The Sound Garden

The Engineers That Could

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1 Problem Formulation

1.1 Introduction

The purpose of the Problem Formulation section of this document is to provide background for and state the objectives of the project.

1.2 Background

The project was presented to The Engineers That Could by the Redwood Discovery Museum in Eureka, CA. The Redwood Discovery Museum is a nonprofit museum that aims to educate children ages 3-12 in the fields of science, art, and culture, and to encourage exploration into these fields. The museum uses exhibits with hands on interaction and puzzle-solving elements to foster kinesthetic, digital screen-free learning. The client requested a new exhibit that would demonstrate to kids the relationships between sound and physics.

The Engineers That Could is a diverse team of capable individuals aiming to blend their experiences, skills, and passions to think of effective, long lasting solutions to client challenges. The team intends to utilize their musical knowledge along with the skills they have acquired in their engineering courses to develop a safe, fun, and interactive way to learn about the nature of sound.

1.3 Objective

The Engineers That Could will provide a new educational tool for the Redwood Discovery Museum to instill in the user an understanding of the physics of sound in an appealing and entertaining fashion. The team will build an exhibit that incorporates musical elements to demonstrate the physical relationships of sound. The project will be made in part from repurposed or upcycled materials to maintain sustainability and minimize environmental impact. The exhibit will serve as a fun and hands on way for museum patrons of all ages to interact with sound instead of learn from a tablet or computer screen. Figure 1-1 shows a Black Box objective model for the project:

Figure 1-1: Black Box model displaying desired results of the project.

2 Problem Analysis and Literature Review

2.1 Introduction

The problem analysis will address the project specifications, criteria, and production volume requested by the client. It will also address design considerations determined by the team. The Literature Review is a compendium of research gathered by the team to and make the necessary considerations for the design problem.

2.2 Problem Analysis

2.2.1 Specifications

Specifications include any parameters that must be met to successfully complete the project. The project may be no bigger than 8 feet by 10 feet, it may not have a sound output of more than 138 decibels (see Loudness, pg. 5), and it must be able to play at least one octave of musical notes (see Notes, pg. 6).

- Size
- Range of Sound
- Sound Output

2.2.2 Considerations

Considerations for this exhibit will include the size, age, and motor skills of the user.

2.2.3 Criteria:

The criteria and their constraints requested by the client and developed by The Engineers That Could are shown below. Table 2-1 shows criteria weighted by their relative importance to the client and the designers.

Table 2-1: Table of project criteria.

Criterion	Constraints	Weight (1-10)
Strength	Must be able to withstand daily use by children and transportation.	10
Safety	Unsupervised children must be able to play with the exhibit without risk of injury.	10
Mobility	The display should fit through a standard door and be easily transported by two people.	8
Cost	The project should cost no more than $500.00.	6
Material Source	The project should utilize some repurposed materials in its construction.	7
Replicability	The project should be replicable by two people in a weekend, given they have the required materials.	7

2.2.4 Usage:

The project will be designed to be used daily by users of all age groups and sizes. The project should be usable both indoors and outdoors.

2.2.5 Production volume:

One model is requested by the client for display and interactive purposes.

2.3 Literature Review

2.3.1 Child Motor Skill Development

In Volume 21, Issue 7 of the Maternal and Child Health Journal, a study was conducted to observe and describe the development of motor skills in children between the ages of 3-5. Motor development is important in children because it will affect their ability to function in a coordinated fashion as they grow older. The method of this study was to directly assess the motor development of children rather than have parents fill out forms to describe their children's behavior. The study considered several factors including: age, gender, socio-economic status, and ethnic background. The results showed that girls tend to have more developed motor skills compared to boys their age. Development did not differ much between children of different demographics. According to the study, up to 10% of the children between the ages of 3-5 may display poor or slow motor development. This is important to the design project because the client could possibly improve the motor development of children through hands on interaction-focused exhibits. The client specified that they would did not want any digital screens or electronic platforms in the project design because the goal of the museum is to teach math, science, art and culture with physical interaction with the concepts being taught. The project revolves around the concepts of sound and playing music; therefore, it should be able to provide motor stimuli for children.

The advantage of knowing this information from the Maternal and Child Health Journal provides insight on how hands-on the project should be, and what needs to be kept in mind when prototyping.

The disadvantage of this is that it provides information on children between the ages of 3-5 while the target age group is 2-12. While the general idea is that motor development improves with age, it is important to learn what specific skills they attain at certain ages.

2.3.2 Connecting Children with the Environment

Connection with the environment increases the awareness of how one's life impacts the world they live in. This can be done by exposing oneself to the problems that modern society perpetuates such as pollution, erosion, and depletion of natural resources. It is easy for a child to grow up never having walked in a forest, or a swarm in a river, and to overlook the subtle detrimental changes occurring every day. Outdoor education programs like "Waldkindergarten" remove the walls from the classroom and get students in tune with nature. The class meets outside five days a week, taking kids into the forest to learn about the world around them, rather than teaching it from inside a classroom. When compared to traditional classrooms, kids attending the outdoor programs performed just as well as conventional peers on fine motor skills, and significantly better on tests of gross motor skills and creativity (Mills, 2009). These teaching settings are becoming popular in Europe, and are spreading into the United States. Learning from the outdoors, not only provides new ways to learn old concepts being taught in traditional schools; it allows for kids to naturally develop the skills they need to survive in the outside world. Kids can learn about math, colors, seasons, and anything else they would learn in traditional schooling, while simultaneously learning about how to be prepared in the outdoors, learning judgement skills when crossing streams or climbing rocks, and increased self-esteem, when they learn to trust their own judgement. It teaches kids to process information from their surroundings, analyze their data, and produce a solution based off what they think is best, rather than simply being taught to memorize, and practice what they are taught. By exposing kids to more elements of the outside world, and the realities we face as a civilization, such as pollution, and the need to recycle, they can begin thinking about the kinds of solutions they will need be finding as they grow up. This allows for future solutions to come from inside the community, rather than people having to look outward for answers to problems. The improvement of existing technologies and the process of raising awareness involves the community from the very beginning (British Columbia Environment & Development Working Group and I.D.E.R.A., 1992). Teaching classes inside provides little to classes when compared to the limitless sources of stimuli that the outdoors offer. By using materials that kids can find around their local neighborhood, rather than buying a store made instrument, they will be taught to look first to their surroundings to solve a problem rather than going to the store to find it.

2.3.3 The Science of Sound

2.3.3.1 What is sound?

In Sir James Jeans' book Science & Music, sound is defined as the sensation felt by the stimulation of the mechanisms of the ear. The word sound can apply to the sensation itself or the external causes of the sensation. A musical sound is described as one that is smooth, pleasant, regular, and possesses a definite pitch; while a nonmusical sound is the opposite. A non-musical sound is unpleasant, irregular, and does not have a definite pitch. Sounds are produced by systems in vibration. Some examples of these systems are strings (violins, pianos), air (organs, flutes), rods (tuning forks), or bars (xylophones).

2.3.3.2 Waves and Sound

Sound travels as waves. In Science & Music, a wave is described as a disturbance traveling through a medium, transporting energy from one location in the medium to another. The medium is the material through which the wave is transmitted, i.e. water or air. Waves have several distinct qualities: wavelength, frequency, period and amplitude. These qualities influence the characteristics of a sound.

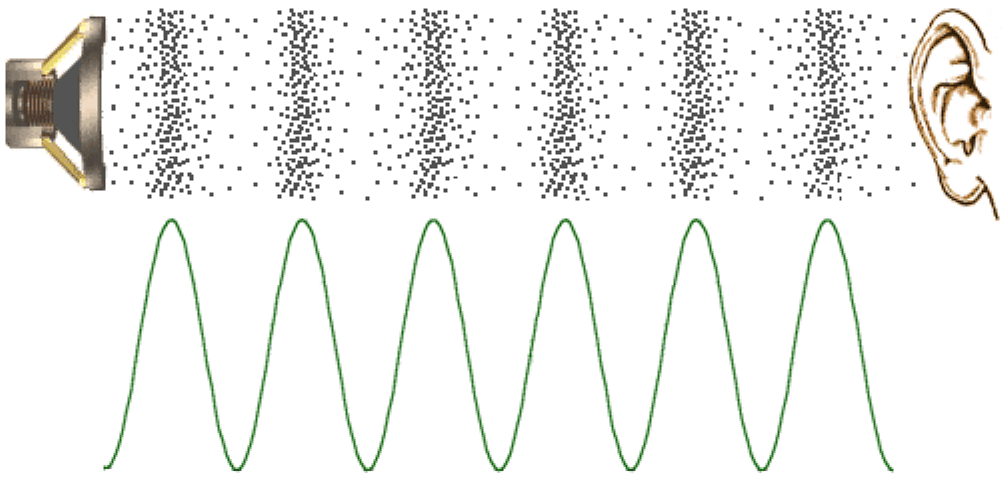

Figure 2-1: A diagram displaying sound as a wave. URL: https://goo.gl/TezYML

2.3.3.2.1 Wavelength

The distance between two high or two low points on a wave is known as wavelength. These high and low points are known as crests and troughs, respectively. Wavelength is often measured in meters (m) or nanometers (nm). The wavelength of a wave is related to the amount of energy transmitted by the wave (see Amplitude, pg. 5) and the frequency of the wave as discussed below.

2.3.3.2.2 Frequency

The frequency of a wave is the number of complete vibrational cycles of a wave in a certain amount of time. Frequency is often measured in Hertz (Hz) where one Hz is equal to one cycle per second. The greater the frequency of a wave, the shorter the wavelength. Figure 2-1 shows the difference between high and low frequency waves and their associated wavelengths.

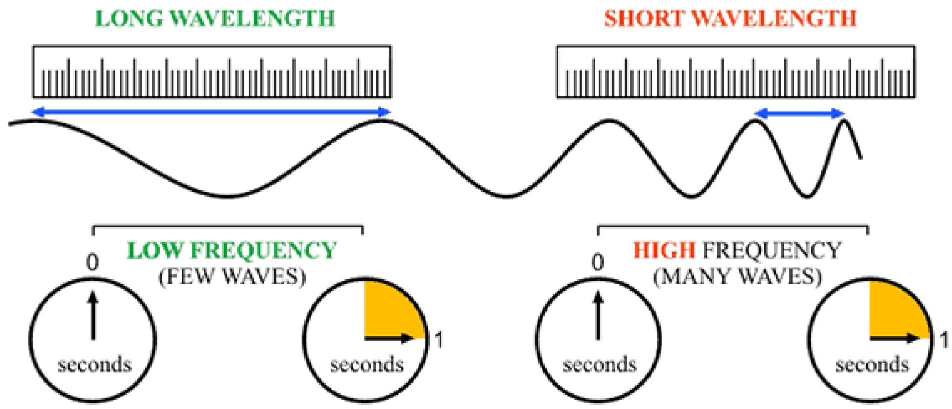

Figure 2-2: High vs. low frequency waves with wavelengths shown. URL: https://goo.gl/qWknB9

2.3.3.2.3 Period

The period of a wave describes the time it takes for a wave to complete one vibrational cycle. Period is often measured in seconds per cycle, while frequency is measured in cycles per second. This means that frequencies and periods of waves are inversely related.

2.3.3.2.4 Amplitude

The amount of energy transmitted by a wave is related to the amplitude of the wave. Amplitude is a measure of the amount of displacement experienced by a point in the medium at its resting position as a result of the wave. The distance between a high or a low point on a wave and the resting position is the amplitude of the wave. Amplitude is demonstrated in Figure

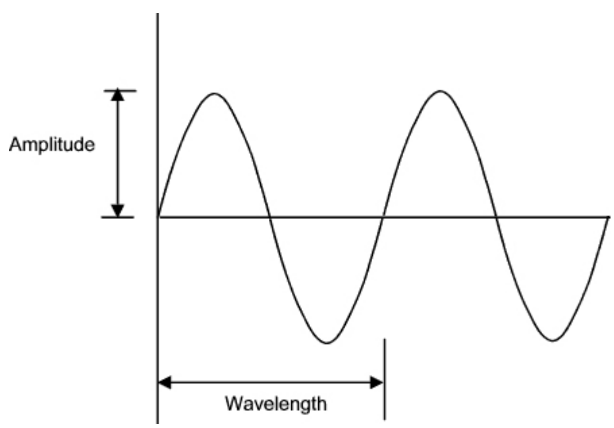

Figure 2-2: Amplitude of a wave. URL: https://goo.gl/iJhLLq

2.3.3.3 Characteristics of Sound

The way sound waves are perceived depends on a few qualities of the waves that produce them. Two characteristics of sound that result from these wave qualities are loudness and pitch.

2.3.3.3.1 Pitch

The pitch of a sound describes how high or low the sound is. Pitch is determined by the frequency of the soundwaves. High frequency sound waves result in high-pitched sounds; while low frequency sound waves make low-pitched sounds. Pitch, like frequency, is measured in Hz. The musical note that a sound produces is dependent on the pitch of the sound. See Figure 2-4.

2.3.3.3.2 Loudness

The measure of the intensity of a sound is its loudness. The loudness of a sound is determined by the amplitude of the sound wave that creates the sound. Waves with larger amplitudes generate louder sounds and transmit more energy. Loudness is measured in decibels (dB). See Figure 2-4.

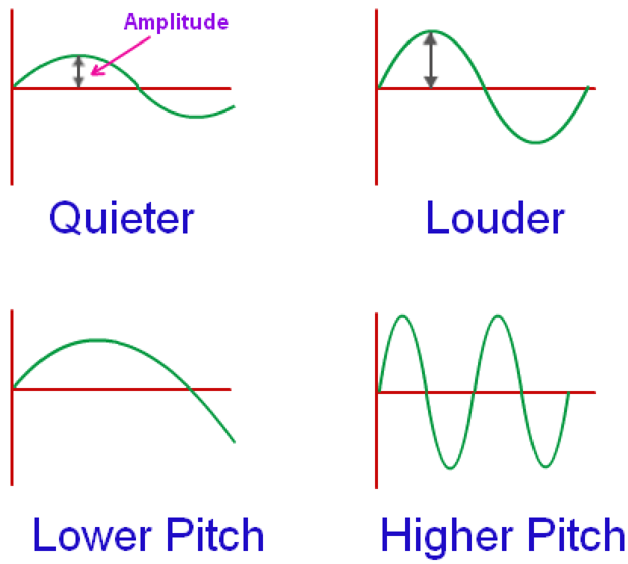

Figure 2-3: Pitch and volume related to wave frequency and amplitude. URL:https://goo.gl/uVpT4K

2.3.4 Sound Safety

In the International Journal of Pediatric Otorhinolaryngology, Volume 21 Issue 2, a study of noise levels in commercial toys was conducted by Dr. Kathleen Yaremchuk, an otorhinolaryngologist (ear, nose and throat specialist) at the Henry Ford Hospital in Detroit, Michigan. It is noted that hearing loss among adults is common. This loss might start in early childhood with toys that are not following regulations or long exposure to noise. According to the journal article, toys “producing impulsive sound levels under 138 dB at 25 cm from the surface of the toy are allowable on the market without restrictions”. Many toy companies use this lax regulation to maximize sound output of toys they make. The detrimental effect of noise pollution on hearing is also addressed in the article, the term “sociocusis” is defined as “noise-induced hearing loss as a result of non-occupational noise exposure,”. The author uses this term to show and explain that industrial noise exposure is not the only reason for hearing loss. Prolonged ambient noise exposure also affects people’s hearing, but because noise pollution a part of everyday life, i.e. roadway noise, people think that their hearing won’t be affected. A lot of the issues that come with hearing loss happen over the span of many years, so it is important to pay attention to what kind of cumulative damage high noise levels can cause for people, especially children. In the article, it is also mentioned that because most children are not able to read warning labels on toys, it is crucial that parents ensure the toys are sound safe for them. With the design project in mind, it is important to know the recommended decibel levels that can children can be exposed to. With developing children being our target audience, it is crucial that the project be safe for them to interact with.

An advantage of reading this study is that it gives a better understanding of the limits and sounds levels that are better suited for children. It also brings to attention the correlation between ambient noise and its exposure over time.

What we can learn from this study is that children often cannot read or understand safety labels, so it is up to the parents to determine if something is safe for their child or not. When designing the project this is important because it will be considered for how loud the exhibit can be.

2.3.5 Music

Music is defined as being sound that is organized with rhythm, melody, or harmony. Knocking pots and pans together in a rhythmic fashion is considered music, while knocking pots and pans together while cooking is considered noise.

2.3.5.1 Rhythm

In music, rhythm is the pattern with which regular or irregular increments of sound are produced. It describes how music moves through time.

2.3.5.2 Melody

A melody is a succession of musical sounds, or notes, that the listener perceives as a single entity. Melodies are also called tunes or lines.

2.3.5.2.1 Notes

In western music, the pitch and duration of a sound is known as a note. Notes are the building blocks of both written and non-written music. In traditional western music, there are 12 notes, characterized by the letters of the alphabet A through G. Notes are organized into scales. These scales contain notes that differ in pitch at intervals that are perceived as regular and pleasant by the human ear. These intervals are known as steps.

2.3.5.2.1.1 Western Scales

Conventionally, the 12 notes of the western musical scale are divided into two sub-scales, the chromatic scale and the diatonic scale. A chromatic scale contains every one of the 12 notes in between A and G, while a diatonic scale only contains 7 of the 12 notes with specific intervals in between them. Each note A through G has its own distinct set of scales. The starting note of a scale is known as the tonic, and the succeeding notes are named by their position relative to the tonic. The tonic determines the scale that is played. For example, if the starting note of the scale is a C note, then the resulting scale is the C scale. When all the notes of a certain scale are played from the tonic to the last note of the sequence, another tonic note is reached at a different pitch than the starting tonic note. The difference in pitch between one tonic and another is known as an octave. A scale could be ascending, in which the pitch of each note in the scale increases with each step, or descending, which moves lower in pitch.

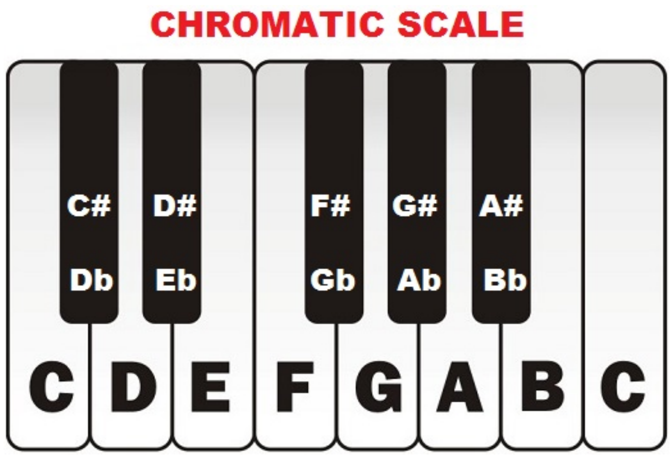

Figure 2-4: One octave of the chromatic C scale represented on a piano keyboard. The two C notes at either end are the tonic notes.URL: https://goo.gl/NWnDxC

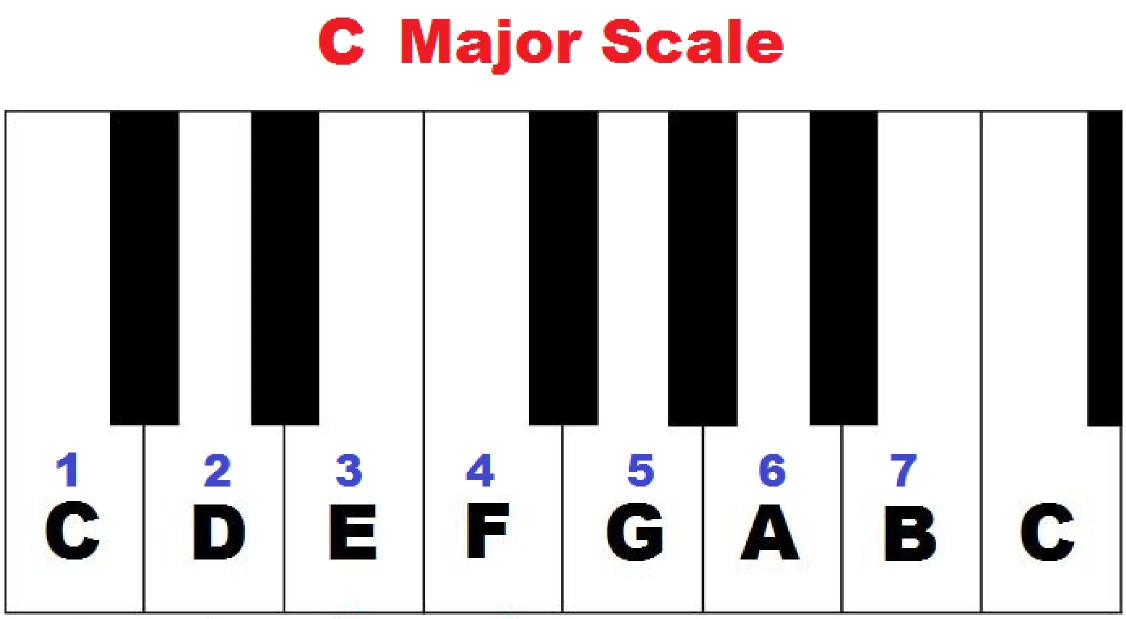

Figure 2-5: One octave in a form of diatonic C scale. URL: https://goo.gl/STpTXr

2.3.5.3 Harmony

The dictionary definition of harmony is an agreement or a concord. In music, harmony describes simultaneous musical sounds that coincide with each other to produce a pleasant effect for the listener.

2.3.6 Music and Children

In her book *Music Therapy with Children and Their Families*, Amelia Oldfield recalls how she realized that including parents in her Music Therapy sessions for children is very beneficial. This idea came to her when a young boy refused to go to his Music therapy sessions without his mother. Having the mother there and participating helped the boy to engage in learning music and rhythm in these sessions. *Music Therapy with Children and Their Families* talks about how music therapy engages the whole family, and provides an environment for effective learning. In the chapter, "Working in Partnership and Supporting Parents: Music Therapy for Pre-school Children and their Parents at a Child Development Centre," Oldfield discusses her experiences with toddlers in her therapy sessions. She goes into detail about the backgrounds of the toddlers and the effect music therapy had on them. After several weeks of therapy, the responses she got from the parents showed that the children were showing much more positive behavior at home. For example, Oldfield states that a toddler named Nick was more communicative and was able to focus longer in a single activity by the end of the music therapy curriculum This book is insightful on first hand experiences with Music therapy with toddlers and parents. It conveys the idea that it is advantageous for children to be exposed to music at an early age.

2.3.7 Xylophones

The xylophone is a percussion instrument that was developed by ancient cultures. It began simply as striking different sized logs laid across one's lap (England). The difference in size of the logs is what changes the pitch of the sound produced by striking the logs. Today, xylophones typically consist of a series of thin metal bars of varying lengths laid out like a piano keyboard. These bars are struck with a mallet that can be covered with different heads. The keys are held in a frame that can be supported on a stand or played on the lap. Xylophones can be made of any materials, although they are typically made of rosewood or made with metal keys. The material of the keys, their length, density, width, and tension will affect the way that it sounds. Xylophones can be tuned to a variety of different musical scales. Some examples of xylophones are shown in Figures 2-4 and 2-5.

Figure 2-6: A children's toy xylophone. URL: https://goo.gl/dzucDi

Figure 2-7: A musician's xylophone. URL: https://goo.gl/KdMNxS

2.3.8 Product Desirability

Desirability is what pushes all goods and products to become successful and popular in society. One of the main things slowly fading away today are physical toys for kids. Nowadays, a tablet can be used as a toy, putting games onto a screen where a child could simply click to accomplish a goal or solve a puzzle, compared to something requiring more physical, hands on problem solving. Fads and trends run rampant in modern society, goods get introduced, things come into style and things go out of style. Fads become very popular quickly and remain popular for usually short amounts of time. All goods that become very desirable to consumers are usually accepted by consumers very quickly since large amounts of the population own the same thing, but consumers often tend to get bored of the product over time using it less creating fads.

Musical instruments are declining in popularity due to more kids wanting tablets or video games since it looks more interesting to them. The xylophone has a main purpose of getting young kids to work with more hands-on objects like the instrument itself compared to playing on a screen. It can be made desirable for young kids by adding all types of colors, different structural designs, and simply the sound it makes when struck. The xylophone is a fun and interactive way for kids to better understand sound and see how it works giving them a great instrument to learn and play. Children love digital entertainment and born straight into the developing world of technology seeing screens all around them either on TV or at a friend's. It is the idea that "everyone has one" forcing someone to want a certain good, like a tablet. An important fact to realize is that a tablet is only designed to go as far as the programmer created it to be compared to a physical toy or instrument where the possibilities are endless when working with it. The xylophone with young developing children creates endless possibilities for the child and can be very beneficial to their growth both physically and mentally.

2.3.9 Upcycling

Upcycling can be thought of as a way to use a waste item for another purpose, and helps divert the problem of waste itself. On many beaches, one can see plastic and other waste washed up shore. “The world’s fleet of merchant vessels dumps at least 450,000 plastic containers, as well as 4,800,000 metal and 300,000 glass containers into the sea everyday” (Center for Environmental Education, 1988). This not only shows the magnitude of the problem, but that it has been an ongoing one. These containers can be recycled to be used again as consumer packaging. The consumer can also choose to upcycle that container, using it for another purpose, such as a gardening container, a pen holder, or a cup. Industry is not the only source of this pollution. “Researchers have noted that beaches cleaned on a regular basis are often more popular than those which are not, even though they may be highly polluted areas … Others have noted that once an area appears visibly polluted by debris, people are more likely to leave their own trash behind” (Center for Environmental Education, 1988).

This problem opens a wide opportunity for solutions, more cleanup efforts could be made, or people could be fined for littering, and people could even stop using disposable packaging for their products. Upcycling can dispose of the “waste” produced by some consumer goods, and inspire others to think of creative, and effective solutions to what they need. It is also an avenue for discussion about environmental concerns with waste, and alternative problem solving. “The advantage of recycling is that it leads to less stuff: less waste in disposal, or less virgin material use in production” (Ackerman, 1997). It is easy to show a kid the impacts of human development by taking them to a polluted beach. It is not as easy for them to understand the impacts of plastic production, or metal mining.

Upcycling will significantly reduce the costs as well as the environmental impact of this project. The project can be used to introduce upcycling to children at a young age. This in turn could lead children to questioning their parents about their own practices at home. Exposing children to upcycling could inspire them to become resourceful, and proactive in problem solving. It will also give them another point of view when looking at solving a problem.

Sourcing used materials for upcycling can be time consuming, and the quality of the materials must be considered. However, the client specified that they already had a supply of PVC tubing, and a source of cheap used materials that could be used for the project.

3 Search for Alternative Solutions

3.1 Introduction

Section 3 outlines alternative solutions for the xylophone project. In addition, this section contains the brainstorming sessions that led to the formulation of these alternatives. The alternatives shown in this section comply with the specifications, constraints, and criteria discussed in the Section 2 problem analysis.

3.2 Brainstorming

The Engineers That Could carried out three brainstorming sessions during the brainstorming process. The first of these sessions was an unstructured idea formulation session, where ideas flowed freely and without restriction. The second session involved brainstorming on the list of solutions, to narrow them down to the seven most practical alternatives. These final alternatives were then analyzed for their individual benefits and drawbacks in the third session

3.3 Alternative Solutions

3.3.1 Hydrophone

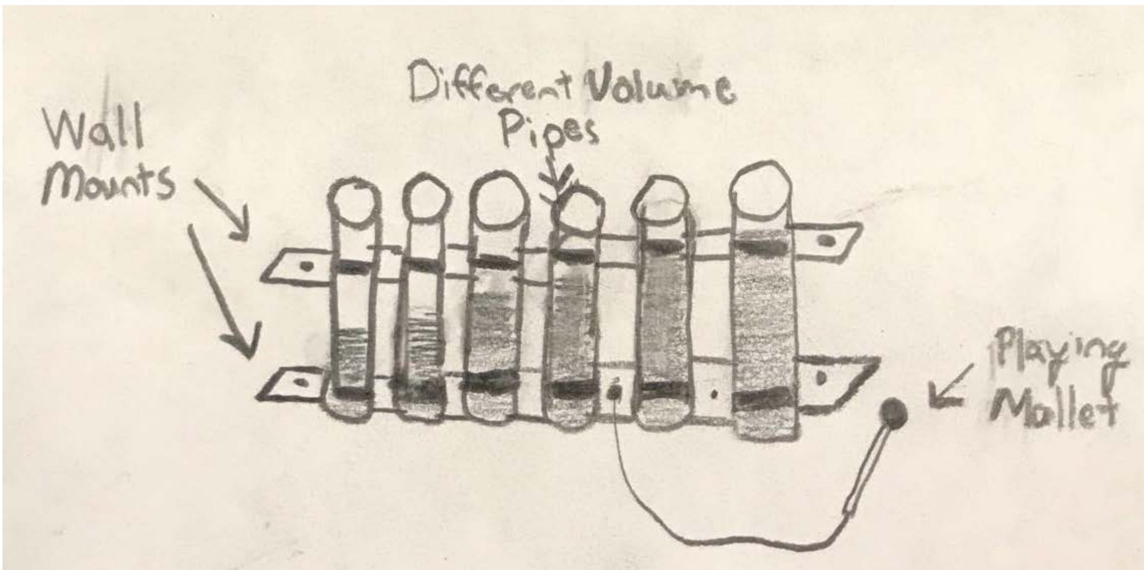

Figure 3-1: The Hydrophone

The Hydrophone shown in Figure 3-1, will utilize water to vary volume, without changing pipe length. The design implements see through tubing, so that the user could clearly see the variation in volume due to water. The Hydrophone uses a standard pipe length for each of the notes, which minimizes the cutting required. The potential for spills, as well as property of water to evaporate will require extra care and maintenance.

3.3.2 Diametriphone

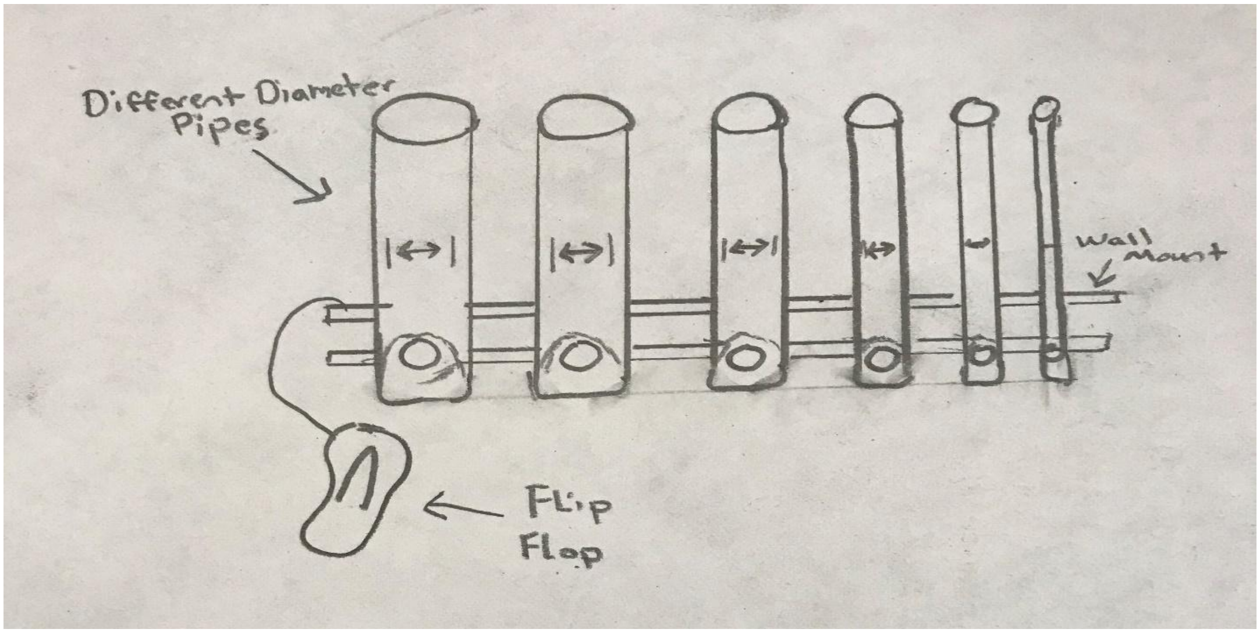

Figure 3-2: The Diametriphone

The Diametriphone shown in Figure 3-2, is an alternative solution that will have circular pipes which increasingly grow in diameter. The solution will allow users to see different pitches of sound correlate with the different diameter of pipes. It is harder to notice how the subtle changes in pipe diameter, effect volume, which will drastically alter sound. This solution is ideal for a location where there are height restrictions.

3.3.3 Heterophone

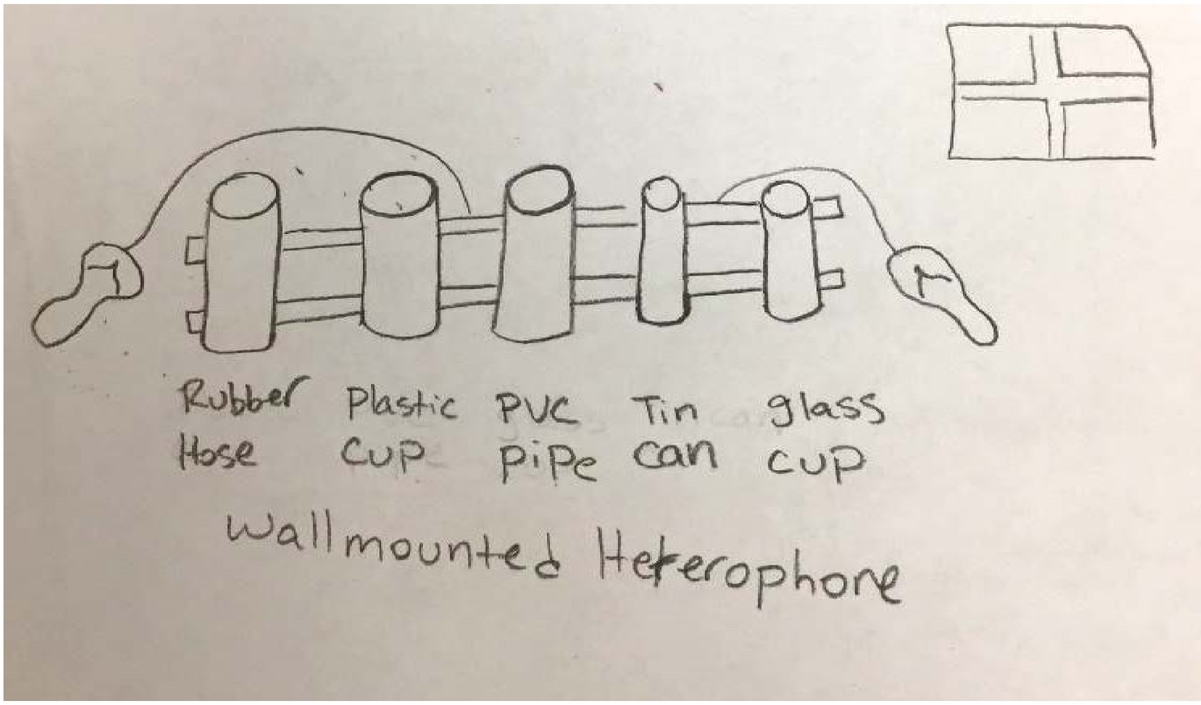

Figure 3-3: The Heterophone

The Heterophone shown in Figure 3-3, will display how the density of a material will influence its sound. Each note's material has a different density, which will change the pitch of the note. Each note will contain approximately the same volume of air, and a variation in material density will impact the sound. The Heterophone will help connect the user to how an instrument's material properties influence its sound quality. The user will not only be able to hear the difference in the sound produced by the Heterophone, but they will also be able to feel the difference in the materials used for each key. The Heterophone will utilize items one could find around the house, additionally connecting the user to the display, and demonstrating how one can repurpose everyday materials to make music.

3.3.4 Sound Garden

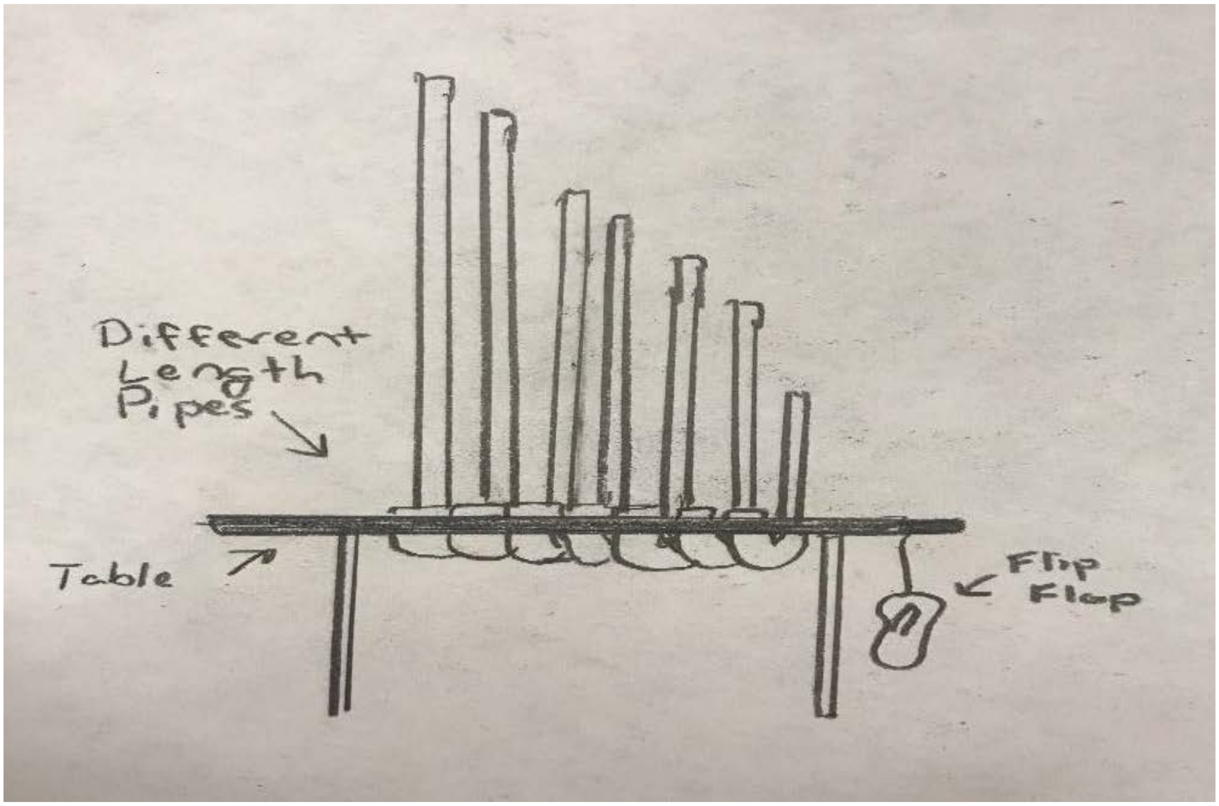

Figure 3-4 The Sound Garden

The Sound Garden shown in Figure 3-4, consist of the same density and diameter tubes. The variable in this design will be the length of the pipes. The tubes will be mounted vertically, allowing the column of air and sound to travel upward out of the top of the tube. The user will play the instrument by striking the bottom of the tube with a repurposed rubber spatula. The Sound Garden can be wall mounted, table mounted, or encased in a frame. Additionally, the mounted could be given wheels for mobility. Variances in pipe length will allow for a range of different notes to be played, visually demonstrating the effect of wavelength on sound.

3.3.5 Vibra-tune

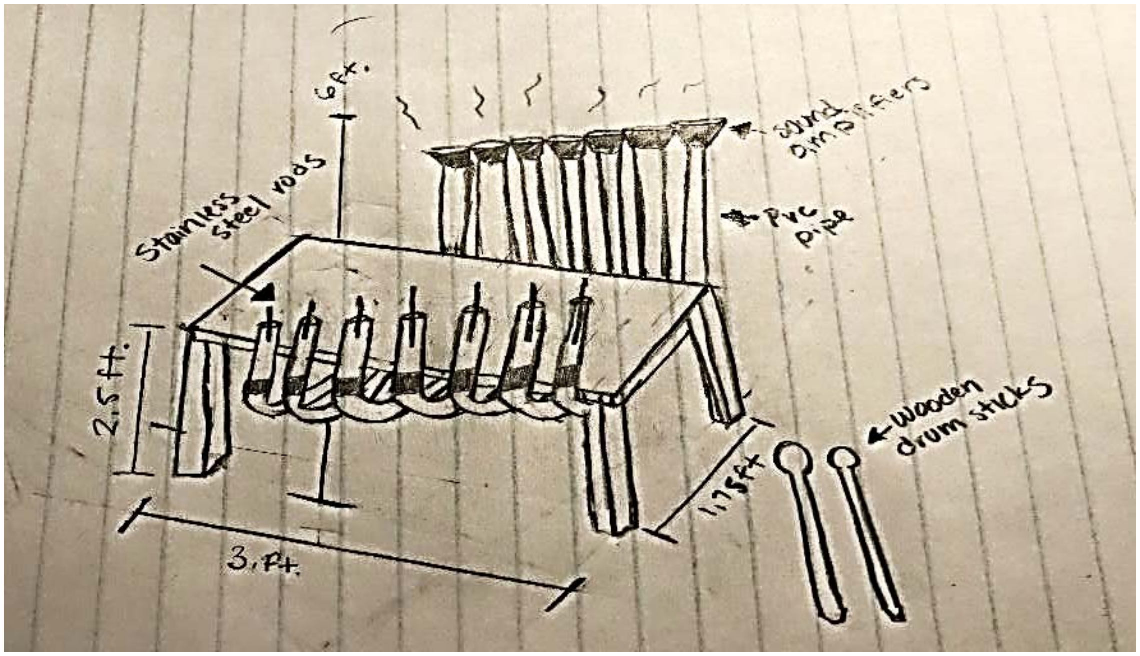

Figure 3-5: The Vibra-tune

The Vibra-tune shown in Figure 3-5, is a musical instrument is for all ages, and is simple to use. The Vibra-tune is made from PVC pipe and sits on a table that is 2.5 ft. tall, 3ft long, and 1.75 ft. wide. The PVC pipe starts at the front by the user. It goes under the table, comes out the back of and goes straight up behind the table. The pipes extend up to 6ft off the ground. The end of the pipes where the sound is going to come out of are capped off with bowl shaped plastic sound amplifiers. This will allow to the user to be able to hear the sound that it emits without having to hit the instrument forcefully. Another component of the musical instrument is that stainless steel rods that come out the pipes on the front end. The rods are going to be about 12 inches long. 8 inches are going inside the PVC pipe and 4 inches will be sticking out. The rods will be suspended in the middle of the pipe hole so that when it is being hit, the rods will vibrate, and that vibration will go follow the PVC pipe to the end making the desired note. The Vibra-tune is a great visual to learn how music works and is tall enough for the target audience to play with.

3.3.6 Underphone

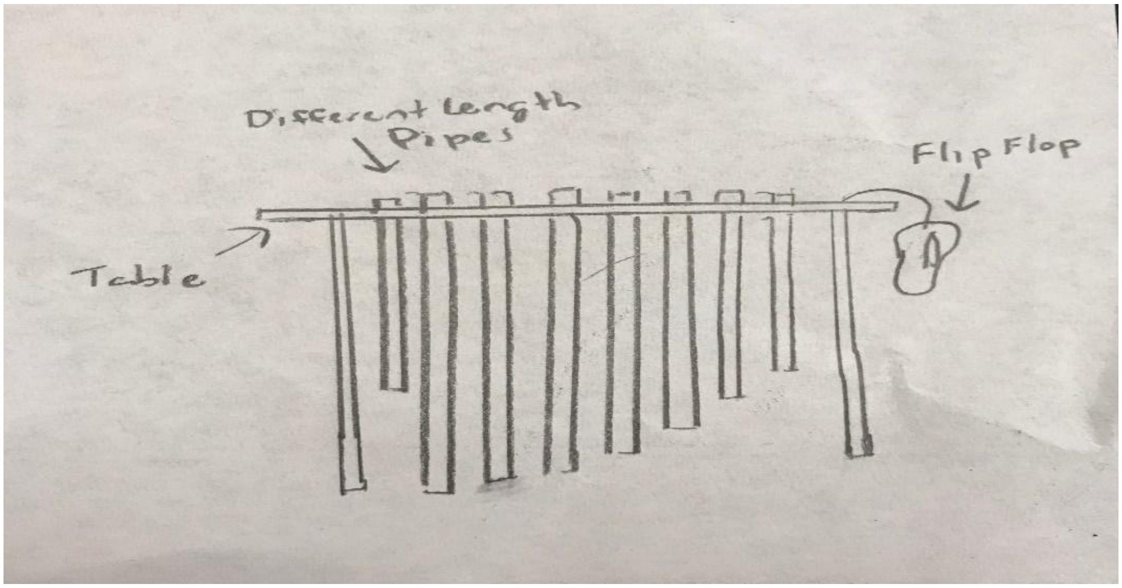

Figure 3-6: The Underphone

The Underphone shown in Figure 3-6, is an alternative solution which would be a compact, table-mounted xylophone. This solution consists of a series of PVC pipes of varying lengths that run underneath a table. One end of the pipes would be exposed on the top of the table; the lengths of the pipes would disappear behind the table; bend and twist underneath using pipe segments and elbow connectors; and the other ends would reside near the feet of the user. The upper ends of the pipes would be struck with some sort of mallet, and the sound produced would be projected from the lower ends. The Underphone would have smaller dimensions than other solutions, more portable, and would not require a permanent wall mount.

3.3.7 Geometriphone

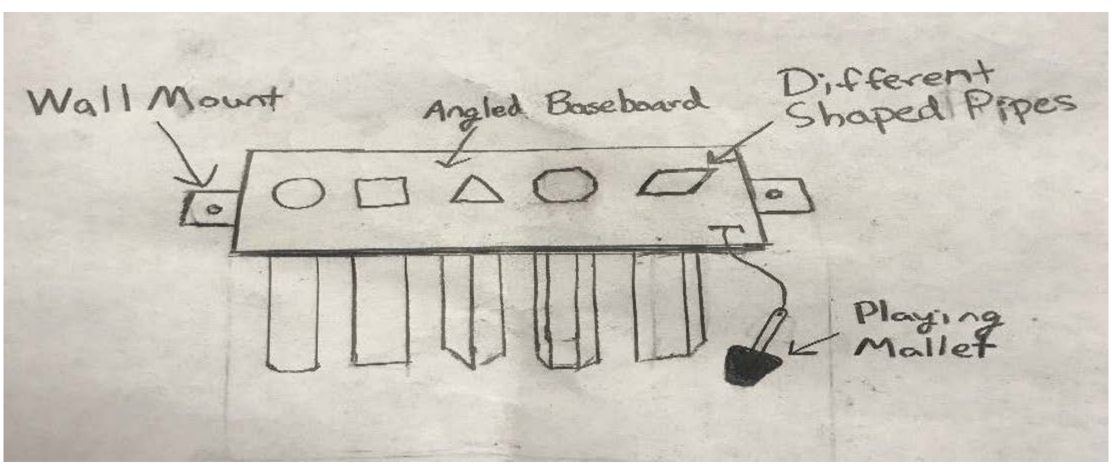

Figure 3-7:The Geometriphone

The Geometriphone shown in Figure 3-7, would be a visual solution for relating volume and sound. A square pipe, a triangular pipe, an octagonal pipe, a round pipe, and other shape desired can be used. The different shaped pipes will work well to help the children visualize the differences in sound since the pipes will be noticeably different. An average kid would most likely drift towards the more uniquely shaped project compared to the ideal solution that is not as appealing for the youth. The main difficulty we could encounter using the shaped base project would be designing the appropriate shaped pipes that deliver the right sound. Overall, the shape based Geometriphone could be reliable and beneficial for the youth. The volume of air capable of producing a sound will be determined by the area made by the shape at the end of the tube.

4 Decision Phase

4.1 Introduction

Section 4 contains the decision-making process. The section will evaluate the alternative solutions discussed in section 3, and select one using the Delphi Method shown in Table 4-1. The Delphi method will be used to make an unbiased decision for the solution.

4.2 Criteria

The criteria given in Section 2 are used in the decision process.

Durability - The structure is expected to last at least 20 years of daily use.

Safety - Unsupervised children must be able to play to play with the exhibit without risk of injury.

Mobility - The display should fit through a standard door, and easily transported by two people.

Cost - The project has a $500 budget, however the less money spent on the project, the better.

Sustainability - The design emphasizes using as many locally sourced used materials, as possible. When used materials cannot be found, locally sourced new materials may be accepted.

Replicability - The design should be able to be recreated by two people in a weekend.

Aesthetics- Attracts 8/10 children that come to the museum.

Educational Value - Does the user gain knowledge on the relation between length and sound.

4.3 Solutions

The following list is of the alternative solutions from Section 3:

- Hydrophone
- Diametriphone
- Heterophone
- Vibratune
- Underphone
- Sound Garden
- Geometriphone

Explanations of each alternative solution are given in Section 3.

4.4 Decision Process

4.4.1 Delphi Matrix

Table 4-1: Delphi chart comparing how well each alternative solution meets criteria.

	Alternative Solutions							
Criteria	Weight(0-10)	Hydrophone	Diametriphone	Heterophone	Vibraphone	Underphone	Geometriphone	Sound Garden
Strength	5	10	8.25 / 10	5.25 / 10	5.5 / 10	7.75 / 10	7 / 10	9.5 / 10
Safety	5.5	10	8.75 / 10	7 / 10	7.5 / 10	8 / 10	7.5 / 10	9.75 / 10
Mobility	4	10	7.5 / 10	7 / 10	5.75 / 10	7 / 10	6.5 / 10	7.5 / 10
Cost	5.75	10	5.75 / 10	7 / 10	6.25 / 10	6.25 / 10	6.75 / 10	6 / 10
Material Source	10	10	10 / 10	9.75 / 10	9.5 / 10	8.25 / 10	8.25 / 10	10 / 10
Replicability	5.5	10	5.25 / 10	5 / 10	3 / 10	3 / 10	3 / 10	8 / 10
Educational Value	6.75	10	6.5 / 10	6.5 / 10	6.75 / 10	6.75 / 10	6.75 / 10	9.25 / 10
AVG	6.07	10	7.43 / 10	6.79 / 10	6.32 / 10	6.71 / 10	6.54 / 10	8.57 / 10

4.5 Final Decision

The final decision was to make build the Sound Garden. The design used the PVC, wood, and hardware that the museum had available.

4.6 Final Decision Justification

The Del Phi method shown in table 4-1 was used to process criteria weights of solutions from Section 3. The Del Phi method determined that the "Sound Garden" was the most appropriate solution for the problem. The values used for the Del Phi method were determined by averaging each individual team member's values for each alternative solution.

5 Specification of Solution

5.1 Introduction

Section 5 contains a description of the final solution and its specifications. The specifications include a description of various components of the solution along with the costs of the design.

5.2 Solution Description

The "Sound Garden" is an original design by The Engineers That Could. The "Sound Garden" is a xylophone-like instrument with vertical pipes enclosed in a wooden body. The instrument is played by striking the ends of the pipes on an angled surface in front of the user with the use of a mallet made from a recycled flip-flop. Sound waves travel through the air columns in the pipes and are emitted from the top of the pipes. The body and the pipes are made from wood and PVC, respectively. Removable pipes and a latched assembly provide for portability and ease of installation.

5.2.1 The Sound Garden

Figure 5-1: The Sound Garden. The assembly contains the front case, the back case, the elbow assembly (not pictured), the playing caps, the vertical tubes, two rubber spatula mallets, latches, and an informational placard.

5.2.2 The Assembly

The fully completed assembly can be seen in Figure 5-1. The split case design is held together using a four hook and eye draw catches. Splitting the assembly in two allows for easier transportation and storage.

5.2.2.1 Front

The front casing is responsible for holding the tubing elbows in place, and keeping the striking surface of the elbow at a 45-degree angle to the pipes. The front casing is made of plywood that was used before as a shelf. The case is held together using 1 ¼” and 2 ½” stainless steel bolts. Bracing for the frame was made using recycled oak pieces. L brackets were used to fix the sides of the casing to the front and the top. The front of the case was made using scrap plywood from a local hardware store.

5.2.2.2 Back

The back casing is responsible for holding the tuned tubes up at a 90-degree angle from the floor. The case is made mostly of reused plywood. It uses the same 1 ¼” and 2 ½” stainless steel bolts that are used in the front case. It also employs the oak bracing and angle brackets used for the front case.

5.2.2.3 Putting it together

The client emphasized the desire to easily transport the display. To make moving the unit safer, and easier, the case was split into a front and back piece. The two halves are lined with felt at the mating surface, to give an aesthetically pleasing seal. The halves are held together with four brass “draw catch” buckles. This allows the unit to be split into two manageable cases, quickly and easily. The vertical pipes are held strain using duct straps attached to braces.

5.2.3 The Pipes

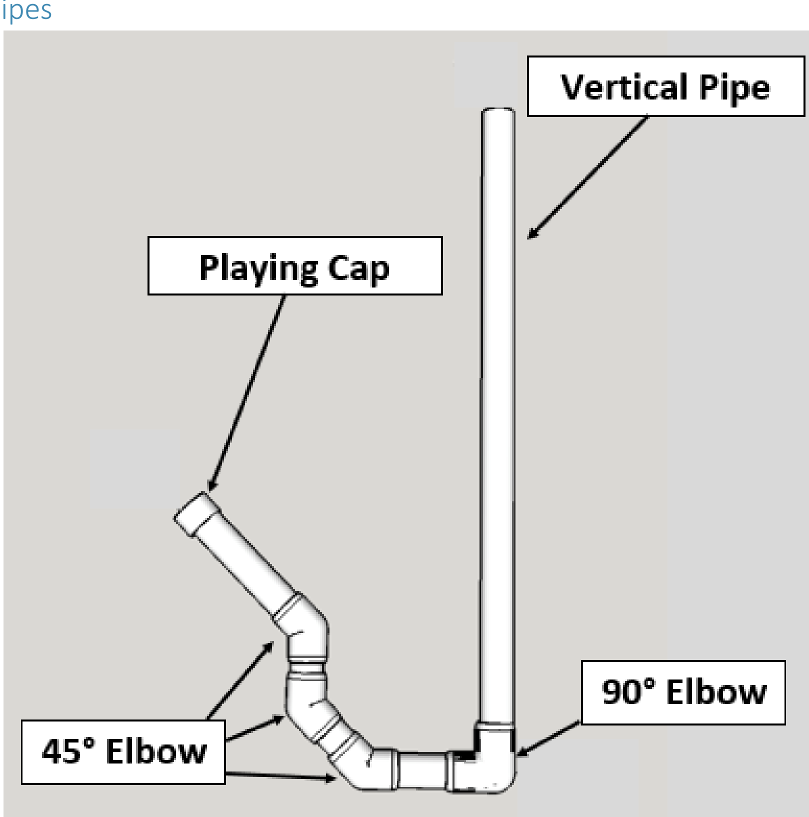

Figure 5-2: Cutaway of the full pipe assembly

The pipes are the sound producing component of the xylophone. Made from secondhand Schedule 40 1-¼” PVC, there are thirteen pipes tuned to a musical scale. A single pipe is shown in Figure 5-2. Each pipe consists of an “elbow” assembly, a playing end, and a vertical sound pipe of a differing length. The elbow assembly is comprised of three 45-degree connectors and one 90 degree connector, with small connecting pipes in between. The length of the vertical sound pipe is what determines the musical note produced from striking the playing end.

5.2.4 The Music

The instrument plays 13 musical notes spanning one octave from C2 and C3, C2 being the second lowest C note on a piano keyboard. The pipes are struck with the rubber spatula to produce a good clear tone. The instrument can be tuned by increasing or decreasing the lengths of the sound ends of the pipes. Figure 5-3 shows the verification of the tuning process.

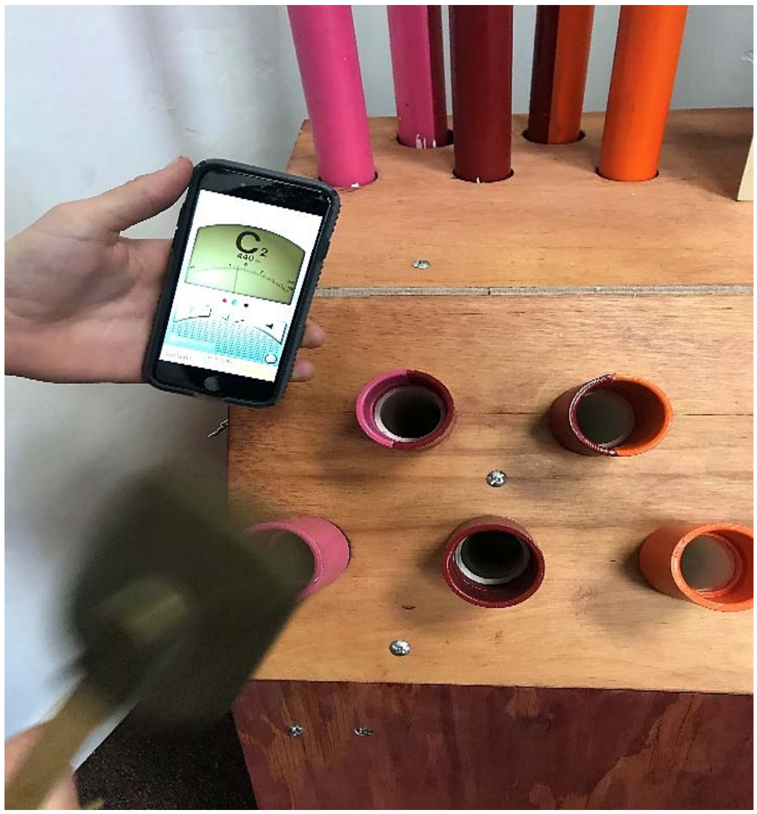

Figure 5-3: The Sound Garden is tuned to a standard scale by varying the lengths of the vertical pipes.

5.3 Cost Analysis

5.3.1 Design Cost (Hours)

The Sound Garden took 295 hours to design and construct, with a little over a third of that time spent on project development. Project development entails client meetings and the first four phases of the design process discussed in this document. Figure 5-4 details the total time spent on the project:

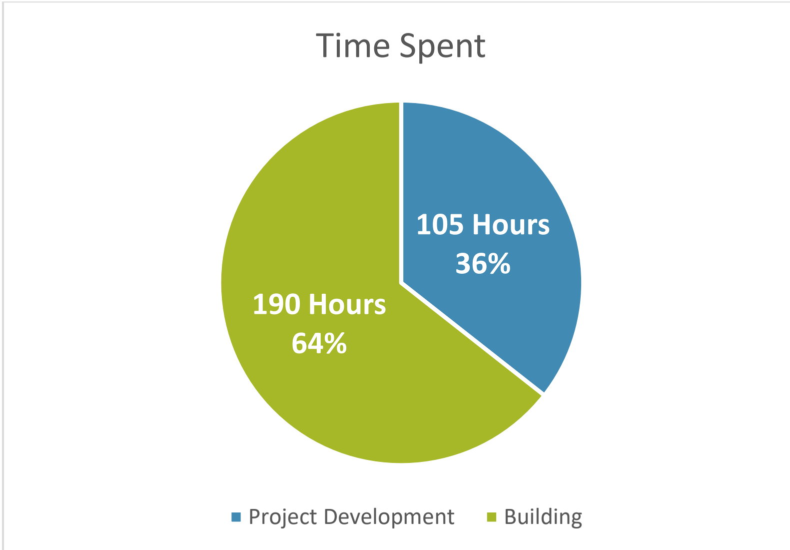

Figure 5-4: Time Costs for developing and constructing the Sound Garden

5.3.2 Implementation Cost ($)

The Sound Garden costed $257 to prototype, build, and implement; shown below in the bill of materials:

Table 5-1 Bill of Materials

Material	Unit	Cost ($)	Total ($)
Schedule 40 1-¼" PVC pipe (varying lengths)	12	Donated	0
Schedule 40 1-¼" PVC pipe (10 ft.)	1	5.99	5.99
45 degree Schedule 40 1-¼" PVC connectors	49	1.29	63.21
90 degree Schedule 40 1-¼" PVC connectors	13	1.29	16.77
1-¼" Schedule 40 PVC couplers	13	0.69	8.97
10-24 x 1-¼" Truss screws (100 ct.)	2	7.99	15.98
10-24 Nut (100 ct.)	2	5.79	11.58
Washers (100 ct.)	1	2.99	2.99
L-Brackets	4	0.89	3.56
Draw Catches	4	3.49	13.96
Hitch Pins	4	0.40	1.60
Primer	1	10.34	10.34
Paint	8	4.49	35.92
Pre-Stain	1	7.99	7.99
Stain	1	12.34	12.34
Felt Padding	2	4.49	8.98
Plywood	8	Donated	0
Plywood ($1.10 per sq. ft.)	8	1.10	8.80
Rubber Spatula (Playing Mallet, Gold)	1	4.49	4.49
Rubber Spatula (Playing Mallet, White)	1	1.00	1.00
		Tax	23.33
		Total	257.8

5.4 Design

5.4.1 The Pipes

The Sound Garden incorporates physics and music to show that they are related to each other. Each pipe is a different length and color coded to show that they are different sounds. The first and the last pipes are the same color (Pink) to show that they are the same musical note but just one octave apart in pitch. Starting at C, the longest wavelength, the pipes are color coded according to their wavelengths. Color wavelength is demonstrated in Figure 5-7. The color of the pipes progress from longest to shortest wavelengths (left to right) just as the notes do. The placement of the pipes is like the placement of keys on a piano, shown in Figures 5-5 and 5-6. The visible light spectrum is shown in Figure 5-8.

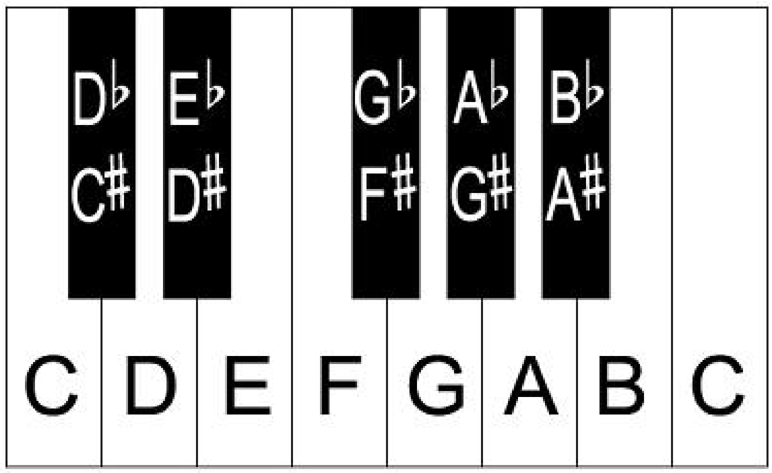

Figure 5-5: Note layout on a piano URL: https://goo.gl/LZVHjB

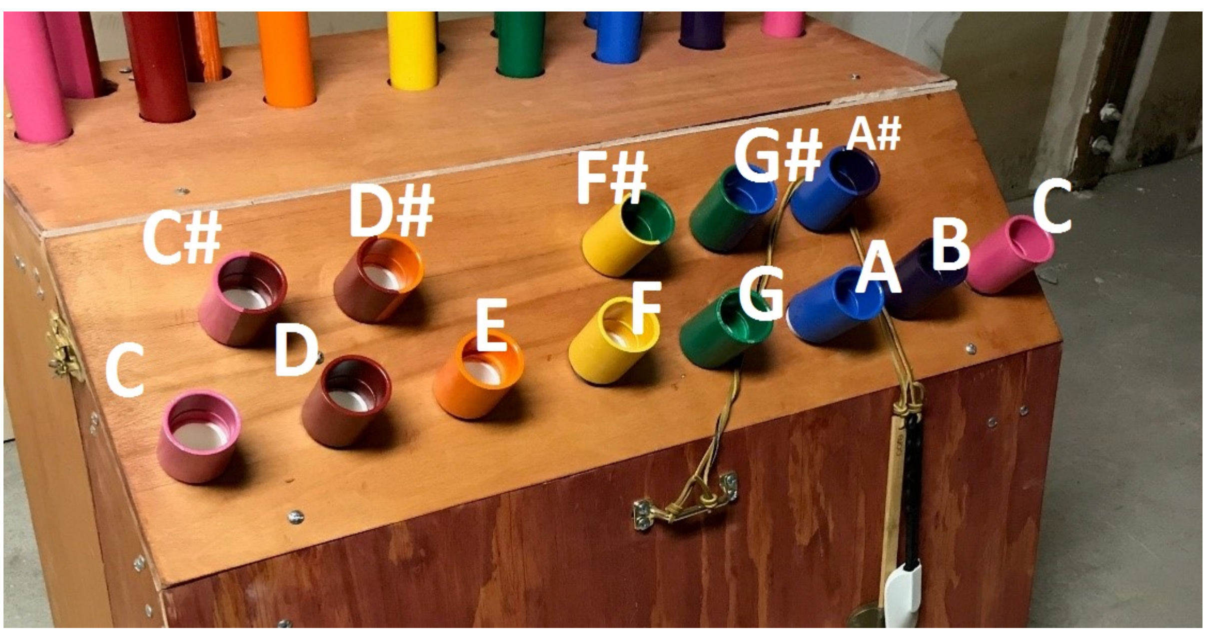

Figure 5-6: Note layout on the Sound Garden.

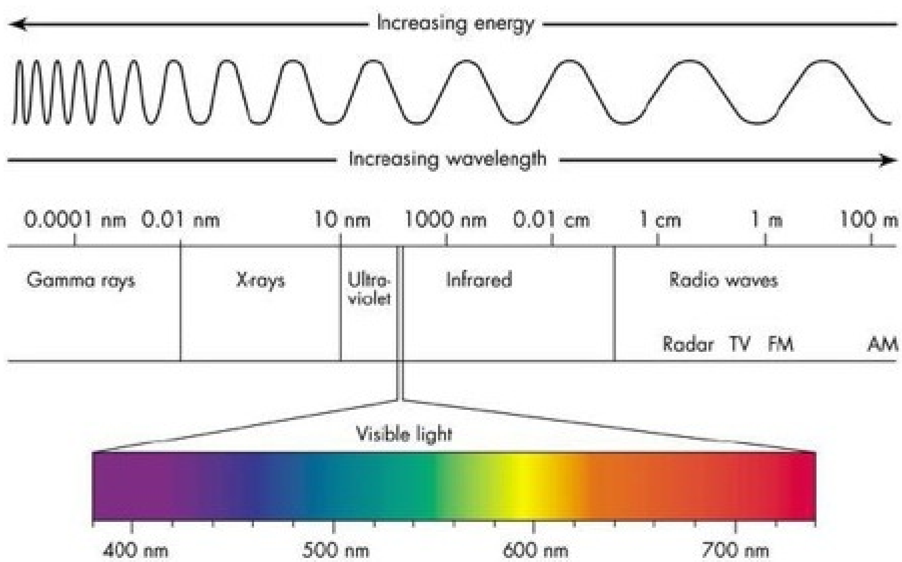

Figure 5-7: Light wavelengths and corresponding colors.URL: shorturl.at/eiyP2

5.4.2 The Frame

In order support the pipes and maintain the portability aspect of the project, the Engineers that Could had to design a frame that would hold the pipes in place, be rigid, and easily mobile if needed to move. To accomplish the mobility criteria, the frame has a draw catch latch system shown in Figure 5-8. These connect the two halves of the frame. An open view of the front of the frame is shown in Figure 5-9. Once the latches are secure, the frame is complete and ready for the pipes to be connected to the elbows. The back of the frame, shown in Figure 5-10, contains brackets that support the vertical pipes. These were made from the bracing used on the rest of the frame, and using duct straps to support the tubes. The brackets are shown in Figure 5-11.

Figure 5-8 Secured Latches

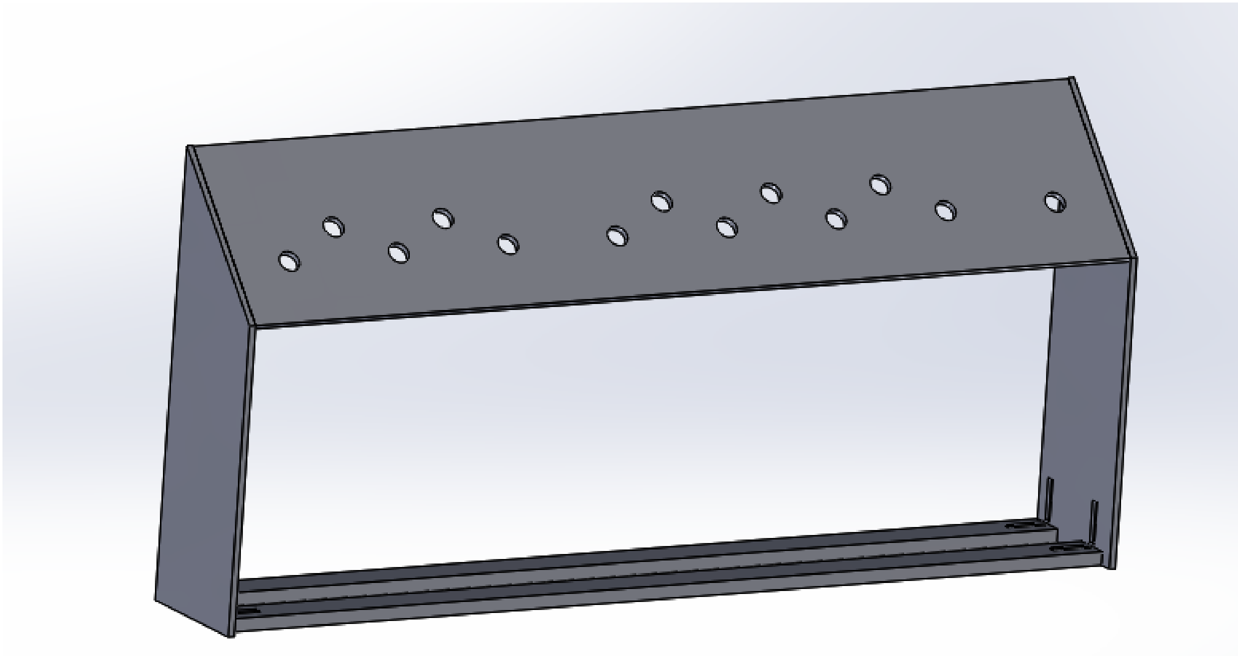

Figure 5-9: Front Half of the Case with bracing

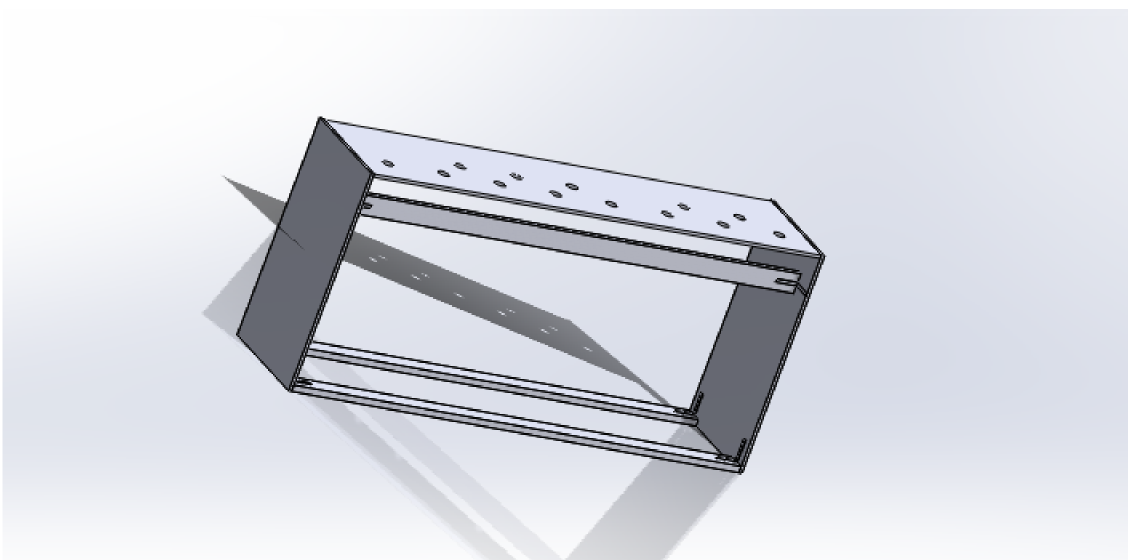

Figure 5-10: Back of Case with bracket

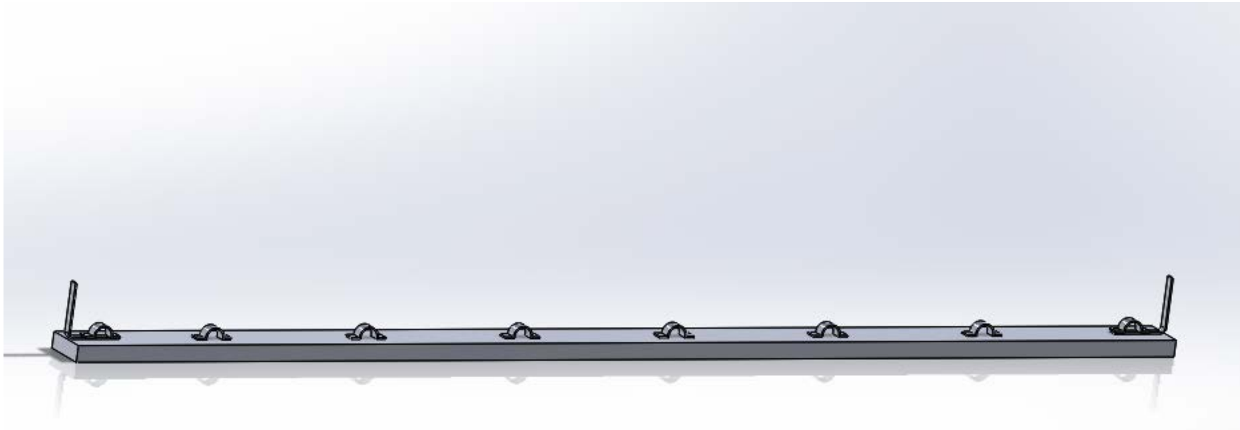

Figure 5-11: Bracket for Supporting Vertical Pipes

5.4.3 The Spatulas

The spatulas were chosen by the team, because of they are easy to find, easy to hold, and have the proper surface area to strike the pipes.

5.5 Construction

The construction process began by calculating each vertical pipe's required length based off its intended pitch. The formula for the total pipe length of each note is shown in Figure 5-12. The lengths of the elbow assembly were kept constant for each pipe, and subtracted from the overall pipe length when determining the length of the vertical pipe. Figure 5-14 shows the corresponding frequencies and wavelengths for each note used. Figure 5-15 shows the process of calculating pipe length, and Figure 5-16 shows the calculated pipe lengths required after subtracting the lengths of the elbow assembly. The elbow assembly is shown exploded in Figure 5-13. The 90-degree elbows, the 45-degree elbows, and the connecting segments were secured with PVC glue. The vertical pipes and the playing ends are detachable. The frame was built using reclaimed wood. Each side of the frame and the top was cut using a table saw. The sides of the frame were held together using oak braces, L brackets, and 1-¼" Truss screws. Felt strips were used between the two halves of the case. The frame was treated with a pre-stain, and then treated with a merlot stain. The end caps hold the elbow assembly in place. The end caps are removable, and the rest of the elbow assembly is held together using PVC glue. The vertical pipes are inserted through the top of the case, attached to the elbow assembly, and held in place using duct strap attached to a brace. The pipes were sanded and coated with a primer. The pipes were then color coded using spray paint, and then clear coated.

$$\text{length in inches} = \left(\frac{\text{tube diameter in inches}}{2}\right) + \left(\frac{\text{speed of sound in inches per second}}{\text{frequency in hertz} \times 2}\right)$$

Figure 5-12: Formula for calculating pipe length. URL: goo.gl/3fJ5ts

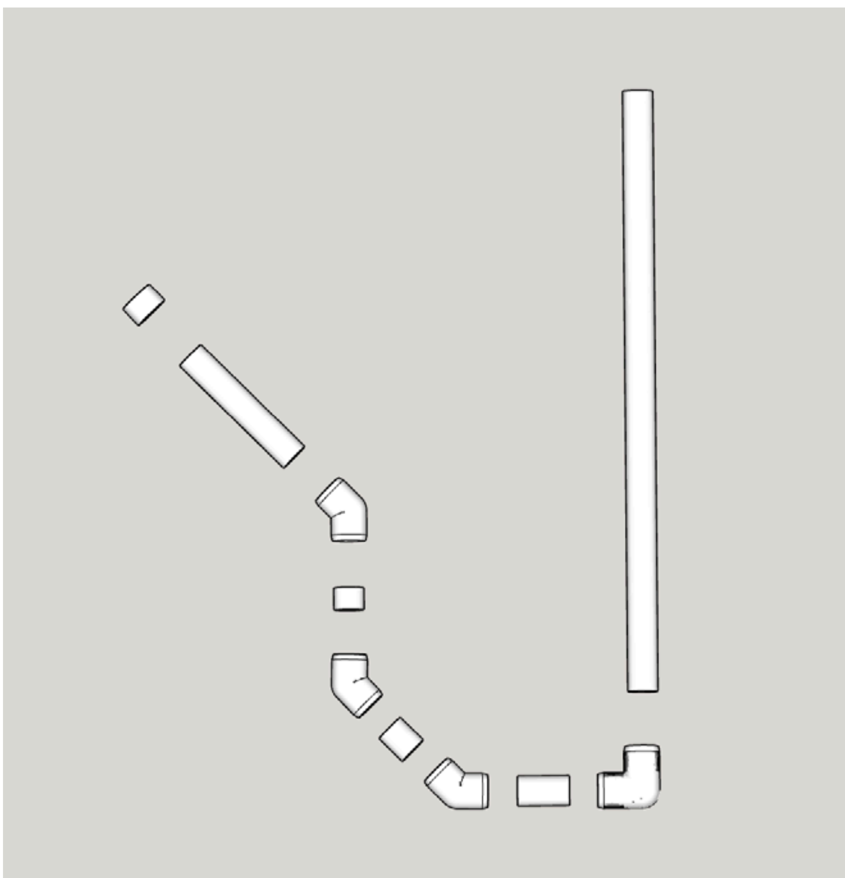

Figure 5-13: Exploded view of elbow assembly with vertical pipe.

Note	Frequency (Hz)	Wavelength (cm)
C_2	65.41	527.47
$C^{\#}_2/D^b_2$	69.30	497.87
D_2	73.42	469.92
$D^{\#}_2/E^b_2$	77.78	443.55
E_2	82.41	418.65
F_2	87.31	395.16
$F^{\#}_2/G^b_2$	92.50	372.98
G_2	98.00	352.04
$G^{\#}_2/A^b_2$	103.83	332.29
A_2	110.00	313.64
$A^{\#}_2/B^b_2$	116.54	296.03
B_2	123.47	279.42
C_3	130.81	263.74

Figure 5-14: Frequencies and wavelengths of musical notes. URL: https://tinyurl.com/y755w787

Figure 5-15: Team member Jonathan Sander calculating pipe lengths.

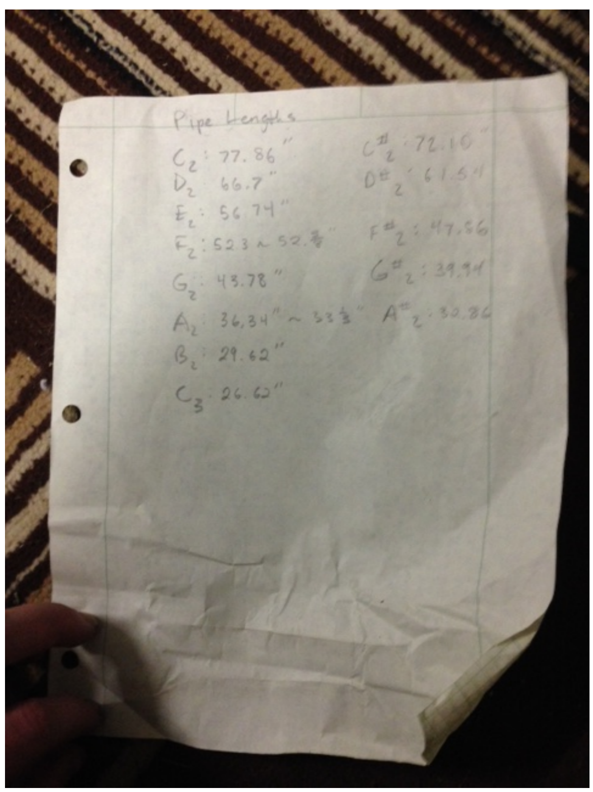

Figure 5-16: Calculated pipe lengths

5.6 Maintenance

It is advised that the assembly is inspected once a week for damaged parts to ensure safety. The exhibit should be inspected monthly for loose parts. Annually, the tubes should be inspected, and the frame should be checked for wear. The rubber spatulas will need to be replaced occasionally depending on the amount of the use. The replacement spatulas can be found locally.

5.7 Implementation Instructions

The display is designed to be mobile and can be set up outside or inside. The case splits in half so that the elbow assemblies can be put into place, and held in place by their respective playing caps. The back half of the case can then be secured using the brass draw catches. Then the vertical tubes can be put into place by sliding them down through the top of the case. The rubber spatulas are attached to the center of the display, and can be left on the front of the case for transportation.

5.8 Prototype Performance

The results of constructing the Sound Garden design model reinforced the idea that a safe, functional, easily portable musical instrument could be built from secondhand wood and PVC pipe materials. This design is inexpensive and the building process labor intensive, but the design could be replicated easily. In the long term; users of this instrument will take away the basic relationships between physics, sound, and music.

6 Appendices:

A. References

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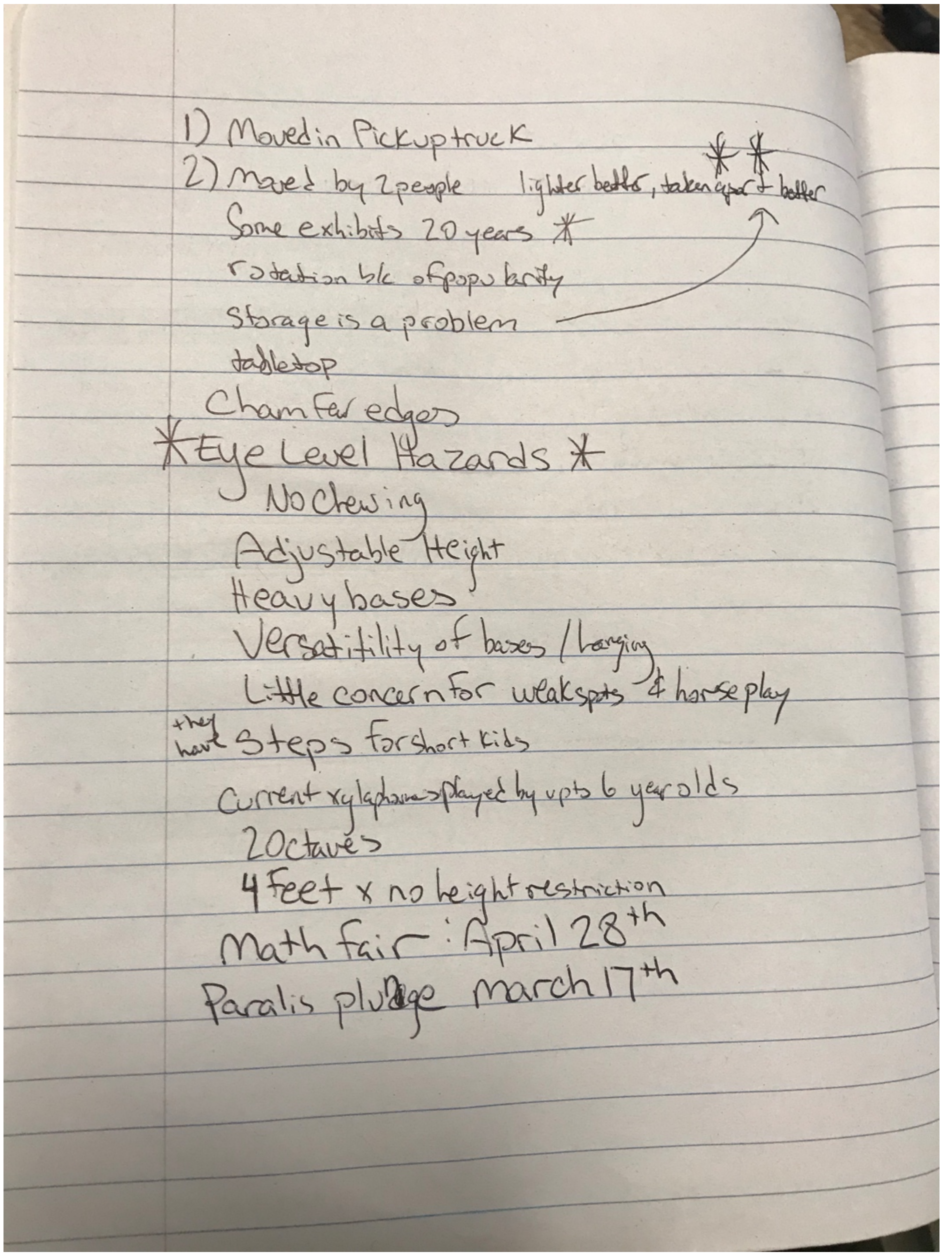
B. Brainstorming Notes (1)



1) Moved in Pickup truck
2) Moved by 2 people lighter better, taken apart better **
Some exhibits 20 years *
rotation b/c of popularity
Storage is a problem
tabletop
Chamfer edges
*Eye Level Hazards *
No Chewing
Adjustable Height
Heavy bases
Versatility of bases / hanging
Little concern for weakspots & horseplay
they have Steps for short kids
Current xylophones played by up to 6 year olds
2 Octaves
4 Feet x no height restriction
Math fair: April 28th
Paralis plunge march 17th

Figure 6-1: First brainstorming session by The Engineers That Could

B. (2)

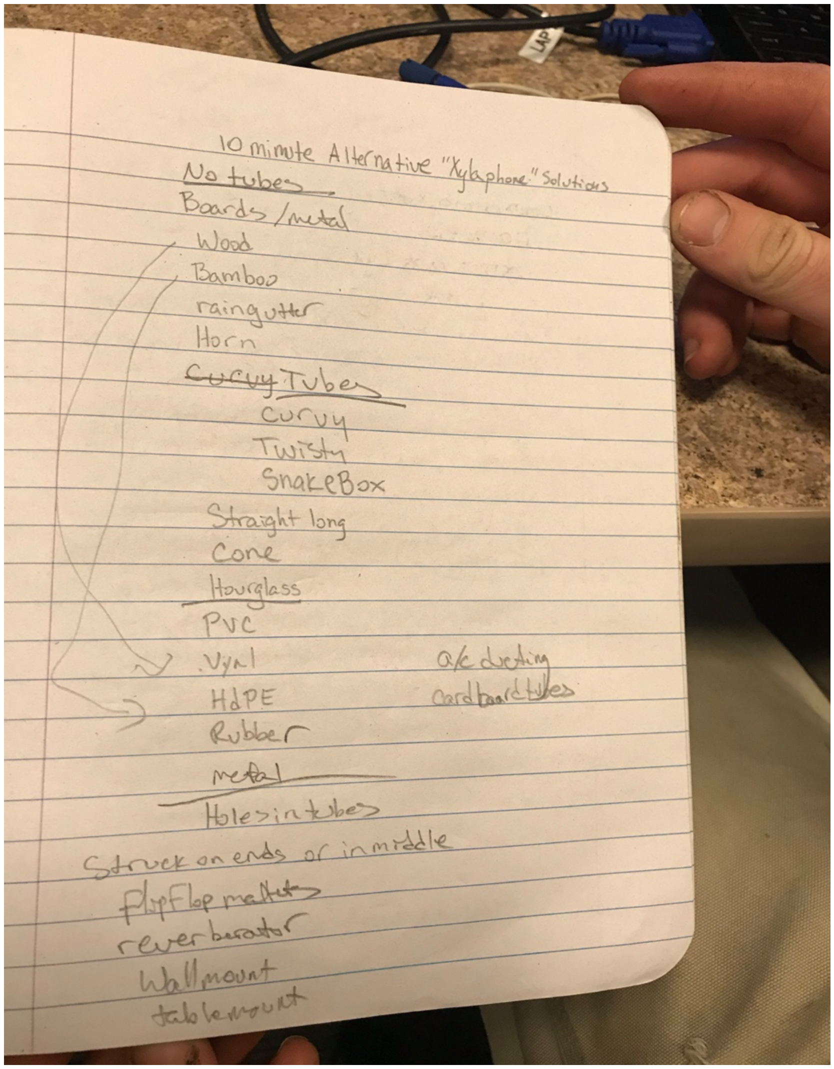


Figure 6-2: Second brainstorming session.

B. (3)

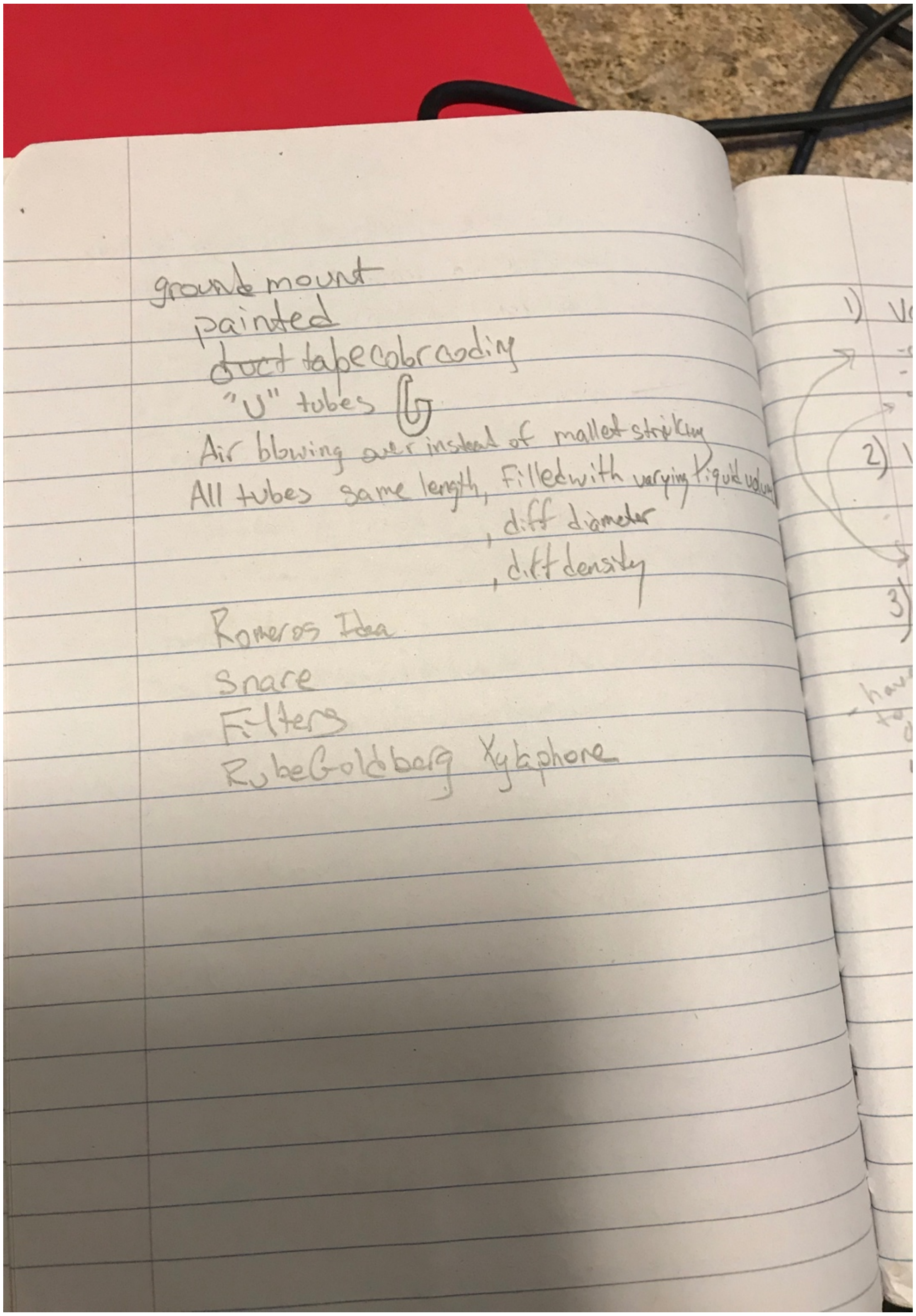


Figure 6-3:Third brainstorming session.

B. (4)

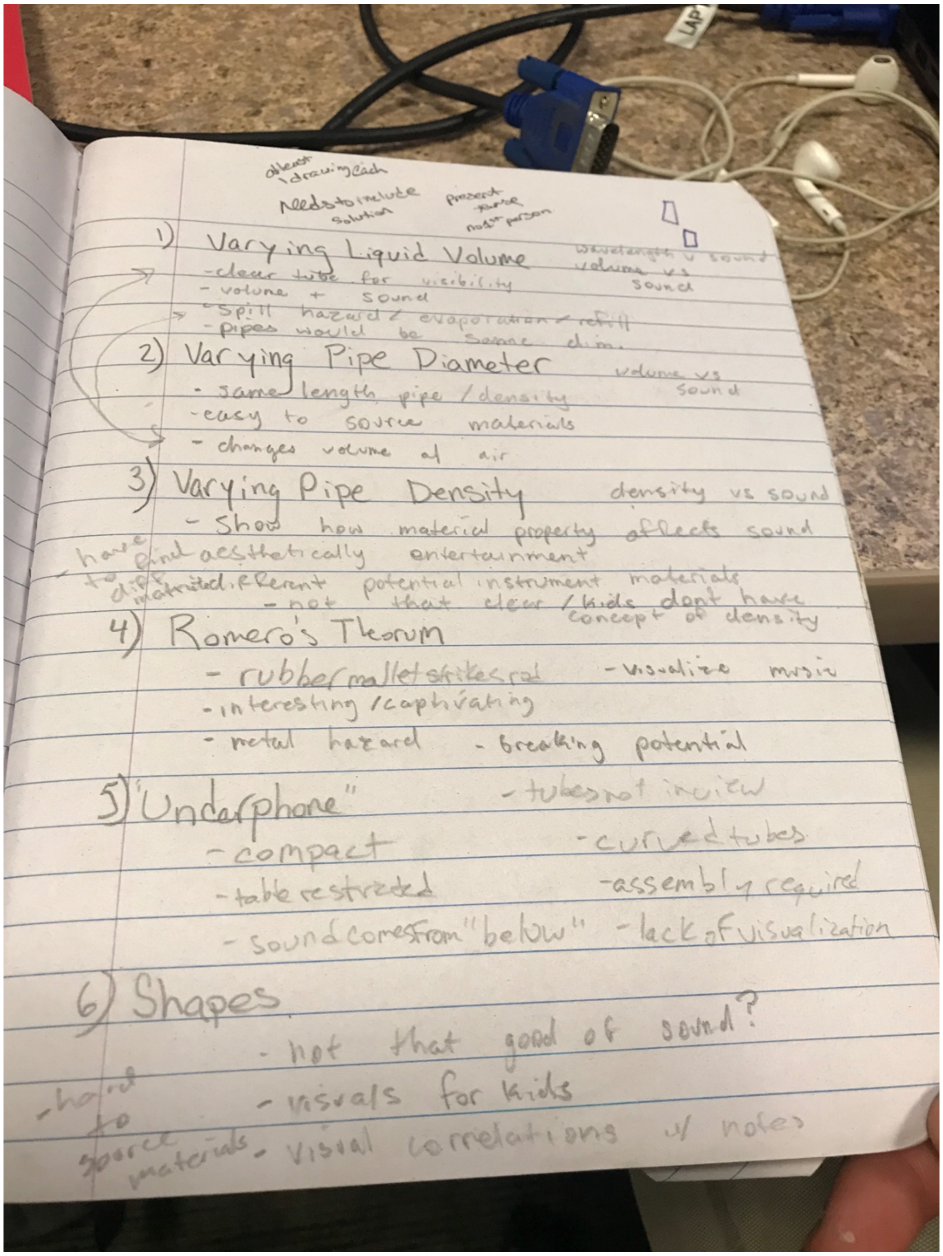


Figure 6-4: Fourth brainstorming session.