The Wonder Factory

Preliminary Report

Team E

London Starlin

Abdullah Alshammari

Mohammed Kattan

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Project Sponsor:

Faculty Advisor: Jennifer Wade

Sponsor Mentor: Jackee Alston

Co-Faculty Advisor: Sarah Oman

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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.'

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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 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 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 need 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
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1.2.4 The Wonder Factory Deficiencies

When interviewing Jackee, she had mentioned they were needing 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 needs 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 key words 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 figure out potential dangerous hazards 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 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 5 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 5 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

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 4 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 assemble 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 4 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 than 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 4, 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 4 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 team work and gets a message to numerous people. The customer assessed this requirement at 3 because it may not be as important as other customer needs, such as safety.

Cost was also weighted as a 3 because the client did not want us to limit our imagination. Cost is still being considered into 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"
Heat Genertion	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 problem persists, like a part malfunction 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 cannot be structurally sound, then we will modify the design appropriately. Our center of gravity must be no more than 1.5ft. with a target of 1ft. We need to know the center of gravity of our display because it can be unsafe for all users standing near the display if the tipping point is reached. The tipping point must be restrained.

-*Organized Components*

This is an important requirement because components must be well organized per the design. Any kind of wiring or attachable parts must be covered or stored in an organized manor. 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 inoperative. 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 dangerous when compared to a 1/64” radius. These types of edges are necessary as children will be using the display and will be interacting with all components. If sharp edges are present, there is a risk of puncture or wound. 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.

-*Heat Generation*

The heat generation 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 flux, meaning they will be moving and changing displacement, we need to account for components generating any heat. Over 80ºF severe 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 tolerance of moderate learning application and a target of novice. 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 are 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 performing 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 the operation should be kept at 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 learning 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 coming 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 because 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*

Story lines 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 a 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's 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 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 high yielding material.

-*Strength-Weight Ratio*

The strength should be at a maximum by keeping the weight at 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:

-Factors

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.

-*Weight*

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:

-Number of inputs

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 nonoperation 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 the display. The price tolerance is $130 and the target is equal to or below $100.

2.3 Testing Procedures (TPs)

The testing procedures are how our team is going to 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

Safety tests are performed to ensure the safety of the user. We might use slight variations of

-*Organized Components*

Some components that are not breakable easily can be organized or joined permanently to lessen the setting time and these components involve the syringes and the connecting pipes. They can be joined together and later it can be assembled with the rest of the parts of the display. The assembly steps will in this case be less than 10 and that criteria are good enough for any hands on experimental display in the house. The components will be organized in such a manner to lessen the assembly steps in the range of 5 to eight steps at most.

-*Corner Radius*

Corner 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 tape. If it leaves a scratch it does not pass.

-*Heat Generation*

To test for heat generation, we will be making sure the surface temperature is constant with room temperature. By doing this we could use an infrared laser thermometer, or simply exam the area where friction is occurring and see if there is a temperature variation.

2.3.2 Preparation Test

-*Design Preparation*

Design preparation will be measured on the number of people who can successfully get the display ready for public consumption. 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

This measurement of assembly time will be tested by keeping track of the period of preparation. If the display needs to be set-up within 30 min then we need to account for that time by designing for limited set-up stage. The assembly time should not be more than 1 hr. The last 10 minutes of assembly should be dedicated to checking the validity of the components. Is everything working or does anything need to be readjusted. Team E will calculate the exact time it takes to set-up the display.

-*Assembly Steps*

Assembly steps will be tested based upon the number of steps it takes to fully assemble the display. This will be practiced to ensure all steps are present.

2.3.3 Durability Test

-*Lift cycle*

The life cycles will be determined by constantly lifting for 2 hrs. until we reach 100 lifts. After reaching that targeted goal we will be recording any possible part malfunction. This will be recorded to better suit the components in high stress areas.

-*Component Repair*

The display will be tested to lift 120 kg with a safety factor included so that the system is reliable. The component repair can be measured in terms of frequency of repair. If any component makes through 4 to 6 months of time and after that it requires repair, then the repair log will be developed and the life of the components will be determined.

-*Yield Strength*

-*Success Rate*

The success rate will be tested by continually interfacing with our design to make sure the desired output is accomplished every time.

2.3.4 Participant Test

-*Attention of Audience*

The attention of the user will be measured using the face value that should be at least three at any instance; it means that at least three people should be engaged together in the experiment at a time. If the value is lower than expected repeatedly then the display characteristics will be enhanced by mutual consideration for the attention of audience.

-*Facial Features*

To measure facial features, we will be counting facial expressions and determine what kind of feelings are present while interface is occurring. We will also make note if there are facial expressions that exude detachment from the display. This will help us determine what areas of the display need changing, or if items need to be added to make it more exciting.

2.3.5 Usability Test

-*Comprehension of User*

For comprehension of the user we will be implementing usability testing. This test will view operators by how the they figure out what needs to be done and if the task is completed, did they understand what happened.

The comprehension of the user is one of the basic purposes of the display. The user must be keen in learning and understanding the phenomenon at the end. The comprehension of user will be measured by dividing the display per assembly steps. We will note down that where the customer was lost while assembling and will make that step easier if the problem persists. The skill level will always be considered novice for the user because they will not have any previous knowledge of the display as assumed.

-*Skill Level*

Testing the skill level of the display will include people from different walks of life interacting with the display and use their reasoning skills to figure out how it works.

-*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 interaction.

- *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*

-*Story Line*

- *Connections*

Finding connections of learning techniques and visual representations in our design will help test for how the public relates to our interactive display.

2.3.6 Counting Test

-*Number of STEAM Concepts*

STEAM concepts will be measured based upon what areas of the design fit each concept and counting those numbers that fit. For example, if the display is deals with fluid power this is both engineering and technology because it is dealing with technical 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*

Number of inputs will be measured 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.

2.3.7 Gravity Test

-*Weight*

Weight will be tested by simply finding out densities of each component and determ

-*Center of Gravity*

We will be determining the center of gravity by either finding the balance point or using a plumb line. This will ensure the tipping point in never reached.

-*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. Since we know specific dimensions and restrictions we can determine what max load will cause buckling. We want to test the structure to ensure we are not over loading the display.

-*Strength-Weight Ratio*

Strength-weight ratio will be tested based on material tenacity. By testing material's tensile strength, we will be able to see a material's mechanical behavior. Through this we will be able to make the distinction of which materials can handle the stresses and strains our system will be experiencing.

2.4 Design Links (DLs)

Design links explain how our design will be meeting the ER targets and tolerances. Each design link will be referenced per the HOQ.

2.4.1 Safety & Simple Instruction

-*Success Rate*

The success rate is determined as 100% as the components are tested well before assembling and re-tested after assembling. There is no chance of lowering this percentage than 100% as the customers will mostly be children and the operation risk is not affordable.

-*Center of Gravity*

-*Organized Components*

The components of the display will be organized. Sensitive components like two way valves and pipes will be permanently attached so the customer will not worry about leakage from the system. This will also low the number of assembly steps.

-*Lift cycle*

The life cycles are declared infinite for the display if the design limitations are met because there are no mechanical components in the display which can wear out with time. However, the regular checkup of the components is recommended so that any possible accidents can be avoided during the usage.

-*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…

-*Heat Generation*

-*Skill Level*

The skill level of the customer is considered as beginner, advanced. Due to the complexity of Pascal's Law it will be displayed in a very simple format so the customers will understand the theory and concept without having any previous knowledge of the law.

2.4.2 Hands-On & Wow Factor

- *Prompts User*

-*Operation Steps*

The operations steps must be lesser than assembly steps. They are kept under 5 because the user will already be feeling accomplished after the assembly steps and eager that he can finally see the working of the display. So we have catered this issue and by keeping the operation of the display very simple.

-*Facial Features*

The facial features are related to wow factor. The display is interesting as we have designed it to lift up to 100 kg using a very small force, the proposed weight to move is a person being lifted using a hydraulic mechanism. However, we will make sure that the wow factor is measured on a definite time span so that any deficiency can be accommodated.

-*Lift Weight*

2.4.3 Simple to Assemble & STEAM Learning Concepts

-*Design Preparation*

Not more than three people will perform the display preparation and thus the least number of people for the setup meets the requirement of easy assembly. The display preparation steps and people must be kept to a minimum so that the mobile displays are easy to be taken anywhere and setup for experimentation.

-*Assembly Time*

Assembly time was designed to take between one and two hours, depending on the level of experience with the display. The assembly time should be assigned keeping in mind the overall activity time of the day and making our display a part of it in an efficient way.

-*Assembly Steps*

The assembly steps are kept less than 10 and this is the ideal situation for a user to not lose interest in the experiment. The assembly steps can be lessened based on the observations and feedback if required in the future.

-*Number of STEAM Concepts*

2.4.4 Narrative & Visual Appearance

-*Story Line*

-*Attention of Audience*

The attention of audience is kept a priority, as the user will be attracted if the display is interesting. The attention will be measured using facial expression values and the daily count or weekly count is kept under consideration for any possible alteration in the design or any other feature that can be changed to make it more interesting.

-*Comprehension of User*

Comprehension of the user is a priority, as the instructions will be given before and during the operation so that every step is fully understood by the customer. Efficient learning will be achieved because our display is transparent, which makes the operations visible as they happen.

2.4.5 Relatable & Durable

- Connections

-*Yield Strength*

-*Strength*-*Weight Ratio*

2.4.6 Educational & Mobile

-Factors

-*Weight*

2.4.7 Multiple Visitor & Cost

-*Number of inputs*

-*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 are weighted on a 0,1,3,9 scale of how they correlate to customer needs. The top ER came out to be connections. This ER outlines how the consumer is relating to the actual display. By doing this we can connect to 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.

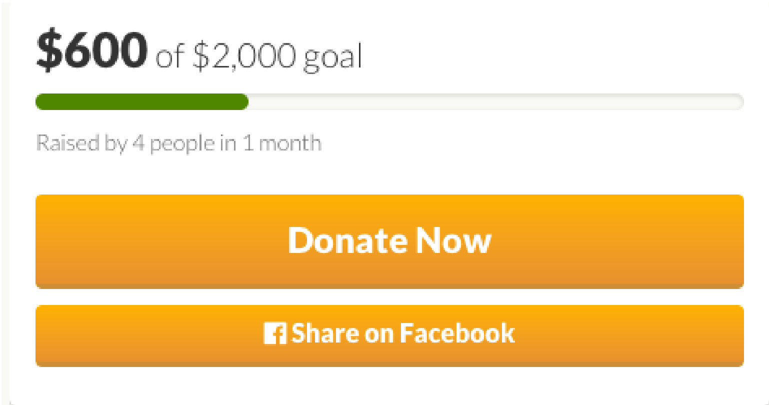


Figure 2: GoFundMe Campaign

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.

- 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 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.

(MORE INFORMATION)

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

Figure 5: Wind Station

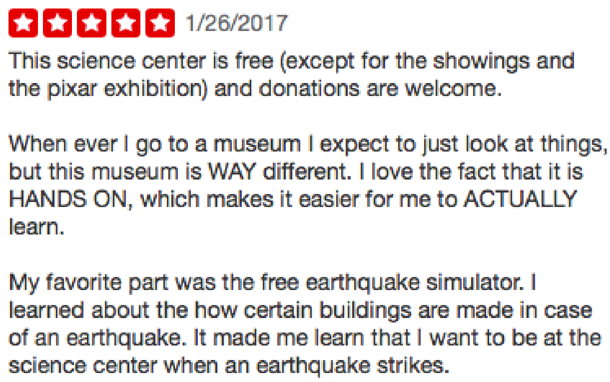
of renewable energy. Users are so drawn to this display because energy is essential to everyone’s daily life, we use it everywhere. It also informs of essential placement of wind turbines, boundary layers, etc. Through the exhibit’s live data tracking, visitors see which of the museum's own turbines 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 Reveiw

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.

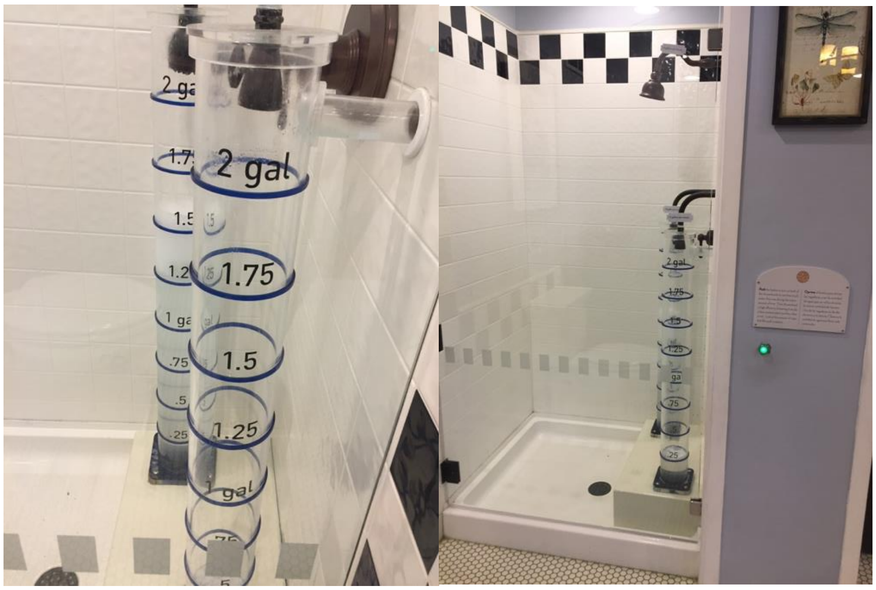


Figure 8: Water Usage

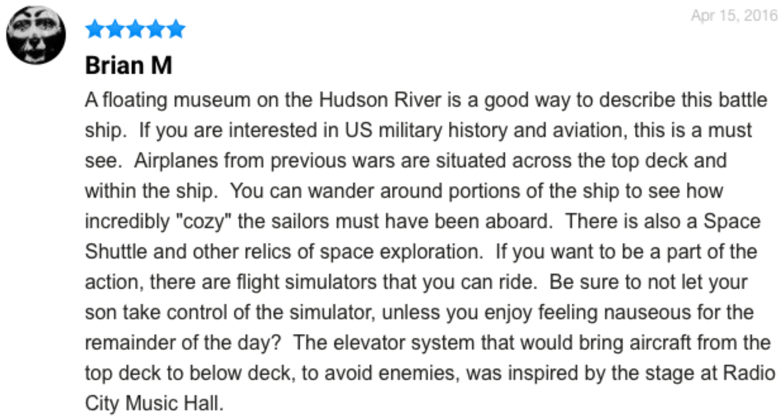
3.3.3 Subsystem #3: Aerospace/Aeronautical

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.


Apr 15, 2016

Brian M

A floating museum on the Hudson River is a good way to describe this battle ship. If you are interested in US military history and aviation, this is a must see. Airplanes from previous wars are situated across the top deck and within the ship. You can wander around portions of the ship to see how incredibly "cozy" the sailors must have been aboard. There is also a Space Shuttle and other relics of space exploration. If you want to be a part of the action, there are flight simulators that you can ride. Be sure to not let your son take control of the simulator, unless you enjoy feeling nauseous for the remainder of the day? The elevator system that would bring aircraft from the top deck to below deck, to avoid enemies, was inspired by the stage at Radio City Music Hall.

Figure 9: Yelp Review

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.

(DESCRIBE DATUM WHY WE CHOSE)

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.

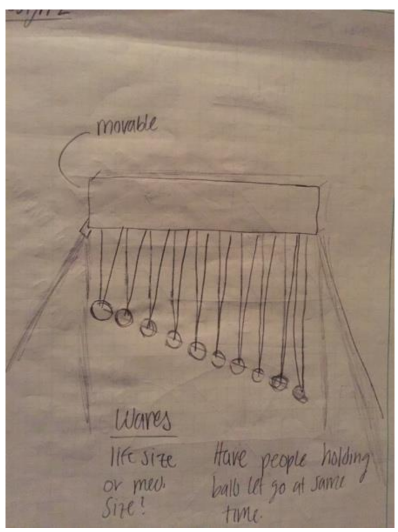


Figure 13: Pendulum Wave

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.

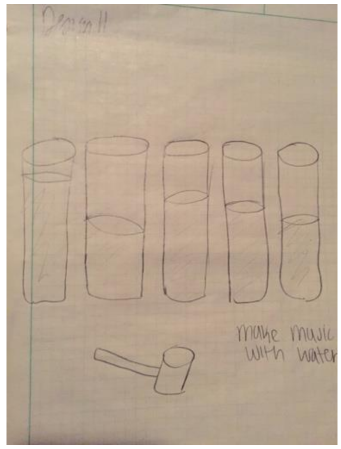


Figure 14: Make Music with Water

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.

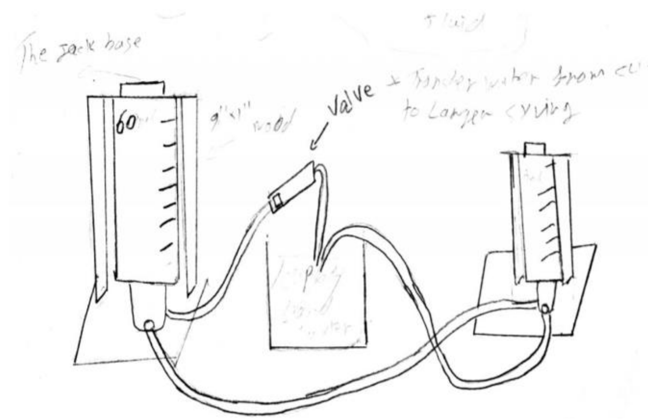


Figure 15: Hydraulic Lift

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.

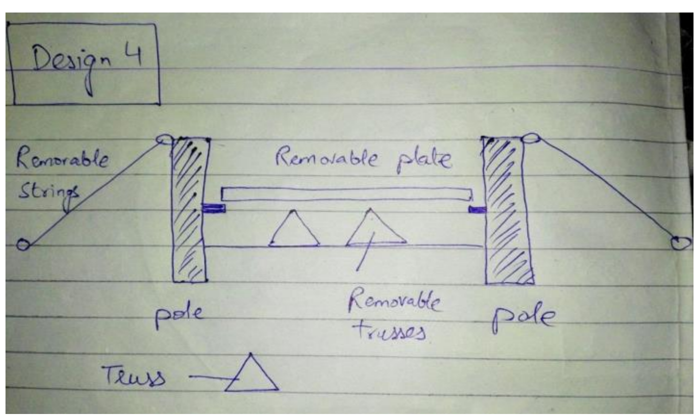


Figure 16: Make a Bridge

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.

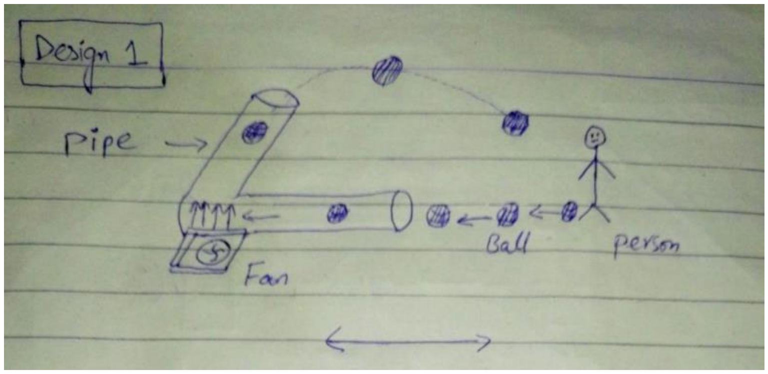


Figure 17: Ball Propeller

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.

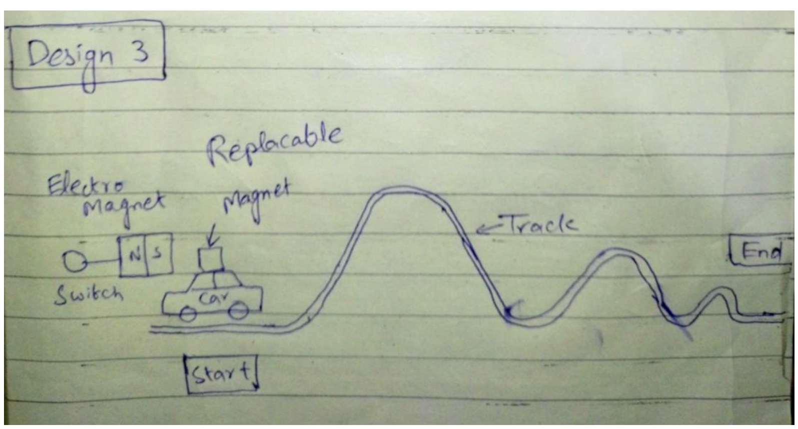


Figure 18: Hill Climbing Race

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.

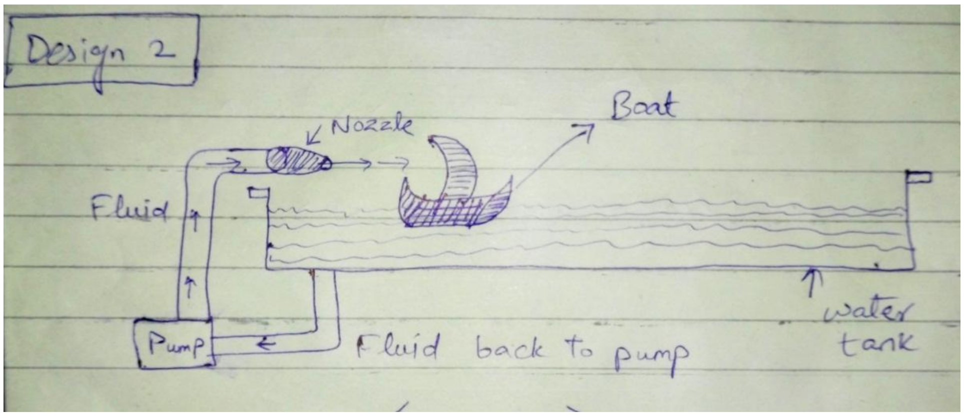


Figure 19: Boat Sailing

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.

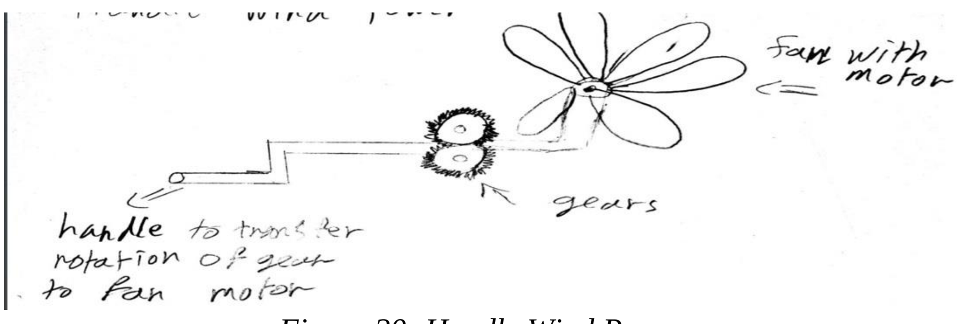


Figure 20: Handle Wind Power

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.

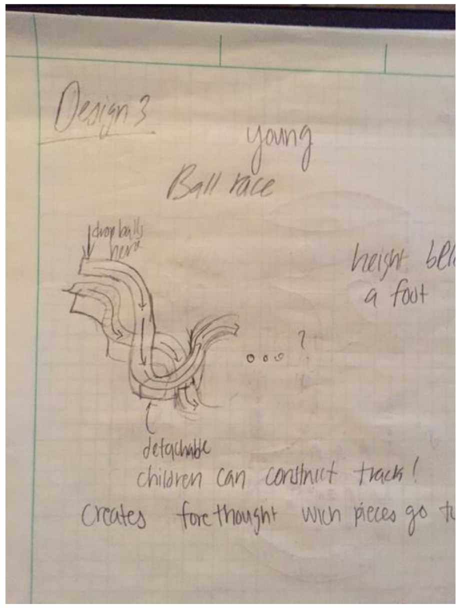


Figure 21: Ball Race

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.

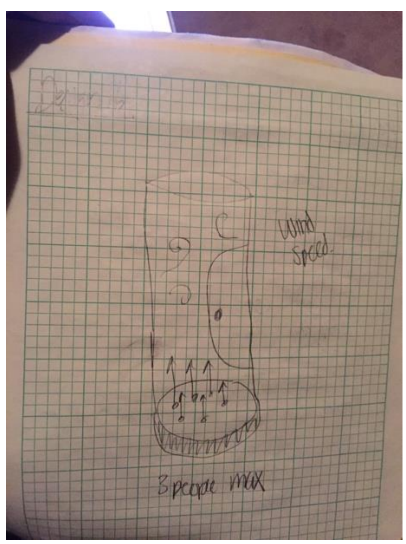


Figure 22: Wind Shoot

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.

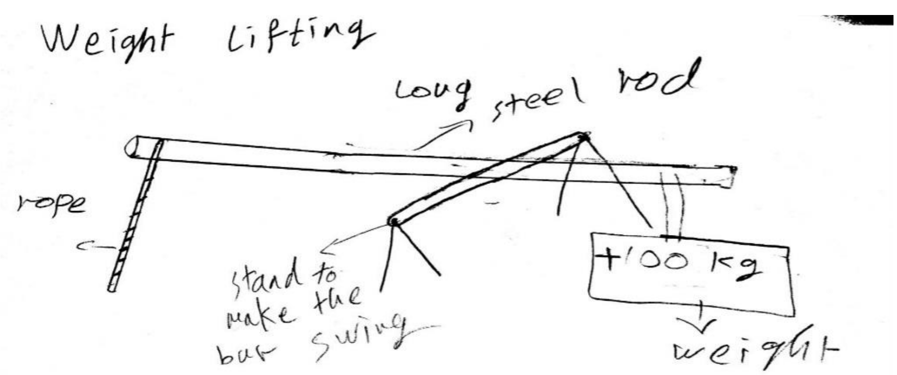


Figure 23: Weight Lift

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.

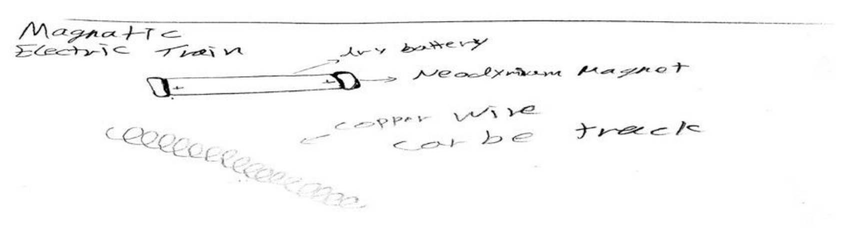


Figure 24: Magnetic Electric Train

5 REDUCED DESIGNS CONSIDERED

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.

5.1 Design #1: 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.

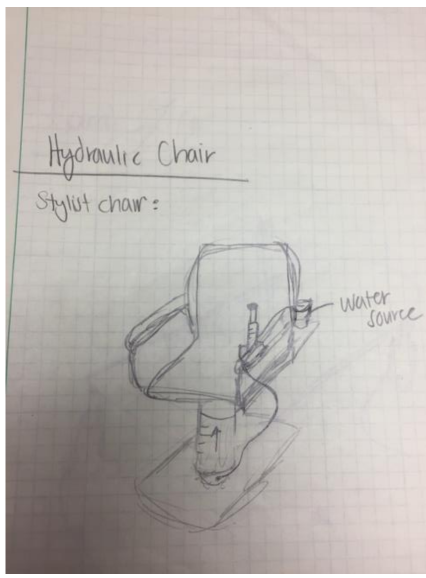


Figure 25: Hydraulic Chair Lift

5.2 Design #2: 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.

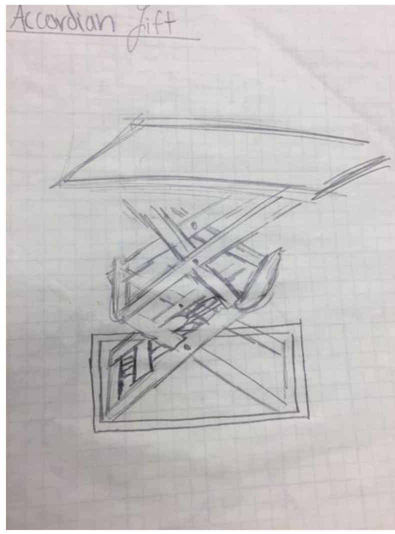


Figure 26: Accordion Lift

5.3 Design #3: 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.

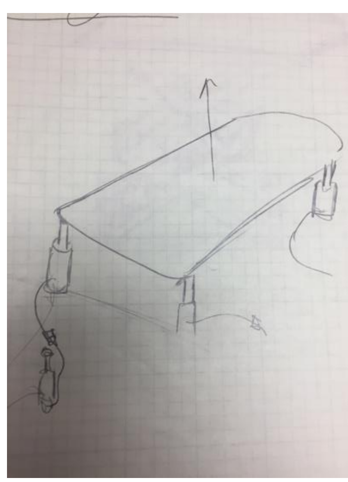


Figure 27: Platform Lift

5.4 Design #4: Hydraulic Arm

This design was used as our datum because it incorporates hydraulics but by moving objects. This design is like a backhoe. It moves an arm to perform a task. This design… [DESCRIBE THE DESIGN ADVANTAGES DISADVANTAGES]

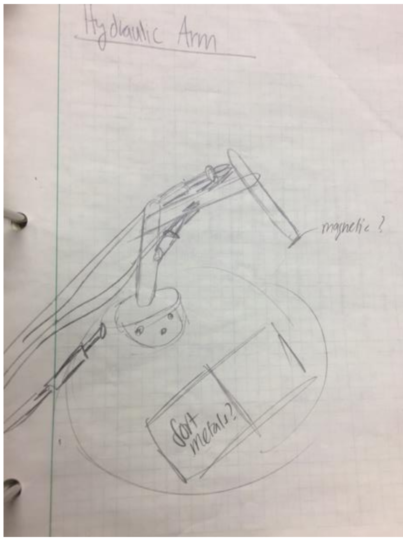


Figure 28: Hydraulic Arm

5.5 Rationale for Design Selection

The design selected from the Pugh chart that is found in Appendix B, was the hydraulic chair. This was chosen based upon the criteria of the customer requirements. The hydraulic chair involves WHAT SECTIONS OF THE CUSTOMER REQUIREMENTS THIS DESIGN fulfils?

6 MODIFIED DESIGNS CONSIDERED

Since we wanted to design a hydraulic chair lift that directly engages the user moving something, we decided to go back and reevaluate the original design. We redesigned multiple subsections of the design to determine which one we could focus on for the duration of the capstone project.

6.1 Modified Design #1: 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.

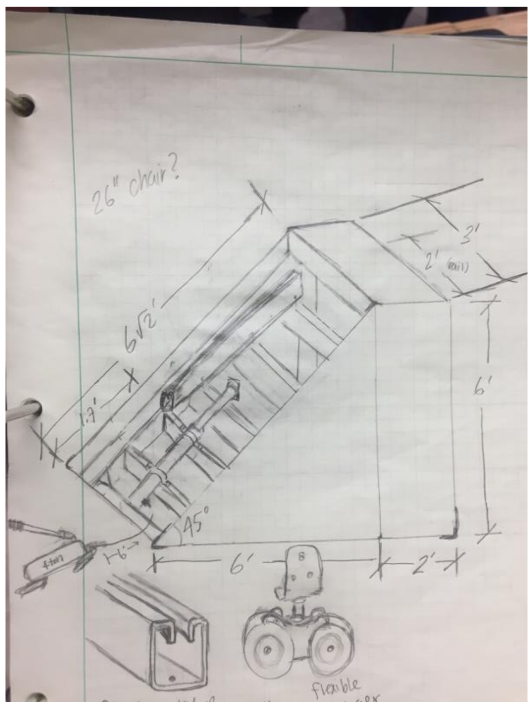


Figure 29: Ramp Lift

6.2 Modified Design #2: 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.

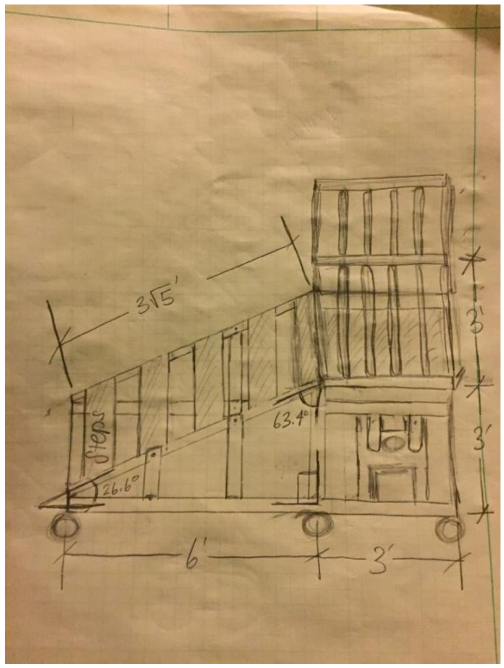


Figure 30: Railing Hydraulic Lift

6.3 Modified Design #2: 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.

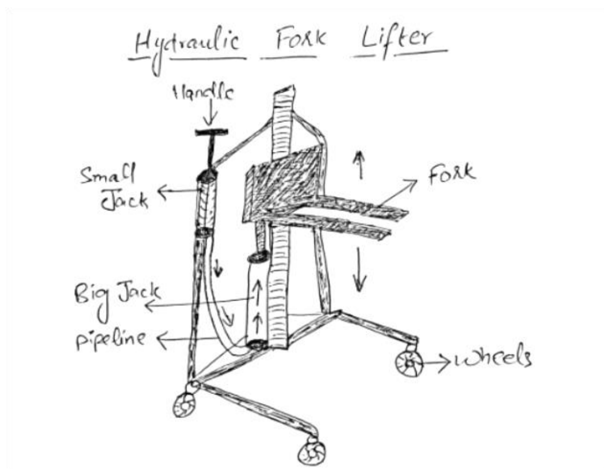


Figure31: Hydraulic Forklift

7 DESIGN SELECTED

7.1 Rationale for Design Selection

The design selected from the Decision Matrix is found below in Table 3. This design is the railing hydraulic lift. This was chosen based upon the criteria of the customer requirements.

The design covers most of the customer requirements such as safety for the users, multiple user functionality, and it covers two STEAM concepts. Customers can ascertain knowledge about how a small amount of water can lift big objects or even their parents using the mechanism of pumping water through tubes.

8 PROPOSED DESIGN

This section will outline what will be implemented in the final design and how we plan to prototype.

8.1 Final Design

For our display, we are using a triangle base with extension box frame which will be the lifting platform as pictured in section 6.1.2. This design is structured this way to have a low tipping point and a low center of gravity. Users will travel up the ramp to either sit in a chair or enter a caged in railing box. 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. All pieces of this design is listed below in a bill of materials.

Table 3.0: Bill of Materials- Final Design

Item #	Description	Cost
1	0.75"X7.5"X42" Lumber (X7)	$13.52 (each)
2	2"X 72" Steel Angle 1/8"thick (X9)	$24.97 (each)
3	2" General-Rubber Swivel Caster w/ Brake (X4)	$5.86 (each)
4	2" General-Rubber Swivel Caster (X2)	$2.55 (each
5	6' X 2" 1/8" thick Steel Flat Plate (X6)	$13.99 (each)
6	Chair	$20.00
7	Everbilt 3/8" X 1" Zinc Hex Bolt (25piece/pack)	$4.21
8	Everbilt 3/8" -16tpi Zinc-plated Hex Nut (25piece/bag)	$2.70
9	4 ton hydraulic hand ram pump (w/ hosing and valve)	DONATED ($141.76)
10	Hydraulic Long Ram Jack (24 3/4"-44 1/16" lift range)	$90.00
11	Cylindrical supports 3" X 0.125"thick 3' long (X2)	$23.81
12	Inner tubes to cylindrical supports (x2)	$20.00
13	36" X 36" X 0.025" Diamon Tread Alum. Sheet Silver	$39.88
14	Everbilt 1-1/2" Zin-Plated Corner Brace (20-pack)	$8.98
Total	$	685.24

The hydraulic hand ram pump as described in the bill of materials was donated to the group. The pump featured in Figure 32 will be connected to a ram coupler which will extend and lift the platform. This hydraulic ram hand pump has a built-in release valve and a 6' hose. As fluid moves through the hose the force will be amplified.

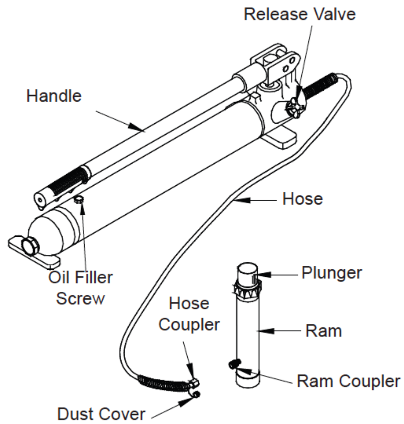


Figure 32: Hydraulic Hand Pump [15]

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. The second piston must have 25X larger area than the first.

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

There are other ways force can be increased. We can either raise the pressure or increase the bore of the cylinder. While force is proportional to pressure, bore size can be greatly influential. This means that if we increase the bore size we can greatly affect the force.

[INSERT ANAYSIS PARTS]

8.2 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.

Table 4.0: Budget

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

8.3 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 the medical field. The chemical and physical properties of polypropylene are for making syringes are as follows [14];

Table 5.0: Material Properties of Polypropylene

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)

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 the 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.

Table 6.0: Bill of Materials- Prototype

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

9 CONCLUSIONS

To conclude our project…..

10 REFERENCES

[1] *The Wonder Factory- ME Project*. 1st ed. Flagstaff: N.p., 2017. Print.

[2] Alston, Jackee. "The Wonder Factory An Engineering And Science Center Making Exibits". 2017. Presentation.

[3] ARIZONA STEM NETWORK BY SCIENCE FOUNDATION ARIZONA ("Arizona STEM Network By Science Foundation Arizona") Arizona STEM Network By Science Foundation Arizona". *Stem.sfaz.org*. N.p., 2017. Web. 15 Feb. 2017.

[4] HOW TELESCOPES WORK ("How Telescopes Work") "How Telescopes Work". *HowStuffWorks*. N.p., 2017. Web. 15 Feb. 2017.

[5] "Home," *Adventure Science Center*. [Online]. Available: http://www.adventuresci.org/. [Accessed: 19-Feb-2017]. "Adventure Science Center photos," *Yelp*. [Online]. Available: https://www.yelp.com/biz_photos/adventure-science-center nashville?select=u4P4uKZcmAgWNaBvOQW4TQ. [Accessed: 19-Feb-2017].

[6] "Catching the Wind," *Museum of Science, Boston*. [Online]. Available: https://www.mos.org/exhibits/catching-the-wind. [Accessed: 25-Feb-2017].

[7] HOW TO MAKE A DRONE / UAV – LESSON 3: PROPULSION - ROBOTSHOP BLOG ("How To Make A Drone / UAV – Lesson 3: Propulsion - Robotshop Blog") "How To Make A Drone / UAV – Lesson 3: Propulsion - Robotshop Blog". *RobotShop Blog*. N.p., 2017. Web. 15 Feb. 2017.

[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.

[9] "Judith Payne Turner Theatre".*Sudekum Planutarium*. Online. Available at: http://www.adventuresci.org/

[10] "Home," *Adventure Science Center*. [Online]. Available: http://www.adventuresci.org/. [Accessed: 19-Feb-2017].

[11] "MUSEUM AFTER DARK | HARRY POTTER". *Amazement Square*. Online. Available at: http://www.amazementsquare.org/

[12] P. Advertising, "Children's Museum Lynchburg VA | Kids Party Planning & Corporate Event

Rental, Summer Camp Activities For Kids, Academic Programs & Annual Museum Events in Lynchburg, Virginia (VA),” *Amazement Square*. [Online]. Available: http://www.amazementsquare.org/. [Accessed: 19-Feb-2017].

[13] “Ace -,” *Ace* -. [Online]. Available: http://www.flysnf.org/ace/. [Accessed: 19-Feb-2017].

[14] What is Polypropylene (PP). Creative Mechanisms. Online. Retrieved from: https://www.creativemechanisms.com/blog/all-about-polypropylene-pp-plastic

[15] “Porto-Power B65114 Operating Instructions And Parts Manual: Product Description; Specifications,” *Manuals Library*. [Online]. Available: https://www.manualslib.com/manual/17621/Porto-Power-Porto-Power-B65114.html?page=3#manual. [Accessed: 15-Apr-2017].

[16] W. Durfee, Z. Sun, and J. de Ven, *Fluid Power System Dynamics*, 1st ed., vol. 1. Minneapolis, Minnesota: University of Minnesota, 2015.

APPENDICES

APPENDIX A: House of Quality & Email Proof

Table 6: House of Quality

Customer Requirement	Weight (Rank)	Engineering Requirement	Moment of inertia (low center of gravity)	Corners must have a raidus of curvature (2-1/2 Corner Radius)	Weigh less than 75lb	High yield strength of materials greater than 150MPa	Strength to weight ratio	Life cycle must exceed 100 operation hours	# of audience paying attention to display	Cannot exceed 10 assembly step	Minimal level of comprehension for user	Easy repair components	Cannot generate heat that exceeds room temperature	Wiring/tubing of any kind must be placed in an orderly manor	Must have 2 or more STEAM concepts	no operation mishap (100% success rate)	no more than 3 inputs at a time	No more than 5 steps to operate	Skill level: Novice to operate	# of excited facial features needs to be 4 or more	Cannot exceed more than 3 people to set up	Assembly time <2hrs
1. Safe	5		9	9	3	9	3	1	0	1	0	1	9	3	0	9	1	1	0	0	1	0
2. Simple instruction	5		0	0	0	0	0	0	1	9	9	3	0	0	3	0	1	9	9	0	9	3
3. Hands-on	5		0	0	0	0	0	1	0	1	1	1	0	0	0	1	9	3	1	0	9	1
4. Wow factor	5		0	0	0	0	0	0	9	0	0	0	0	0	1	0	1	1	0	9	0	0
5. Simple to assemble	4		0	0	1	0	0	0	0	9	0	9	0	3	0	9	0	1	1	0	9	9
6. Integration of mult. STEAM concepts	4		0	0	0	0	0	0	1	0	1	0	0	0	9	0	0	1	0	0	0	0
7. Narrative	4		0	0	0	0	0	0	3	0	3	0	0	0	3	0	1	0	0	1	0	0
8. Visual appearance	4		1	3	3	9	1	0	9	0	0	1	0	9	0	0	1	0	0	3	0	0
9. Relatable	4		0	0	0	0	0	0	9	0	9	1	0	0	1	0	0	0	9	0	0	0
10. Durable	4		9	3	1	9	9	9	0	1	0	9	3	0	0	9	0	1	0	0	0	0
11. Educational	4		0	0	0	0	0	0	9	0	9	0	0	0	9	0	1	0	3	9	0	0
12. Mobile	3		3	1	9	1	9	0	0	3	0	1	0	9	0	0	1	0	0	0	3	3
13. Multiple visitor	3		0	0	0	0	0	9	3	0	1	0	0	0	1	0	9	0	0	3	0	0
Absolute Technical Importance (ATI)			94	60	62	120	82	73	183	104	141	108	57	90	111	122	102	82	102	106	140	65
Relative Technical Importance (RTI)			12	19	18	5	14	16	1	9	2	7	20	13	6	4	10	15	11	8	3	17
Target(s), with Tolerance(s)																						
[add or remove T/T rows, as necessary]																						
Testing Procedure (TP#)																						
Design Link (DL#)																						

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

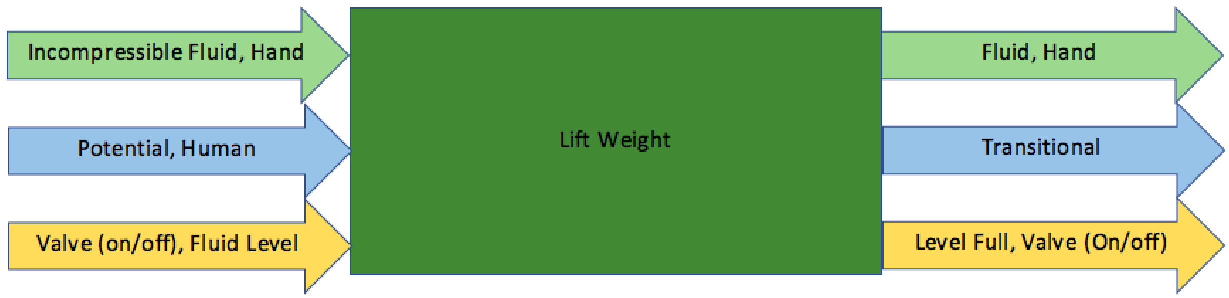
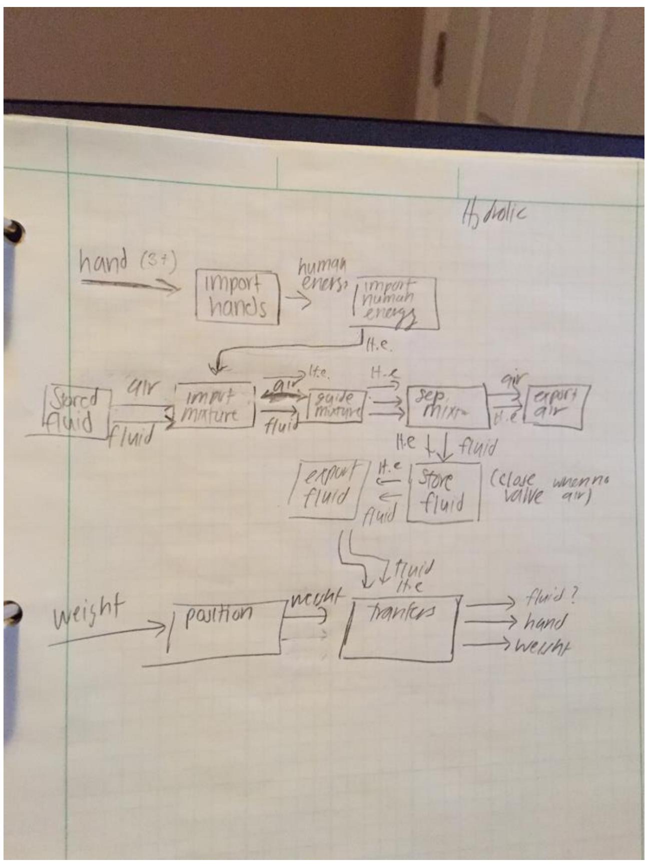


Figure 25: Functional Model –Hydraulic Lift (THIS WILL BE CHANGED)



Appendix C: Decision Matrix

(INSERT DECISION MATRIX)