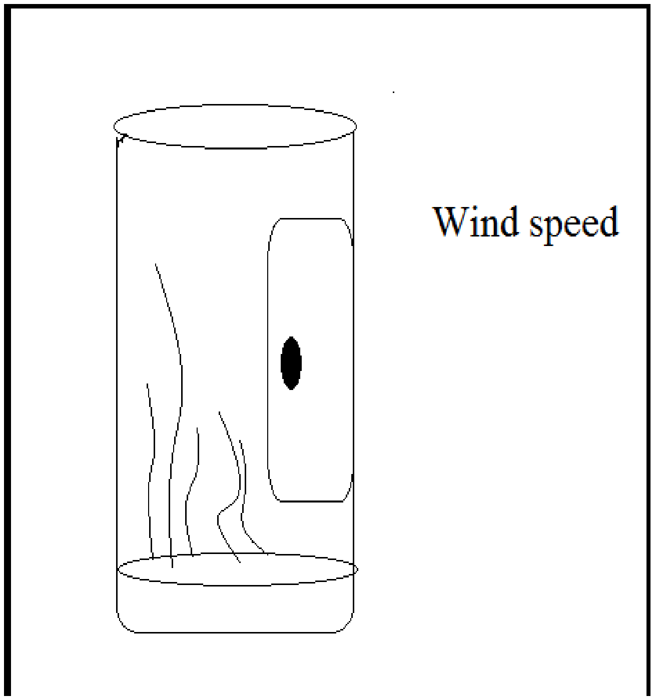


Figure 22: Wind Shoot

4.11 Design #11: Weight Lifting

This design is for children to show them how they can carry large weights based on the science of physics. As shown in the figure below, the design is made by a steel stand to hold a long steel shaft or a pipe. At the end of one side of the shaft, a rope will be tied up to the shaft so the user can hold it and pull the weight down. The weight will be 100+ kg. The main concept used for this display is that the pulling force which the user will pull, will allow the shaft to swing on top of the stand and make the weight move up from the ground. This is a multiple users design and inexpensive to build. The disadvantage of this design would be that it needs a larger space to be applicable.

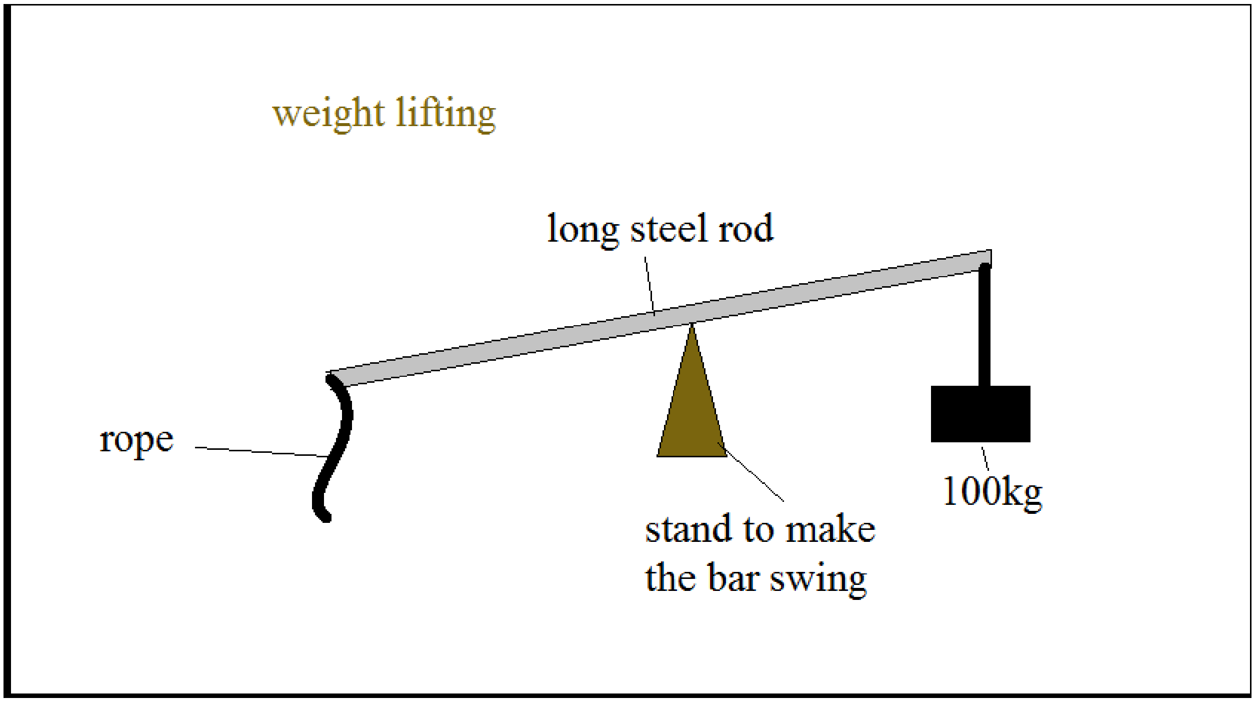


Figure 23: Weight Lift

4.12 Design #12: Electric Train

The goal of this design to teach the customer the main goal of magnetic fields and how magnetic power is greater than mechanical power. The design as shown in figure 23 below is simply a made of copper wire, neodymium magnets and dry battery cell battery 6V or 9V. Magnets radius have to be bigger than the battery radius. The area between the magnets and electric current will flow to a coil which will cause the movement of the battery. Copper wire will act as a track for the Magnet train and by applying the battery inside the wire. Both sides of the magnet poles against each other very hard and force become bigger inside the track. For faster train, need a battery with bigger voltage. Advantages for the design are cheap to build, safe and easy to assembly. The only and most important disadvantage would be, the difficulty to deliver the scientific concept behind the design which is electric and magnetic sciences.

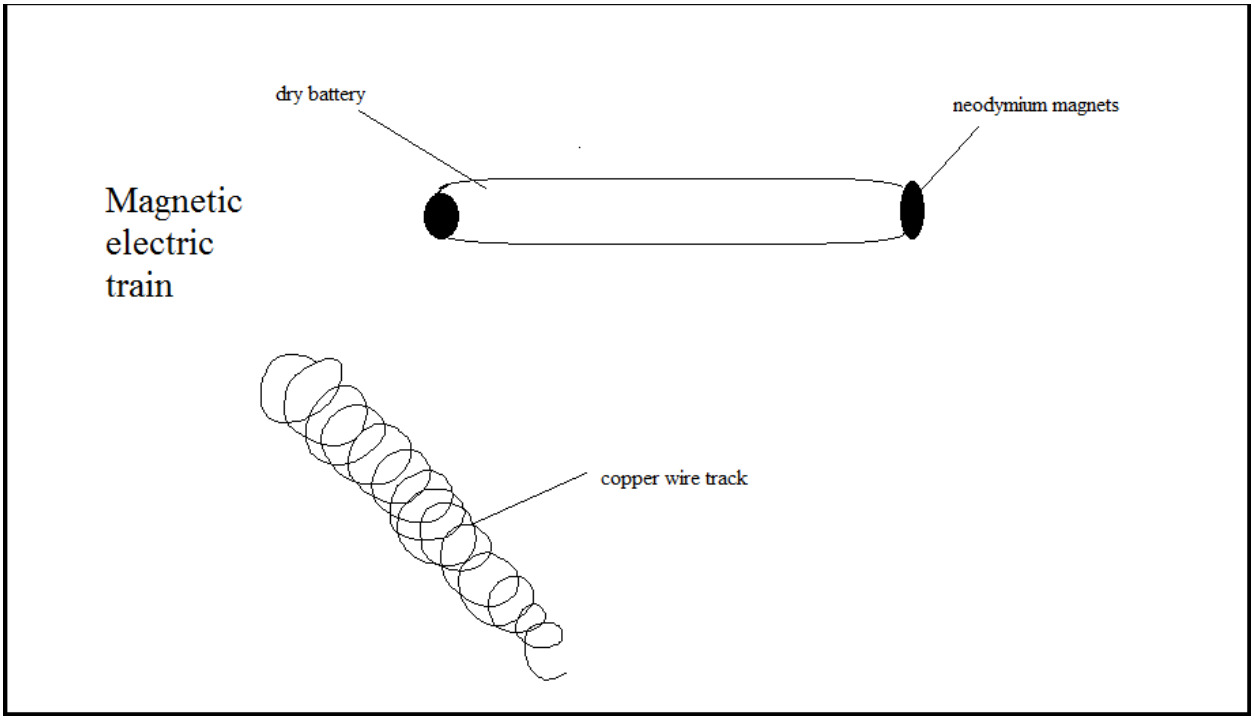


Figure 24: Magnetic Electric Train

From our original concept variants, we determined to go forth with a hydraulic system. To better identify what type of hydraulic system we wanted, we came up with different styles of hydraulics.

4.13 Design #13: Hydraulic Chair

The hydraulic chair is like our original system but is redesigned into a chair support. The chair would situate users comfortably while their child pumps water into the larger cylindrical piston which creates a lift force. Displayed below in Figure 25, is a visual representation of the hydraulic chair. This design would visually show the liquid substance traveling through the translucent tubing into the larger syringe creating a lift force showing the fundamentals of fluid power. This is essential when trying to get an educational aspect across because users will be seeing what is directly happening in the system.

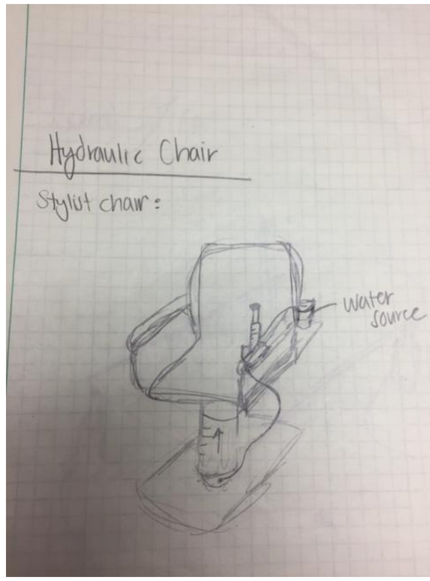


Figure 25: Hydraulic Chair Lift.

4.14 Design #14: Accordion Hydraulic Lift

The accordion lift or sometimes known as the scissor lift, Figure 26, is seen in many warehouse departments lifting worker up to exponential heights. Its goal is to assist users with reaching high up work places or items stored at hard to reach places. The ram helps extend the scissor supports out to full displacement. This design would meet the customer requirement of wow factor because it could incorporate hydraulics giving the illusion of high lifts with the accordion style.

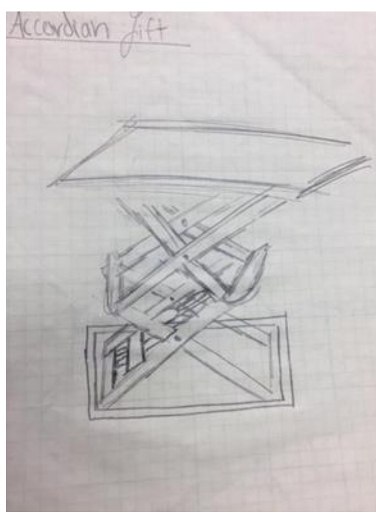


Figure 26: Accordion Lift

4.15 Design #15: Platform Hydraulic Lift

This system, Figure 27, could be built into the ground or be just above the ground. It would gradually rise multiple users above the ground as other people are moving the fluid by means of syringes to the multiple larger syringes. This hydraulic system would involve four components working together to lift a given weight. This design would have to involve team work to lift people or objects because it could be uneven if we did not control the fluid power moving to each cylindrical ram by a connecting valve.

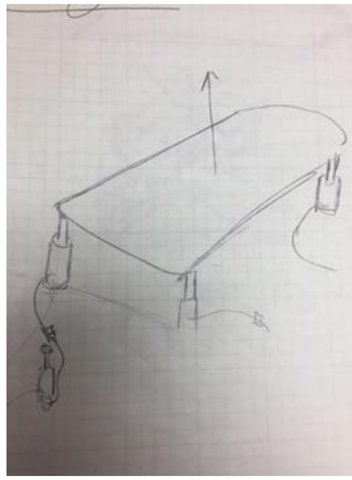


Figure 27: Platform Lift

4.16 Design #16: Hydraulic Arm

This design (Figure 28) was used as our datum because it incorporates hydraulics but by moving objects with a magnet. This design is like a backhoe or computer based machine at a manufacturing plant. It moves an arm to move an object to a different location. This design became our fixed reference because it measures up to customer needs but starts at a basis for a hydraulic system. This design is simple to manufacture but could be difficult for children to figure out how to work.

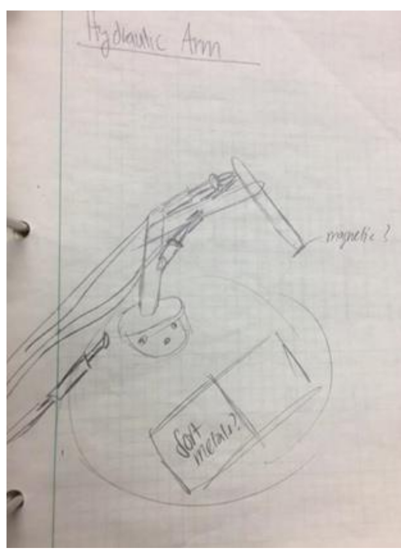


Figure 28: Hydraulic Arm

4.17 Modified Design #17: Ramp Lift

This hydraulic design places the chair on a track. When the ram is extended it gradually pushes the chair up the ramp. This is different from the original hydraulic design because it places the user on a 45º ramp. As children move the hydraulic hand pump it pushes their parents up the ramp, as illustrated in Figure 29. While this is stable, there are many points where injury can occur. The track has gaps that could pinch or puncture the user's fingers.

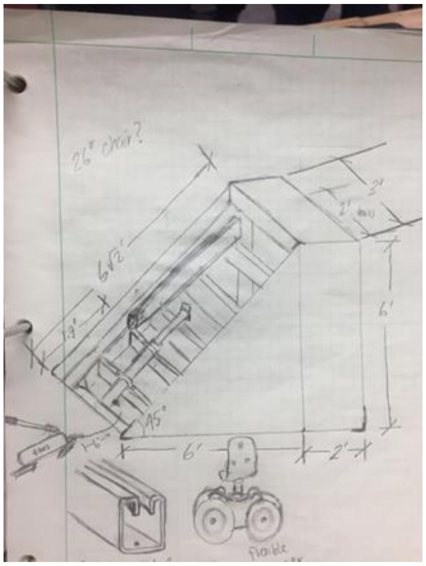


Figure 29: Ramp Lift

4.18 Modified Design #18: Railing

This design, Figure 30, is like 6.1 in the aspect of the triangular design but has a square frame extension. This square frame is the lifting platform where users will open the closed railing to step inside the lifting area. A hydraulic jack will be placed underneath this platform and be hooked up to a hydraulic hand pump. This design works as the original syringe design discussed earlier in section 4.3.

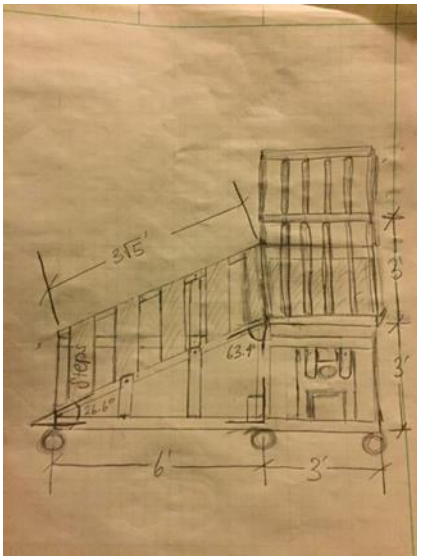


Figure 30: Railing Hydraulic Lift

4.19 Modified Design #19: Hydraulic Forklift

The hydraulic fork lifter, Figure 31, will work on the principal of Pascal’s law in which hydraulic pressure is used with mechanical advantage to obtain heavy duty work. The smaller jack will be pushed by the user with smaller force and the larger jack that will pick up many times heavier loads and then the user can manually transport them to another place. The vehicle edition of this mechanism is also available. The fluid pressure will do the work which is transferred between the jacks through hydraulic pipeline which should be tested to bear the pressure.

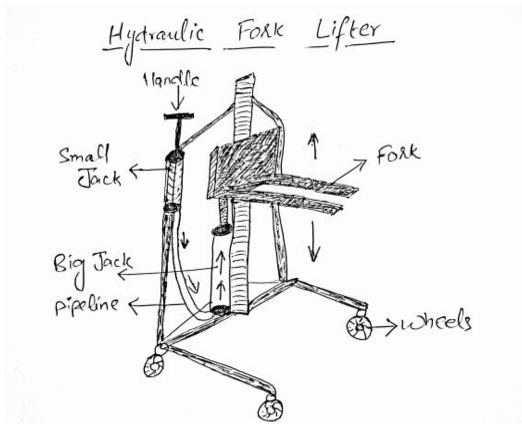


Figure 31: Hydraulic Forklift

5 DESIGN SELECTED

There was couple of processes helped us to choose this design of hydraulic lifting. These methods were Pugh charts and the Black Box model for the total designs the team agreed on. The team did in total two Pugh charts, first chart is to compare between the main twelve designs and reduce the list to four top designs to compare them with our selected design Hydraulic lift. The second Pugh chart is to compare between different hydraulic lifting designs the team has picked to be the best fit for the customer and Engineering requirements. As shown in the below tables, these are the results of the methods been used to determine the final selected design.

Customer Requirements	Weight lifting	Handle Wind Power	Pendulum Wave	Wind Tunnel	Hydraulic Lift
Safe	0	0	-1	0	0
Simple Instruction	0	-1	0	0	0
Hands-on	0	0	0	-1	0
Wow Factor	1	1	1	0	1
Simple to assemble	1	0	1	0	1
mult. STEAM concepts	0	0	0	0	0
Narrative	-1	0	0	0	0
Visual appearance	1	1	1	1	1
Relatable	1	1	0	1	1
Durable	0	0	-1	0	0
Educational	-1	0	0	0	0
Mobile	0	0	1	0	1
Mult. visitors	1	0	1	1	1
Positive	5	3	5	3	6
Negative	2	1	2	1	0
Same	6	9	6	9	8
Total	3	2	3	2	6

Table 3: Selected Designs (Pugh Chart 1)

Customer Requirements	Acordian Lift	Hydraulic Arm (DATUM)	Chair Lift	Board Lift
Safe	0		0	-1
Simple Instruction	0		0	0
Hands-on	0		0	0
Wow Factor	1		1	1
Simple to assemble	-1		0	0
mult. STEAM concepts	0	D	0	0
Narrative	0	A	1	0
Visual appearance	0	T	0	-1
Relatable	0	U	0	-1
Durable	0	M	0	0
Educational	0		0	0
Mobile	0		0	0
Mult. visitors	1		1	1
Positive	2		3	2
Negative	1		0	3
Same	9		9	8
Total	1		3	-1

Table 4: Final design Pugh Chart 2

5.1 Rationale for Design Selection

The design that was chosen was the modified hydraulic design in section 4.18. This design has been further modified to fit specifications of a ramp for persons of disabilities. The dimensions of parts acquired and material being used has also changed the vertical height of the lifting platform from three feet to 15 inches. These changes were decided upon based on a decision matrix viewed in the below table.

Weight		Steps/2Cylinder		Ramp/2Cylinders		Ramp/1Cylinder/NoRailing		Ramp/1Cylinder/Railing	
Criterion									
1. Safety	0.25	3	0.75	4	1	0	0	5	1.25
2. WOW Factor	0.2	4	0.8	4	0.8	2	0.4	3	0.6
3. Skill Level	0.1	4	0.4	3	0.3	3	0.3	4	0.4
4. # of Inputs	0.05	3	0.15	3	0.15	3	0.15	4	0.2
5. Education	0.15	3	0.45	3	0.45	3	0.45	3	0.45
6. Hands-On	0.15	3	0.45	4	0.6	4	0.6	4	0.6
7. Durable	0.1	4	0.4	3	0.3	3	0.3	5	0.5
Totals	1		3.4		3.6		2.2		4
Relative Rank			3		2		4		1

Table 5: Decision Matrix

5.2 House of Quality (HoQ)

The House of Quality (HoQ) in Appendix A correlates customer needs to engineering requirements. We determined customer requirements through an initial interview with the client. These were then rated, five being most important and one, least. Appendix A also contains verification that both Jackee and Steve Alston rated these requirements and approved them. By gathering this information from the client, we can define important standards that must be incorporated into our design and then translate them into engineering requirements.

Engineering requirements were weighted on a 0,1,3,9 scale of how they correlate to customer needs. The top ER came out to be attention of audience. This ER outlines how the consumer is relating to the actual display. By meeting this requirement, we can establish a connection with the user and the display. Therefore making it stand out when compared to other displays.

5.3 Funding

The capstone team is required to raise funds before the construction of the interactive display. There was not a given budget for the design so we were given freedom to choose our budget. With the help of the platform GoFundMe, we have raised $600 which is displayed below in Figure 2. After withdrawing there is a platform fee and tax which brought our campaign funding to $551.40. With the Northern Arizona University funding match, we added $500 to our original budget which will bring us to a total of $1,051.4 raised.

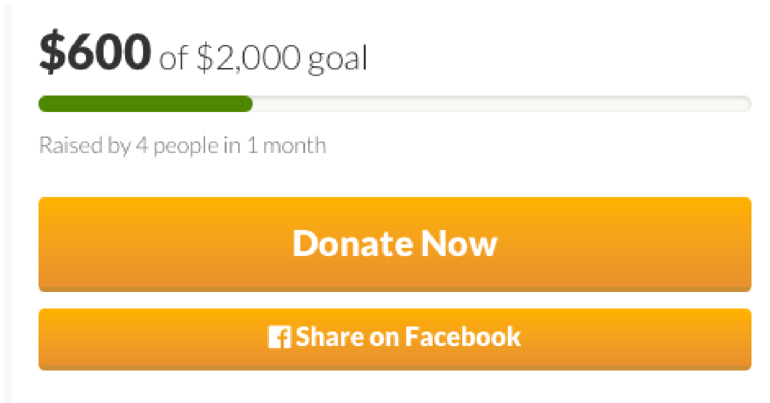


Figure 2: GoFundMe Campaign

https://www.gofundme.com/the-wonder-factory-capstone-team

5.4 EXISTING DESIGNS

Northern Arizona University capstone teams, over the past years, have contributed largely to The Wonder Factory by designing and constructing interactive displays with STEAM concepts. This has allowed The Wonder Factory to expand its exhibits and give more opportunities to the youth and young at heart through fun interactive learning tools. Listed below are some of the existing designs already in place at The Wonder Factory.

Existing designs at the Wonder Factory
Catapult
Wind Tunnel
Vortex Cannon
Rocket Launcher
Buoyancy Demo
Fog Machine

5.5 Design Research

The team researched existing interactive displays and centers where these displays were presented. The goal for this task was to find different science centers and how they inform the community about the concepts of the displays.

Members of the team had to answer why people were drawn to the displays in the first place, what the user was acquiring from this display, how they were absorbing the information, and the teaching style the center was exercising. The point of these questions is to get a better understanding of what is happening in the underlying methods of teaching users STEAM concepts. Most research was preformed through looking at the science center's website and going through exhibits. Yelp reviews of the science centers indicated the popularity of different displays and revealed details about how each concept was presented.

5.6 Existing Centers

At the state and national level there are many places where all kinds of people can get introduced to STEAM. In this chapter, we will be describing these places and how they interact with consumers, what techniques they use, and how they correlate to our customer requirements. By identifying these requirements in different centers, we can see trends that will help our team identify what works when trying to design an interactive display.

5.6.1 Existing Center #1: Science Foundation Arizona

The Science Foundation Arizona focusses on STEAM education. Its mission is to diversify Arizona's economy, link the industry needs with university research, and ensure the education system that creates 21st century workforce. This center has a wide network were students work on robotics. Projects require participants to be hands on and interactive like the customer requirements we determined earlier.

Students not only develop electronic, mechanical, drawing, software, and programming skills, but also teamwork and project management techniques. Students can participate in local and statewide competitions that motivate the individual to proceed in STEAM occupational fields. Recently the students made a clever robot that can perform many technical tasks such as: pass a ball, catch it, run down a field and launch the ball. This center makes connections and establishes fun and exciting new experiences with hands on opportunities which helps its community.

5.6.2 Existing Center #2: Amazement Square

The Amazement Square has the possibilities of learning more about structures and buildings and there is the usual experimentation that is also present for hands on practices. They have a separate section for the Harry Potter fandom which includes specific fan foods as well the best restaurants in town. The basic learning is centered for toddlers and children. It is open interaction and multiple members can accomplish a task. The visual scheme is very appealing especially the harry potter section. This science center is more related to science than engineering and it does not have moving mechanical machines. Many members want to come back because of the scientific laboratories that give them access to

5.6.3 Existing Center #3: Intrepid Sea, Air & Space Museum

This museum is unique in the aspect that it is located on an aircraft carrier base. It has hands-on-displays of items used in everyday life. There are views of the lower living quarters, and an outdoor flight deck with an assortment of fighter jets and helicopters. This center places ordinary people in WWII veteran's lives. Users leave with an extended knowledge of aviation and aerospace. There is a mix of hands on and informational teachings.

5.6.4 Existing Center #3: The Discovery Cube, CA

Similarly, to The Wonder Factory, The Discovery Cube is meeting a need for a specific region of Los Angeles (LA), California. While southern LA has many science centers, there are smaller communities within LA that do not have access to large science facilities. The Discovery Cube satisfies this need in the San Fernando Valley. The Discovery Cube is 71,000 square feet but when compared to other science centers it is small. For instance, the California Science Center has over 200,000 square feet. When visiting this center, there were many interactive displays that correlate to what is happening in California, such as, water and energy preservation, the science behind The Kings hockey team, smart shopping, and technology integration with youths. These displays are all engaging the user to learn and develop strategies to think when it comes to daily problems in life. The exhibit that pertained to hockey gave children the opportunity to put themselves into the role as a hockey player and learn about friction on a puck, the force behind shooting a puck into a goal, and blocking an incoming puck. This exhibit also had displays for multiple users to compete in racing games and promote teamwork through getting a puck past a simulated goalie. Other displays incorporated proper ways to recycle, smart shopping strategies when faced with different styles of packaging, and concepts to better sustain the environment.

5.7 Subsystem Level

The Wonder Factory team had to complete an analysis of components of displays, how they functioned, and which ones were popular. This section will consist of how team members determined why these individual displays are popular based on consumer interface. We will also analyze how the center demonstrates the educational aspect and how the displays correlate to customer requirements.

Each subsystem has a theme: astrology, environmental, and aeronautical. Existing designs under these subsystems are similar in the aspect of what they are educating individuals on but different in how they relay or display this information. This will be essential in determining trends between different displays.

5.7.1 Subsystem #1: Astrology

Since we live in a vast universe, astrology is forever expanding. There are several ways interactive displays can educate a community on our planetary system and other aspects of the universe. The following existing designs are different learning modules from centers that demonstrate many aspects of astrology.

5.7.1.1 Existing Design #1: Star Parties: Hands on Optics & Astronomy

The purpose of the hands-on display below (Figure 3) is to help students learn STEAM through astronomy by putting telescopes in the hands of middle class students. Just before the sunset or 2-3 hours later, students can observe the universe through a telescope. They are instructed on how to use the telescope, and the origin of the telescope.

Figure 3: Telescopes

The telescope is an invention to explore the universe. While commercial grade telescopes are bulky, the ones provided to these students are scaled down. Smaller telescopes are useful for understanding the importance of exploration at a more direct and portable teaching tool. These students look at distant objects to have a better understanding of space and to put the universe into perspective. Users are educated about how telescopes must have two properties, how well it can collect light and how well it can magnify the image. By visually showing these students constellations and providing a hands-on approach when using the telescope, they can travel further into the universe and explore astrology.

5.7.1.2 Existing Design #2: Planetarium

The Adventure Science Center has a 63 feet dome called the planetarium consortium. It projects stars in the sky and gives audio presentations of past stories related to constellations. This center has research and experimentation facilities that involve multiple individuals into collaboration with one another involving any aspect of astrology or exploration. This center is delivering information through visual projection of astronomy by showing the galaxy we are living in as seen below in Figure 4. The ocular presentation is exceptional and the pleasant environment makes people relaxed. The space rides and the stories told here make a very constructive impression in the minds of the participants and they leave with concepts related to astronomy along with visual amusement.

Figure 4: Planetarium

5.7.2 Subsystem #2: Environmental

This subsystem focuses on displays that engage the user with renewable energy, and environmental disasters or phenomenon.

Mostly the nature has been described in this section. The earthquakes, flash floods, wind energy and tornados. These subsystems able learners to learn about nature by simulating the effects, displaying a visually engaging media and by simulating the events in physical world at small scale.

5.7.2.1 Existing Design #1: Catching the Wind

This display has users see what goes into converting wind energy into usable electric energy. The display ties into actual wind turbines and shows the user how energy is converted by having them not only view, but interact in the steps leading up to actual energy use. This display, as shown below in Figure 5, educates the user of renewables and fossil fuel energies. Multiple users can be at different stages of the conversion of renewable energy.

Figure 5: Wind Station

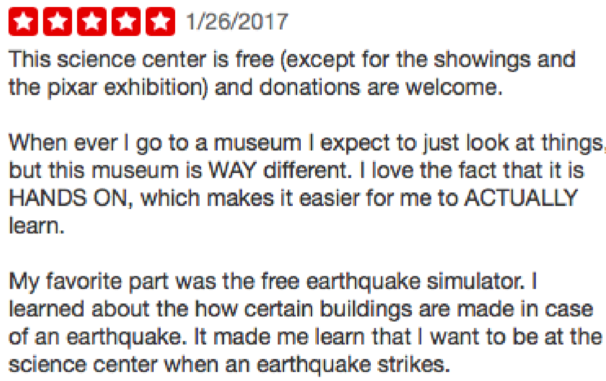
Users are so drawn to this display because energy is essential to everyone’s daily life, we use it everywhere. It also informs of essential placement of wind turbines, boundary layers, etc.
Through the exhibit’s live data tracking, visitors see which of the museum's own turbines are currently producing electricity and hear about why and how they installed them.

5.7.2.2 Existing Design #2: Flash Floods

There is an exhibit in the Smithsonian that takes the user down a dark hallway that has rain storm sounds. Users read lit up facts surrounding the canyon like walls that give information of flash floods and how fast they can occur. When you walk into the open area that are two Plexiglas walls in the surrounding area and then water suddenly fills up the outer walls. This exhibit surprises users by showing them how fast flash floods occur and educating them of natural disasters. This is a popular display because it has that “Wow” factor and element of surprise. It makes the user think and gain a knowledge beforehand when the action takes place. They leave with a level of understanding from both informative and visual aspects. Since it is a walk through multiple users can go through at once all being surprised. The small space out of the safety from the user is water tight and filled with water by pumps.

5.7.2.3 Existing Design #3: Earthquake Simulator

At the California Science Center, there is an Earthquake simulator. This is a popular attraction due to the element of surprise that occurs when consumers engage in this display. This simulator not only shows how earthquakes feel but also informs them about certain buildings and how structural analysis can protect people from natural disasters. Illustrated below in Figure 6, is a review of someone’s experience at this center. As you can see the interface communicates what makes buildings structurally enhanced to survive an earthquake. This is conveyed by allowing the user to reenact a scaled down version of an earthquake. Users step onto an area where the simulation takes place and get surprised by the vibrations made by a suspension system. When activated it


1/26/2017

This science center is free (except for the showings and the pixar exhibition) and donations are welcome.

When ever I go to a museum I expect to just look at things, but this museum is WAY different. I love the fact that it is HANDS ON, which makes it easier for me to ACTUALLY learn.

My favorite part was the free earthquake simulator. I learned about the how certain buildings are made in case of an earthquake. It made me learn that I want to be at the science center when an earthquake strikes.

Figure 6: Yelp Review

5.7.2.4 Existing Design #4: Tornado Vortex

The Tornado Vortex, Figure 7, at The Discovery Cube has a panel that controls different settings of a giant tornado vortex machine. You can essentially control the speed, color, and amount of fog it gives off. The intake fan is located at the top of the ceiling which draws vapor up made from a fog machine. Users have total control of how the vortex is created. The interface system can be used by multiple persons but there is usually just one person in control.

The educational aspect of this display is showing airflow and the science behind vortexes which can be seen in nature. Vortexes can hold lots of energy and they interact with gravity to create its form. Users liked to watch this phenomenon in a controlled space. It contained this wow factor because of the size and how fast you could make the actual vortex spin.

Figure 7: Tornado Vortex

5.7.2.5 Existing Design #5: Home Section

This interactive display had users travel around a scaled down home and learn about different utilities that are in everyday life. This exhibit presented house hold items and how they use energy or different types of resources. For instance, pictured below in Figure 8, is cylindrical container measuring how much gallons of water someone uses in a time span of taking a shower. This can get users more aware of how water is wasted when simply taking a shower.

Figure 8: Water Usage

5.7.3 Subsystem #3: Aerospace/Aeronautical

This section focuses on aerospace or aeronautical concepts.

5.7.3.1 Existing Design #2: Drones

The current focus of Science foundation Arizona is Aerospace & Defense Initiative. This center helps users design commercial unmanned aerial systems (UAS) and associated protocols for safe integration into national airspace.

Unmanned aerial systems are most commonly known as drones. This is an aircraft under remote control by a human or onboard computers. There are many types of drones as pictured below in figures 9 and 10. Drones are used for different purposes like surveillance, aerial photography, and military applications that are dangerous for human beings.

During flight drones usually require a controller. It is like what pilots use to navigate commercial planes for takeoff, and landing. Controllers communicate with drones using radio waves and are controlled by skilled individuals. This center provides hands-on training and experience in designing and aviation navigation. This is popular because it directly involves the users in implementing advanced technology while giving them experience of simulated flight and structural knowledge of these flight systems. Users leave this compound proficient in aeronautical awareness.

Commercial Drone Sample Drone

5.7.3.2 Existing Design #4: Helicopter ride

This ride is featured at The Discovery Cube in Los Angeles. When you enter the helicopter like door (Figure 12) you walk into a small room that has two sets of three rows that face a white screen. When the presentation starts, it projects you into a role as a pilot. The room is setup to look like the helicopter cockpit and you get to fly around the Los Angeles area. While the presentation progresses, you learn about water resources and how you can limit your water use to help the current drought in California. It informs the user about water ways and how water can be recycled through a water treatment plant. While this interactive display is mostly visual, there is a part where the video makes you feel like you're crashing which is exciting and gives the illusion of danger. People leave the display more aware of the limiting water resources and a sense of accomplishment from surviving a crash.

Figure 12: Helicopter Tours

The advantages of having a ramp instead of steps leading to the lifting platform is that it gives access to a new group of individuals who want to use our interactive display. We provide inclusiveness to more individuals in the spectrum of humanity. Another design feature we added to the ramp design that increased safety was the ramp having railing. Even through our vertical height is only 15 inches we wanted railing on both sides of the ramp to provide safety from falling, or rolling off the sides. The lift zone also incorporates railing. It is only 5-6-inch lift, bringing the total height of the lifting platform to be around 21 inches but we need to make sure people are secure and not falling off.

One improvement we have added from the original design was only using one cylindrical support. This cuts down on manufacturing costs and allows for more freedom to rotate the lifting platform if applicable. This gives our display more of a WOW factor.

Since we want stability and durability we will be using steel. This steel will be welded together to make strong lasting connections to each part. Using steel is great for yield strength but can be negative for the strength-weight ratio. To absolve this, we are making sure our design is detachable and foldable for mobility and reducing weight. The sections of the design will be easily put together because the lifting platform is its own frame. The only added portion is the ramp. This will cut down on assembly time, assembly steps, and component repair. If there are less detachable parts it will make preparation time efficient and effective for consumers to be able to use the interactive display sooner.

Since there are two inputs this meets our engineering requirement of having a targeted number of inputs of two people. The two forms of prompting the user to interact is also met by this. Where users will input energy will be in the form of the pump and the ramp. Consumers must travel up the ramp and others must interact with the piston hand pump to move the lifting platform. This causes two interactions with the display.

While users are interacting, they will be, unbeknownst, learning the fundamentals of fluid power. After users reach one lift there will be displayed facts that occurred while they lifted someone. This will be in the form of work applied, energy used, time to perform one lift, etc. This will be outputting more knowledge to users and meeting ERs that include: number of STEAM concepts, story line, connections, factors, facial features, and several other ERs.

5.8 Design Description

The first original design we incorporated a triangle base with steps leading to an extension cube frame with railing. This cube frame would be the lifting platform. As pictured below in Figure 32, the left is our original design. The modified design is pictured to the right of the original. This design is only picturing skeleton of the lifting platform without the extended metal and railing.

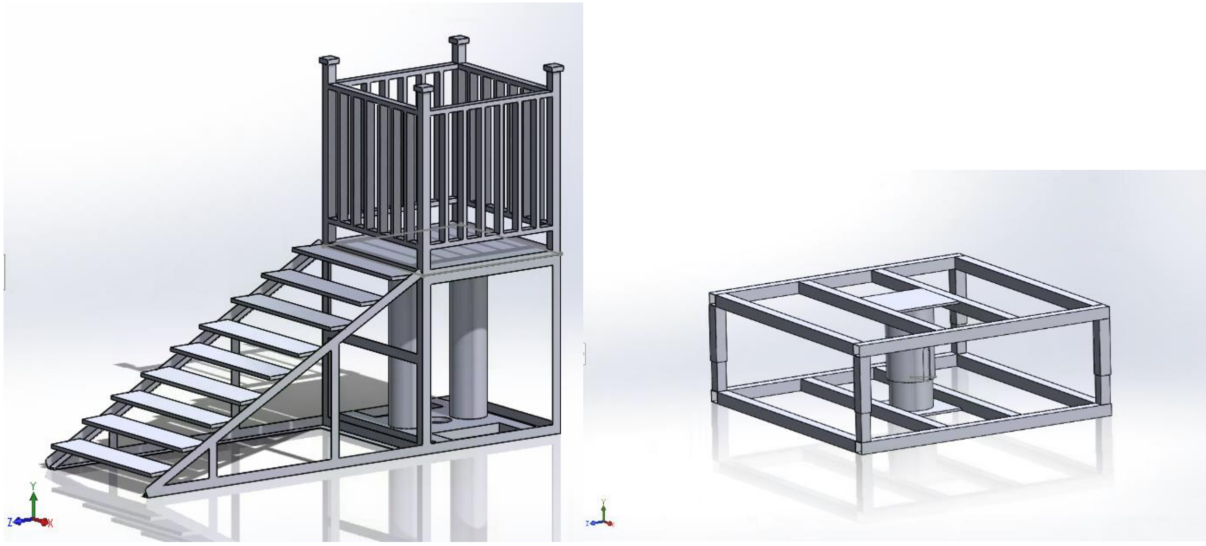


Figure 32: CAD Drawing of Design Evolution

5.8.1 Input Analysis

The hydraulic hand ram pump being used for this display was donated to the group. The pump featured in Figure 33 will be connected to a ram. This output hydraulic ram will extend and lift the platform. The hydraulic hand pump has a built-in release valve and a 6' hose. As fluid moves through the hose the force will be amplified.

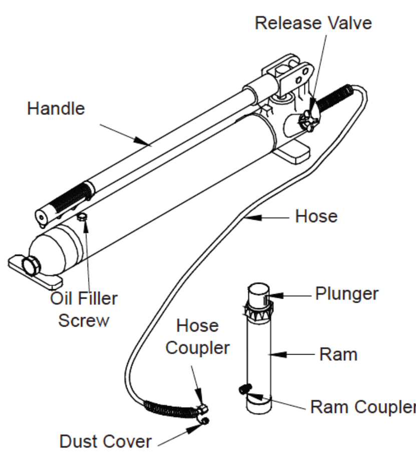


Figure 33: Hydraulic Hand Pump [15]

To find the force amplified we will be using Pascal's Law in Equation 8.1. It is assumed when applying this equation, the fluid is confined and at rest in the system. Pressure is acting equally and perpendicularly throughout the piston chambers, hoses, and spaces. It is also known that both pistons have a required ratio.

Force = Pressure*Area *(Equation 8.1) [16]*

Since the second piston must have 25X larger area than the first, we must determine the input force. The average input vertical push force of a child between 2-5 years is 246.28N. This number was found using the journal on Strength Data for Design Safety [17]. With these factors known, we can solve for load lifting capacity. These calculations are found in Appendix D. The output force that was calculated came out to be 1,384lbs. Since children do not output this force constantly a MATLAB code was developed to see the fluctuating potential output force.

The input hydraulic pump has a stroke of 4.75". If we have the output hydraulic ram to an area of 25X greater than the first is means that every 25" the output will move 1". We need to determine if a child can withstand the duration of one lift. To move the output ram 1" there will need to be a total of about 6 cycles. These cycles are the action of pumping the hydraulic pump. We want around a 5-6" lift, so it will take 36 cycles to get maximum lift. If there are 30 cycles per minute, then it will take a child around 1 minute to extend the lifting platform. This time was calculated with the average pushing strength of a child. Another graph display below shows the time of one lift for a child outputting different forces.

5.8.2 System Losses

There are many losses in a fluid power system. These losses can result from resistances in the system, leakage, seals, pressure losses, types of friction, and even compressibility. All these losses may cause a substantial effect on the overall efficiency of our system. The pump's maximum efficiency is found to be 91% at Ns(specific speed)=8000, since it is an axial pump[2].

Fluid resistance of the system can come in the form of pressure drops. This difference can be calculated by first determining if the flow is laminar or turbulent. This can be done by calculating the Reynold's number. D_h is the inside bore diameter of the piping. Viscosity of the fluid is important to consider because high viscosity means high resistance. In our hydraulic system, we have chosen oil which has a viscosity at 20º.

$\mathbf{R_e = (Density*V*D_h)/\mu}$ (Equation 8.2) [16]

If the Reynold's number is below 2300, then the flow is laminar. If it is above 4000, then we consider it to be turbulent. The pressure drop at points in the system is then calculated based on different equations. If it is in the piping and it is laminar we use the equation displayed below. Since we will not be using fittings in our system, we do not have to approximate pressure drops for turbulence. For instance, if we used a 90º elbow fitting we could expect turbulence at the corner which will result in a pressure drop.

$\Delta P = 128\mu L/(\pi D^4)$ (Equation 8.3) [16]

6 PROPOSED DESIGN

6.1 Bill of Materials for Final Design

The final design requires a lifting platform made of steel. This will require a cut-list to get the right dimensions of the material so they will fit together. The cut-list is in the form of a bill of materials displayed below in table 6.

	CUT LIST Lifting Platform			
Item #	Description	Size	Quantity	Price(Est.)
1	2"X2"X.125" Angled Steel (or X 1/4" thick)	44"	2	
2	2"X2"Xthick(.065-1/4")Square Steel Tubing	44"	6	
3	2"X2"Xthick(.065-1/4")Square Steel Tubing	46" (4')	4	
4	2"X2"Xthick(.065-1/4")Square Steel Tubing	11"	4	
5	Cylindrical Steel Tubing(ROUGH EST.)MORE INVESTIGATION	OD 6"X thick(.28-1")	4	
Total			16	

Table 6: Bill of Materials- Final Design

Once material is acquired we will be welding the frame together. Jeff Hightower will be assisting the group with welding this frame.

6.2 Budget

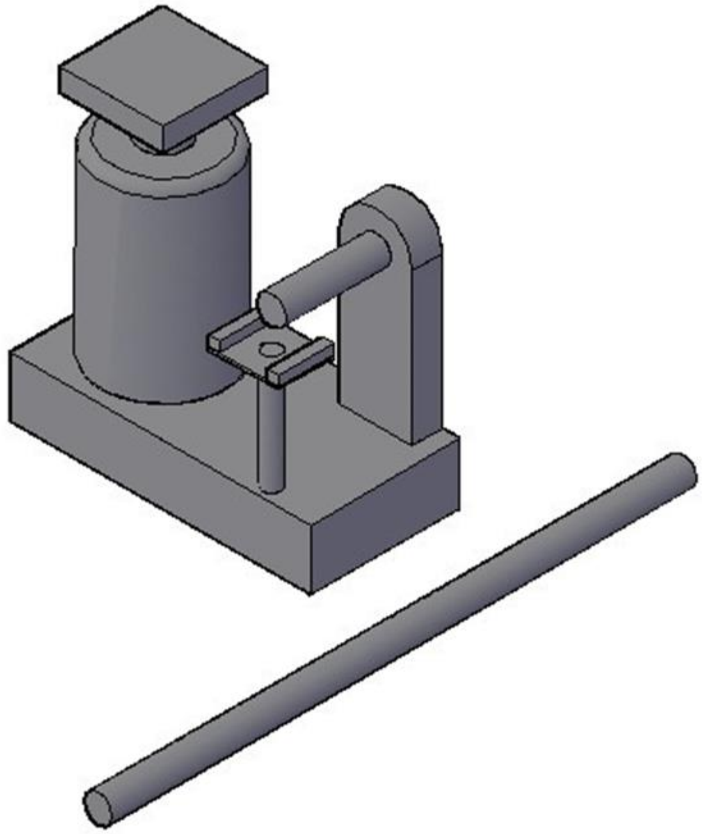
The original goal for our funding was $2,000 but we could not meet that goal. The budget, as illustrated in Table 3.0, was based on this goal. Since we raised up to $1,051.20, we will be further adjusting the actual price when purchasing occurs and shipping costs can be improved.

Income			Budget	Acutal	Difference
		Budget	2,000	1,051.40	948.6
Total Income			2,000	1,051.40	949
Expenses			Budget	Actual	Difference
	Materials		700	685.24	14.76
	Prototyping		100	30	70
	Shipping		177	205.57	-28.57
	Manufactoring		225	160	65
	Mic. Expenses		250	TBD	TBD
		Subtotal	1202	TBD	TBD
Total Expenses			1,202	TBD	TBD
Net (Income-Expenses)			1,202	TBD	TBD

Table 7: Budget

6.3 Prototype

The prototype we are using for our display is described in section 4.3. The main material used in our prototype system is polypropylene plastic which has already been tested for its toughness. It is commercially used in the medical field. The chemical and physical properties of polypropylene are for making syringes are as follows [14];



Sr. No.	Property	Numerical value
1	Melt Temperature	130°C (266°F)
2	Typical Injection Mold Temperature	32 - 66 °C (90 - 150 °F)
3	Heat Deflection Temperature (HDT)	100 °C (212 °F) at 0.46 MPa (66 PSI)
4	Tensile Strength	32 MPa (4700 PSI)
5	Yield Strength	43 MPa (6236 PSI)

6	Shrink Rate	1.5 - 2.0 % (.015 - .02 in/in)

Table 8: Material Properties of Polypropylene

The plastic used for syringes has all the desired properties for our prototype system. The number of lift cycles determined for this assembly are specified on test basis and it is concluded that none of the materials used in the system are pruned to wearing out with time as the moving parts mostly involve fluid and hence lesser frictions in the system. Other materials in this prototype are as follows in Table 4.0.

Item #	Description	Cost
1	Ball Bearings (1/4")	.65ç/bag
2	60mL Syringe	$1.50
3	5mL Syringe (X2)	$1.20
4	Everbilt 1/4" O.D. X 0.170" I.D. X 20ft PVC Clear Vinyl Tube	$3.73
5	Hot Glue (Package 10 sticks)	$6.76
6	Small Bucket (Pint)	$5.00
7	Three Way Valve (1/4" HB Series 326 Three way PVC)	$11.00
8	Wood Framing	Scavanged
Total	$	29.84

Table 9: Bill of Materials- Prototype

7 IMPLEMENTATION

Our design has gone through several selection methods. We selected our design based on Pugh charts c decision matrix which included all the requirements from consumer to engineering requirements. The design we have selected is on the basis of the ranking how it meets these requirements. After theoretical analysis of the design features and specification such as input and load, this design is modified to a newer version. This new design is now capable of meeting the specified requirements such load to be lifted and input to be given to lift the load. Our theoretical analysis includes some factor of safety in it for the reliable operation of the instrument.

7.1.1 Cylindrical Support Analysis

Cylindrical steel pipes will be directly welded to two steel plates connected to the lifting zone. The steel pipe columns will support a total load around 78lbs unloaded. The average person will weigh around 200lbs. The total load the cylindrical supports will be experiencing will be around 350lbs if we add a wheel chair. From the calculations in Appendix D we can determine the total bearing stress between the steel pipe and the steel plate at rest which came out to be 27psi. Since we know this value, we can limit the bearing stress and then determine the minimum area required for the steel plate. Knowing these numbers, we can keep this stress at a minimum and make sure our structure meets structural requirements from these calculations. If we limit the bearing stress to 3psi then the minimum area for the steel plate will be 116.6in^2. The plate will be 12”X12” giving a two inch more plate to minimize bearing stress.

7.1.2 Durability Analysis:

The durability analysis is done to check the designs resistance against wear, pressure, and other damages. In our design we have used cylindrical steel tubes, whose working pressure is necessary to be determine to check for its reliability under different pressure inputs. This working pressure also tells us about the range of pressures this instrument can robustly work. As we know that the tensile strength of the steel is 200 GPa. We can use Barlow's formula [18] to determine the internal pressure at minimum yield. The Barlow's formula stated mathematically as:

$P = \frac{2\sigma_y t}{d_o}$ (Equation) [18]

Where

σ_y *is the tensile strength of the pipe material*
t *is the thickness of the pipe*
d_o *is the outer diameter of the pipe*

Now we know that, σ_y of the steel is 200 GPa, thickness of the walls of tubing is 0.28 in (0.007112 m) and outer diameter of the tubing is 6 in (0.1542 m). Putting these values in the above equation,

$$P_i = \frac{2(200 \times 10^9) \times 0.007112}{0.1542} = 18.45\ GPa$$

This is the internal pressure at minimum yield.

Now for the calculation of ultimate burst pressure, we will use the ultimate tensile strength of the pipe material, which is 400 GPa for steel.

Now using the Barlow's formula again, we find the burst pressure to be:

$$P_b = \frac{2(400 \times 10^9) \times 0.007112}{0.1542} = 36.9\ GPa$$

Now finally we will calculate the working pressure of the cylinders, to find the working pressure we will have to include the design factor F_d which is equal to 0.72 for liquid pipelines [19].

The Barlow's formula would then become:

$P = \frac{2F_d\sigma_y t}{d_o}$ [18]

$$P_w = \frac{2 \times 0.72 \times (200 \times 10^9) \times 0.007112}{0.1542} = 13.24\ GPa$$

This would be the limit of the pressure which should not be crossed for the safe conduct of force and for the safety of people using it. If the required weight is too high we can use multiple cylinder tubing's of same specifications. We have used 4 cylindrical tubing's in our design.

The final design uses steel as its structuring material, which provides durability and strength. By using steel there was a risk of exceeded weight, that's why hollow tubing's is used. The rectangular hollow tubing is used in the fabrication of platform. This gives it the required strength with minimum weight. The joints are made with tolerances to make a perfect joint when welded. Welding is done carefully keeping the torch at 45 degrees to the material. Finally, to keep the steel from rusting we can paint the body of the design. The use of grease and other lubricants with the cylindrical shafts can decrease the frictional losses and may ultimately decrease the wear and tear. These all contribute towards the strong and durable design of the project.

7.1.3 Factor of Safety:

Factor of safety ensures that the design is safe to use, or it may not cause any serious injury and damage. The greater the factor of safety the lesser be the risk associated with the real-time usage of the design.

Mathematically it can be expressed as:

$$Factor\ of\ Safety = \frac{Actual\ Breaking\ Strength}{Normal\ Working\ Load}$$

As numerator and denominator have same units, the factor of safety is a unit less number. Greater the factor of safety more it will be reliable and safe while use but this incurs additional costs of the product.

To calculate the actual working load, and the maximum breaking strength we use the following calculations:

The weight is uniformly distributed and two tubes are welded to the cylindrical shaft. Each of these two tubes make a pair of cantilever rectangular tubes, which have opposite bending moments.

As weight of the platform is equal to

$$P = 250\ lb$$

According to our assumption there are four cantilever beams that bears this weight and as weight is uniformly distributed each of the tube bears quarter of the load of platform.

$$P_t = \frac{250}{4} lb = 62.55\ lb$$

Now we first find the bending stresses that are induced in the tubes as follows

$$Maximum\ Bending\ Moment(M_{max}) = \frac{wl^2}{2}$$

$where,$

$w\ is\ weight\ per\ unit\ length\ of\ the\ tube$
$l\ is\ the\ length\ of\ the\ tube\ from\ the\ end\ to\ center\ of\ the\ cylinder$

Using the above formula, we calculated maximum bending moment which occurs at the fixed point or at the center of the cylinder as follows:

$$M_{max} = \frac{wl^2}{2} = 11244$$

Now to find the maximum bending stress we use the above calculated maximum bending moment as given by the formula below:

$$\sigma_{pmax} = \frac{M_{pmax}y}{I}$$

$where,$
$y\ is\ the\ distance\ from\ neutral\ axis\ of\ the\ tube$
$I\ is\ the\ area\ moment\ of\ inertia\ of\ the\ tubes$

$$y = \frac{d}{2}$$

$where,$
$d\ is\ the\ depth\ of\ the\ tube$

$$I = \frac{bd^3 - hk^3}{12}$$

$Here,$
$b\ is\ the\ outer\ breadth$

h *is the inner breadth*
d *is the outer depth and,*
k *is the inner depth of the tubin*

7.2 Design Changes

By looking at further modifications the design was improved to suit persons with disabilities. These modifications changed the vertical height of platform from 3 feet to 12 ½ inches. These modifications were necessary to keep in mind the customer and engineering requirements of the design. These specifications helped us meet both of these requirements.

The initially selected design uses two syringes which were connected to each other using plastic tube. Valves were used for the simulation of water pump that would generate a specific amount of pressure to lift the weight. The original design we selected consists of a triangle base with steps leading to an extension cube frame with railing. This cube frame was a lifting platform. The modified design is pictured to the right of the original. This design is only picturing skeleton of the lifting platform without the extended metal and railing. The initial design was later modified for the more stable and durable version of the design so it become easier for special need users to use our display. It consists of a square frame extension. This square frame extension is the new lifting platform, where railings can be opened and closed to let people in and out of the lifting platform. In this design instead of syringes we have used hydraulic jack with hydraulic pump, this will help people lift with lesser input power. Today jacks are available in market which can lift above 400 Kg weight. The principle behind this and the original design is same i.e. Pascal's law.

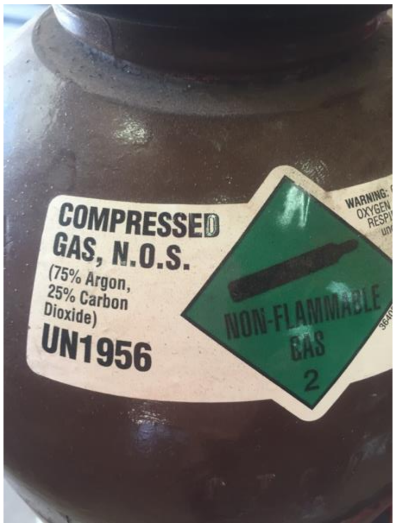
Our modified design consists of following components:

1- Hydraulic Hand Pump
2- Hydraulic Jack
3- Cylindrical Steel Pipe
4- Railing
5- Extended Steel Ramp
6- Lifting Platform
7- Rubber 6’ Tube
8- Display Unit

The cylindrical tubing also contain ramping which also provide the stability to the platform while it is elevated or lifted upwards. The lift zone is only 5-6-inch high, which makes the total height equals to 18 inches. Cylindrical support is added in the design which allows the user to rotate the lifting platform. This makes it attractive and consumable because children can learn how the hydraulic system works. We have used steel as the structuring material for higher durability.

7.21 Manufacture Process

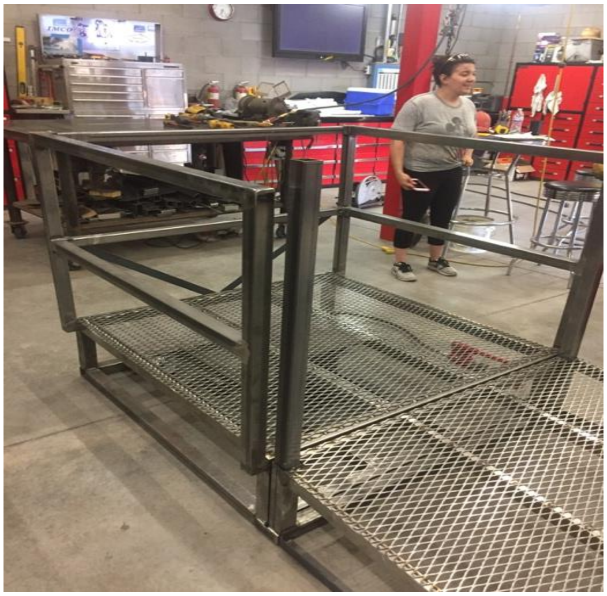
In this section of the report is a description of the manufacture process that the team achieved in the last five weeks. The manufacture processes includes building the lifting platform and the ramp and the railing system of the whole design. An electric welding machine been used to build this design also grinding the metals. This welding machine which is help to attaches the metals in our design very well. This machine is using a compressed gas as shown in figure 34. So when you weld, if you're too far away gas gets blown away and makes popping noise. This mean if you weld too slow, metal will puddle too much and create a hole.



Compressed Gas Figure 34

7.2.2Lifting Platform

The ramp and lifting platform will have a steel framing which will be welded together. We decided to incorporate welding into our manufacturing because when comparing other sources of securing materials this is the best way to fuse metals. The ramp will be detachable and can be bolted together as shown in figure 35.



Ramp attached to lifting Platform Figure 35

The best weld angle is 45º and the welding gun should be close but not touching the metal until it make a perfect hum. Electric current to melt metal makes puddles when these form you make a small slow horseshoe shape going down between the metals. Welding inside corners bring the metal pieces inward so we had to adjust corners to meet dimensions by tight fitting. After we weld, we must grind down where the puddle has solidified as shown in Figure 36 below.

Grinding Process Figure 36

7.2.4Cylindrical Supports

The cylindrical supports purchased were both 8” in diameter, plus tolerances. As seen in the CAD drawing, one cylindrical support fits inside the other. To do this, we had to figure out the circumference of the outside diameter and the inside diameter, then subtract the two to get the width we needed to cut from one support. This can be seen in the calculations in Appendix D the amount we needed to cut was around 1.5 inches. Before making the cut, we needed to consider the blade width because this can add to the original length we need to cut. Once this cut was made, we needed to figure out how to fit the cylindrical support back to its original shape. Two, steel cable ties were used to squeeze the metal back together but there was still a gap that could not be welded. Two nuts were welded onto the cylindrical support a bolt was used to tighten until both sides were touching. Both ends were then welded together on the inside.

The ties were removed but the cylindrical support now had an egg shape. To correct this, a hydraulic 20-ton bench press was used to press the cylindrical metal until the diameter was congruent. This can be seen in the image below, Figure 37 After making the shape back to its original, the bolts and nuts were removed and the cylindrical support could now be welded onto a plate below the lifting zone.

Cylinder Manufacture Figure 37

7.2.5Ramp

We have used self-made ramp instead of steps for the uniqueness of the design, that people will learn more from a single project. The ramps are self-fabricated because they were expensive when the team start searching for quotes of the ramp. This will be useful and easier for the handicap users so they can use the display and will attract new individuals who like this interactive display. Further we have designed the ramp with railing for the safety of people that it might not fall of the sides. Ramp is in three sections all detachable and stackable onto lifting platform. First section goes from the 12 ½" height to 8" → 4" → 2" to base with a flat steel piece welded to make contact with the ground. So the first connection is held together by sliding a welded handle in the bottom openings of both and the second section is bolted together. The third is held together by a groove and bolt that is welded at the base to slide into the slot as shown in the below figures 38and 39.

Ramp Manufacturing Figure 38

7.2.6 Railing

The railing and the ramp will be detachable. Also the rail will be able to tighten with hand using bolts nuts. The ramp railing will have wire looped though each one. The platform will have a rope latch that can be secured since only a small lift is being performed. The main reason for the railing usage is to protect the user from failing of the platform of the display.

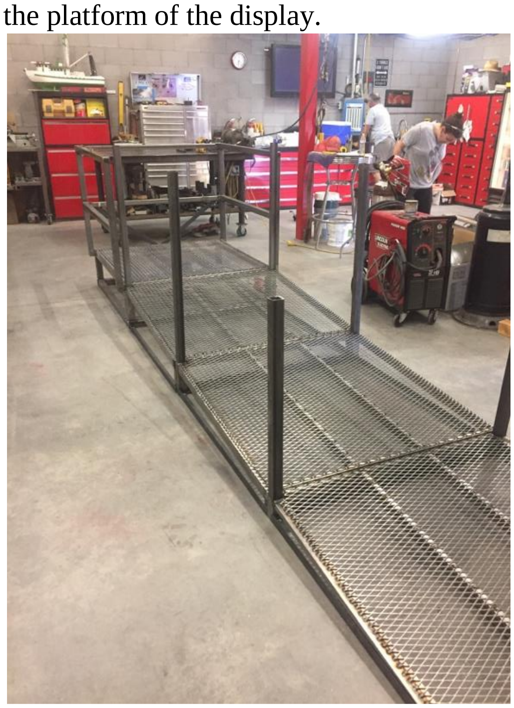


Figure 39

7.2.7 Fabrication Budget

One of the most important part in this design is to build it up with the range of our budget, which is 2000$. The most expensive part for our design is the ramp. London did couple of price quotes for the best ramp company to buy one and attaches it to the display. Many companies can build up the ramp and sell it or rent it to the consumers such as America's Leading Ramps. This store can build up the ramp needed for the design and it will cost 3516.29$ to buy one. For renting a ramp from the same company, it will cost 1236.20$ a month. These prices includes the materials, travel and tax costs which is considered above the team budget. Therefore, the team decided to build up a ramp from scratch, which it cost much cheaper because the welding will be free. The materials been used to build up the ramp costs 266.74$ and the welding is donated. This helped us to reduce the design total budget and helped the team to save money.

8 Conclusion

The hydraulic jack is much advanced machinery than the conventional scissor jack in terms of load bearing capacity and the lesser amount of power needed to be applied for making the jack work. This design has been completed keeping in mind every aspect of a successful lifting jack that it must be cost saving, powerful, easy to use and portable without taking up much space. The design of the jack has been tested on several light and heavy weight vehicles and the data denotes the success of the device. With proper marketing, this is bound to bring a revolution in the market of automotive accessory. The final design will be completed in sections. The framing will involve 2”X2” square steel tubing. This will be completed by our first hardware review. Since we want the whole design to be mobile, we will be researching ADA compliant ramps that will be able to fit our lifting platform’s vertical height.

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APPENDICES

APPENDIX A: House of Quality & Email Proof

Table 6: House of Quality

Customer Requirement	Weight (Rank)	Engineering Requirement	Attention of Audience	Connections	Yield Strength	Design Preperation	Comprehension of User	Component Repair	Success Rate	Number of STEAM Concepts	Assembly Steps	Facial Features	Skill level	Number of Inputs	Lift Cycle	Center of Gravity	Factors	Strengh to weight ratio	Organized Components	StoryLine	Operation Steps	Prompts User	Lift Weight	Assembly Time	Weight	Corner Radius	Surface Temperature
1. Safe	5		0	0	9	1	0	1	9	0	1	0	0	1	1	9	0	3	3	0	1	0	1	0	3	9	9
2. Simple instruction	5		1	0	0	9	9	3	0	3	9	0	9	1	0	0	0	0	0	1	9	0	0	3	0	0	0
3. Hands-on	5		0	3	0	9	1	1	1	0	1	0	1	9	1	0	3	0	0	1	3	9	9	1	0	0	0
4. Wow factor	5		9	9	0	0	0	0	0	1	0	9	0	1	0	0	0	0	0	3	1	0	3	0	0	0	0
5. Simple to assemble	4		0	0	0	9	0	9	9	0	9	0	1	0	0	0	0	0	3	0	1	0	0	9	1	0	0
6. Integration of mult. STEAM concepts	4		1	9	0	0	1	0	0	9	0	0	0	0	0	0	1	0	0	1	1	3	0	0	0	0	0
7. Narrative	4		3	1	0	0	3	0	0	3	0	1	0	1	0	0	1	0	0	9	0	0	0	0	0	0	0
8. Visual appearance	4		9	3	9	0	0	1	0	0	0	3	0	1	0	1	0	1	9	1	0	1	0	0	3	3	0
9. Relatable	4		9	9	0	0	9	1	0	1	0	0	9	0	0	0	9	0	0	3	0	0	0	0	0	0	0
10. Durable	4		0	0	9	0	0	9	9	0	1	0	0	0	9	9	0	9	0	0	1	0	0	0	1	3	3
11. Educational	4		9	1	0	0	9	0	0	9	0	9	3	1	0	0	9	0	0	1	0	0	1	0	0	0	0
12. Mobile	3		0	0	1	3	0	1	0	0	3	0	0	1	0	3	0	9	9	0	0	0	0	3	9	1	0
13. Multiple visitor	3		3	3	0	0	1	0	0	1	0	3	0	9	9	0	0	0	0	0	0	3	0	0	0	0	0
14. Cost	3		1	0	9	1	0	9	1	0	1	0	0	0	9	1	0	3	0	0	0	0	0	1	3	1	0
Absolute Technical Importance (ATI)			**186**	**161**	**147**	**143**	**141**	**135**	**125**	**111**	**107**	**106**	**102**	**102**	**100**	**97**	**95**	**91**	**90**	**85**	**82**	**70**	**69**	**68**	**68**	**63**	**57**
Relative Technical Importance (RTI)			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Units			**#**	**#**	**Mpa**	**#**	**Level**	**$**	**%**	**#**	**#**	**#**		**#**	**Lifts**	**ft.**	**#**	**kN*m/kg**		**#**	**#**	**#**	**kg**	**hrs.**	**lbs**	**in.**	**°F**
Target(s), with Tolerance(s)			5	3	250	3	Mod.	130	100	3	3	4	Mod	3	100	1	2	46.4	Inline	1	5	2	120	2	200	11/16"	70
Tolerance			4	2	200	2	Min.	100	90	2	10	3	Easy	2	90	1.5	1	76	Within	0	6	1	100	1.5	150	9/16"	74
Testing Procedure (TP#)			4	5	3	2	5	3	1	6	2	4	5	6	3	7	5	7	1	6	5	5	7	2	7	1	1
Design Link (DL#)			4	5	1	3	4	7	1	3	3	2	1	7	1	1	6	5	1	4	2	2	2	3	6	1	1

Approval

Team member 1: London Starlin LS 3/24/17

Team member 2: Abdullah

Team member 3: Mohammed

EMAIL PROOF:

Jackee Alston <thewonderfactoryflagstaff@gmail.com> Feb 15

to Abdullah, me, Mohammed

Hi All,

Steve and I filled these out. Should Vicki fill one out, please disregard it. She's just learning how to make exhibits but I'm glad she came along to meet you guys. Thanks!

Talk to you soon,

Jackee

APPENDIX B: Pugh Charts

Table 7: Pugh Chart 1

Customer Requirements	Weight lifting	Handle Wind Power	Water Cycle	Ball Race	Catapult Rubber Gun	Wind Turbine Using Gears	Lifting Jack Using Gears	Magnetic Train	Pendulum Wave	Wind Tunnel	Musical Water	Life Size Operation
Safe	0	0	0	0	-1	0		0	-1	0	-1	-1
Simple Instruction	0	-1	-1	0	0	-1		-1	0	0	0	0
Hands-on	0	0	-1	0	0	0		0	0	-1	0	0
Wow Factor	1	1	0	0	1	0		0	1	0	1	0
Simple to assemble	1	0	0	1	1	0		1	1	0	0	1
mult. STEAM concepts	0	0	0	-1	0	0	D	0	0	0	0	0
Narrative	-1	0	0	-1	-1	0	A	-1	0	0	0	0
Visual appearance	1	1	1	0	0	1	T	0	1	1	1	1
Relatable	1	1	0	0	1	1	U	1	0	1	0	0
Durable	0	0	-1	0	-1	0	M	-1	-1	0	-1	-1
Educational	-1	0	0	-1	-1	0		-1	0	0	-1	0
Mobile	0	0	1	1	1	0		1	1	0	0	0
Mult. visitors	1	0	0	0	0	0		0	1	1	0	1
Positive	5	3	2	2	4	2		3	5	3	2	3
Negative	2	1	3	3	4	1		4	2	1	3	2
Same	6	9	8	8	5	10		6	6	9	7	8
Total	3	2	-1	-1	0	1		-1	3	2	-1	1

Table 8: Selected Designs (Pugh Chart 1)

Customer Requirements	Weight lifting	Handle Wind Power	Pendulum Wave	Wind Tunnel	Hydraulic Lift
Safe	0	0	-1	0	0
Simple Instruction	0	-1	0	0	0
Hands-on	0	0	0	-1	0
Wow Factor	1	1	1	0	1
Simple to assemble	1	0	1	0	1
mult. STEAM concepts	0	0	0	0	0
Narrative	-1	0	0	0	0
Visual appearance	1	1	1	1	1
Relatable	1	1	0	1	1
Durable	0	0	-1	0	0
Educational	-1	0	0	0	0
Mobile	0	0	1	0	1
Mult. visitors	1	0	1	1	1
Positive	5	3	5	3	6
Negative	2	1	2	1	0
Same	6	9	6	9	8
Total	3	2	3	2	6

Appendix B Pugh Charts

Table 9: Pugh Chart 2

Customer Requirements	Acordian Lift	Hydraulic Arm (DATUM)	Chair Lift	Board Lift	
Safe	0		0	-1	
Simple Instruction	0		0	0	
Hands-on	0		0	0	
Wow Factor	1		1	1	
Simple to assemble	-1		0	0	
mult. STEAM concepts	0	D	0	0	
Narrative	0	A	1	0	
Visual appearance	0	T	0	-1	
Relatable	0	U	0	-1	
Durable	0	M	0	0	
Educational	0		0	0	
Mobile	0		0	0	
Mult. visitors	1		1	1	
Positive	2		3	2	
Negative	1		0	3	
Same	9		9	8	
Total	1		3	-1	

Appendix C: Black Box & Functional Model

Figure 24: Black Box Model – Hydraulic Lift

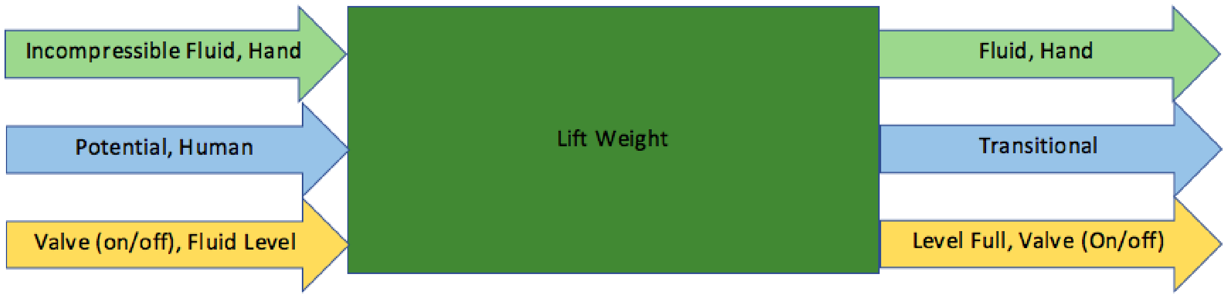
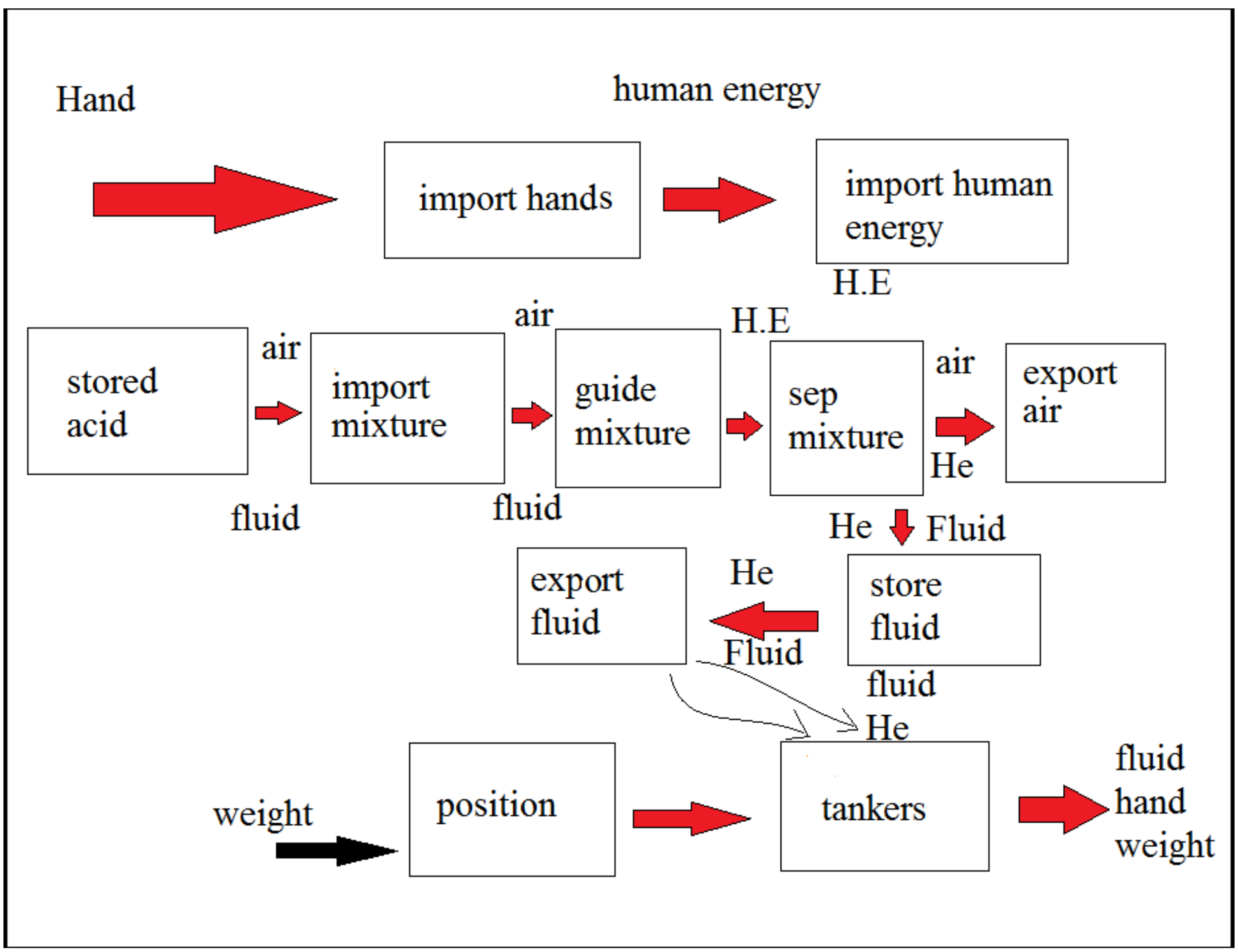


Figure 25: Functional Model –Hydraulic Lift (THIS WILL BE CHANGED)



Appendix C: Decision Matrix

Table 10: Decision Matrix

Weight		Steps/2Cylinder		Ramp/2Cylinders		Ramp/1Cylinder/NoRailing		Ramp/1Cylinder/Railing	
Criterion									
1. Safety	0.25	3	0.75	4	1	0	0	5	1.25
2. WOW Factor	0.2	4	0.8	4	0.8	2	0.4	3	0.6
3. Skill Level	0.1	4	0.4	3	0.3	3	0.3	4	0.4
4. # of Inputs	0.05	3	0.15	3	0.15	3	0.15	4	0.2
5. Education	0.15	3	0.45	3	0.45	3	0.45	3	0.45
6. Hands-On	0.15	3	0.45	4	0.6	4	0.6	4	0.6
7. Durable	0.1	4	0.4	3	0.3	3	0.3	5	0.5
Totals	1		3.4		3.6		2.2		4
Relative Rank			3		2		4		1

Appendix D: Calculations

Input (Hydraulic Piston Pump):

Knowns:

4Ton Porto-Power

-Fully Extended: 15-3/4" *-A_{eff}=.998in^2* *-F_{Child}=246.28N = F_1*

-Fully Retracted: 11" *-Stroke(inside): 4.75"*

-Displacement(handle) = 11.75" (30 cycles/min) *-25" displacement = 1" output*

Load Lifting Capacity

$P_1=P_2$ *(Assumed)*

$F_1/A_1 = F_2/A_2$

$F_2 = (A_2/A_1)F_1$

$A_2/A_1 = (\pi r_2^2)/(\pi r_1^2) = 5^2/1^2 = 25$

$F_2=25F_1$

F_2 *= 25(246.28N) = 1384lbs* *(conversion factor 246.28N →55.36lbs)*

Pushing Force to Get up Ramp

Average Human Weight = 140lbs *Static Friction (μ_s) = .42 (est. between rubber and steel)*

W_{wheel_chair}*=35lbs*

Child Age 6 Weight = 44lbs *Ramp incline (1:12) 4.8°*

$F_{push} = mg\sin ø + \mu_s mg\cos ø$ *= 175lb(9.81m/s^2)sin(4.8)+.42(175lb)(9.81m/s^2)cos(4.8) = 391.02N (Adult)*

(conversion factor 1lb = 0.453592kgs)

F_{push} = *176.53N (6yr old)*

Time for 1 Lift

4.75" Stoke (inside) → 5.263 cycles to

Maximum lift = 5-6"

*Total cycles = (5.263cycles/1") * (6") = 31.578 cycles*

*Time for 1 Lift = 31.578 cycles * (1min/30cycles) = 1.05 minutes Average Time*

b/a	0.1		0.5		0.7
r_o/a	0.5	0.7	0.7	0.9	0.9
$K_{y_{max}}$	−0.0066	−0.0082	−0.0010	−0.0010	−0.0003
K_{θ_a}	0.0194	0.0308	0.0056	0.0084	0.0034
$K_{M_{rb}}$	−0.4141	−0.3911	−0.1172	−0.0692	−0.0519
K_{Q_b}	3.3624	2.8764	1.0696	0.4901	0.5972

$$ending\ Stress = \frac{My}{I}$$

Shear Stress:

$$Shear\ Stress = \frac{T}{A}$$

Maximum Stress:

$$Maximum\ Stress = \frac{\sigma_1 + \sigma_2}{2} + \sqrt{(\frac{\sigma_1 + \sigma_2}{2})^2 + \tau_{xy}^2}$$

Factor of Safety:

$$Factor\ of\ safety = \frac{Maximmum\ stress}{Working\ Stress}$$

Bearing Stress Between the Angle Steel and Cylindrical Support

$A_{cylindrical\_inner} = \pi/4(D^2-d^2) = \pi/4(12^2-11.44$^2) $= 10.309\ in^2$

$d = D - 2t = 12 – 2(.28) = 11.44in$

$Stress_{bearing} = F/A_b = 300lb/10.309in^2 =$ 29.099psi

Pushing Force to Get up Ramp

Average Human Weight = 140lbs *Static Friction* (μ_s) *= .42 (est. between rubber and steel)*

W_{wheel_chair}*=35lbs*

Child Age 6 Weight = 44lbs *Ramp incline (1:12) 4.8º*

F_{push} = mgsinø + $\mu_s$mgcosø = 175lb(9.81m/s^2)sin(4.8)+.42(175lb)(9.81m/s^2)cos(4.8) = 391.02N (Adult)

(conversion factor 1lb = 0.453592kgs)

F_{push} = 176.53N (6yr old)

Weight of Lifting Platform

Given: 5.41lb/ft. for 2"X2"X0.0.065-1/4" square tubing

BASE = 3.666' (2) +4' (2) = 15.332'

Legs = .9166(4) = 3.666'

Lift Zone = 4' (2) + 3.666' (4) = 22.664'

Total = 41.662'(5.41lb/ft.) = 225.39lbs (not including cylinders and angle steel and added people)

Cylindrical Piping Bearing Stress

$A_{pipe} = \pi/4(D^2-d^2)$ d = D-2t = 8.75-2(.5)

$A_{pipe} = \pi/4((8.75^2)-(7.75^2)) = 12.95in^2$

$Stress_{bearing} = F/A_b$ = 350lb/in^2 = 27.008psi

Minimum Area required for steel plate to limit bearing stress → 3psi

$A_b = F/A_b$ = (350lb)/(3psi) = 116.66in^2

√116.66 in^2 = 10.80in

Cylindrical Piping Cut Calculation

Circumference of a Circle = 2πr   OD = 8 ¾"   ID = 8 ¼"

C_1 = 2π(4.375) = 27.488

C_2 = 2π(4.125) = 25.91

C_1-C_2 = 27.488-25.91 = 1.578 – (Blade width)