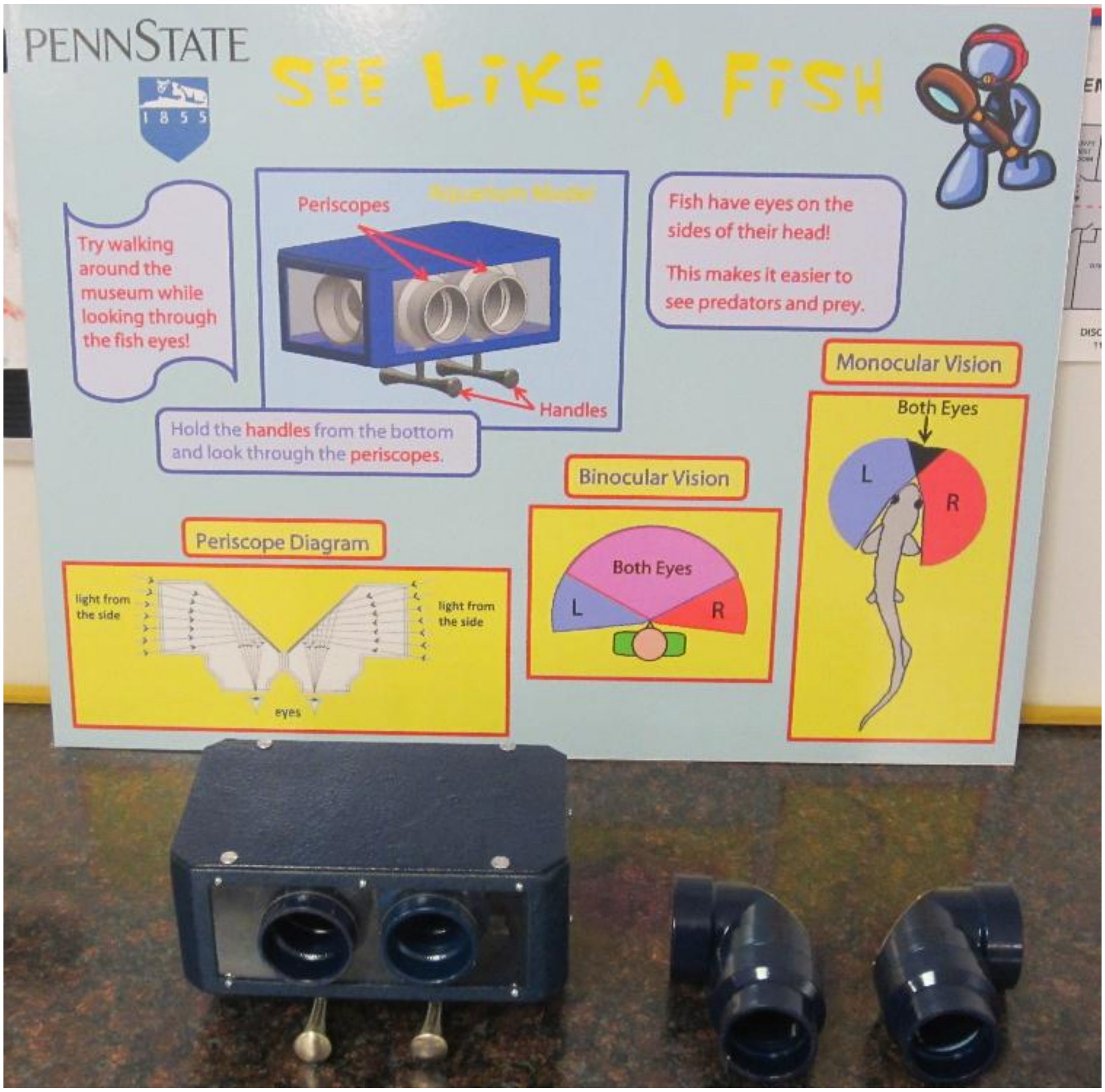
Discovery Space Museum of Central Pennsylvania
Final Report



See Like a Fish Exhibit

Harlan Chernoff
Daniel Lavery

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Executive Summary

The United States has long been a leader in technology and innovation, but lately, its ability in the engineering and science fields has been lagging according to a recent CNN report. In order to maintain our current technological status, today's kids need to be inspired to pursue careers in science and engineering. The Discovery Space Museum of Central Pennsylvania recognizes this need, and provides fun educational exhibits that engage children in science. Our team has constructed a new exhibit for the museum that will encourage learning in the STEM fields.

The See Like A fish exhibit is comprised of two components. One component is a pair of PVC elbow joints with mirrors mounted on the corners, which will be called periscopes for the purposes of this paper. The other component, called the "Aquarium", is an aluminum box with two periscopes mounted inside. The exhibit is expected to teach children about a fish's vision and principals of reflecting light. For them, it's fun to play with, but it also portrays simple scientific concepts.

Construction of the exhibit was completed successfully in a timely manner. The resulting prototype has been tested at the museum. Kids liked it and the staff had constructive feedback. Some of this feedback encouraged modification of the devices, which was done aptly in attempt to satisfy customer needs. The exhibit is safe, reliable, easy to use, and aesthetically pleasing. Furthermore, it is safe to say that the exhibit could be reproduced by a competent person with the correct tools and materials. The calculated $160 construction cost provides that the exhibit is an affordable and worthwhile addition to any children's science museum.

During the development and construction process, Team C learned to do quality work despite interpersonal conflict.

1 Project Overview

1.1 Problem Statement

The United States has historically been a world leader in innovation and technological development. But in recent years, certain evidence suggests that this will not hold true in the future. Engineers and scientists all have a strong foundation in math and science. This foundation is essential to move the country forward technologically. Our future relies on today's children and their skill in math and science. However, America's children struggle in these fields. CNN repors that, "American students score 23rd in math and 31st in science when compared with 65 other top industrial countries" [1]. In order for the United States to continue to be a world leader, these rankings must improve. One way to accomplish this is to foster interest in today's youth in science and math. Science museums that target kids are good way to do this. Museums offer interactive and mind captivating exhibits that have the potential to spark interest in the subject matter. The purpose of this project is to help correct our nation's declining rank by building a new science exhibit. It will be designed for the Discovery Space Museum in State College, PA and tailored to the specific needs emphasized by the staff. Although they are the primary target market, the exhibit could just as well be marketed to other children's science museums. This project has a budget of $100 and must be developed and constructed by December 11, 2012.

1.2 Background Information

Figure 1: Discovery Space of Central Pennsylvania

The mission of The Discovery Space of Central Pennsylvania is "to provide engaging science experiences which spark creativity, imagination, and curiosity" [2]. In order to help complete its mission, the museum has enlisted the help of Dr. Lamancusa and his Engineering Design Methodology class to design new exhibits for the museum. Dr. Lamancusa's class teaches the importance of design methodology and the various steps and processes that engineering companies use when developing new products. This project provides his students with an excellent opportunity to apply what they have learned in class and benefit the engineers of tomorrow.

With experience in engineering design, Solidworks, math, science, and engineering principles, mechanical engineering students provide a good source for exhibit design and development. Our knowledge and experience, coupled with our ability to use the Learning Factory, will allow us to generate prototypes and ultimately a successful exhibit that satisfies the customer's needs.

1.3 Project Planning

In order to complete the project efficiently, a team contract was written to provide structure to the group. This contract laid the basis for team meetings, and the division of work based on members strengths and weaknesses. Originally the team functioned using an equal-authority system, in which each member will have equal input in the project.

As described by the book, “Product Design and Development”, a total of ten steps are needed in order to complete the project: Customer needs identification: customer needs evaluation, concept generation, concept selection, concept development, system level design, detail level design, prototype construction, prototype testing, and production [3]. Included in these major steps are minor steps and checkpoints that need to be met in order to complete the project.

Through the use of a Gantt chart, found in Appendix A, our group organized the project tasks and estimated the time needed to complete them. Our estimates and the course schedule were used to develop the deadlines for each task. Throughout this project, we will keep the instructor and customer informed through progress memos that document our progress and efficiency.

2 Customer Needs and Design Specifications

This section discusses the determination of customer needs and their translation into engineering specifications for this project.

2.1 Identification of Customer Needs

To obtain information about the customer needs for this project, we communicated to the staff and visitors of the Discovery Space Museum, and tested and observed the current museum exhibits. The interviews with the museum staff provided useful information about the current exhibits and what they would expect of an ideal exhibit. The DSCP staff noted that some of the exhibits have been damaged due to improper use from the children. Because the way a child handles an exhibit cannot be controlled, durability was stressed as a customer need. Communication with the parents of the children in the DSCP provided insight from the parents’ perspective. Parents enjoy when their children can interact and use the exhibit with minimal input and help. From this, we identified interactivity as an important customer need.

Safety scored the highest weighted percentage of all the customer needs since children will be the primary users of the exhibit. The second and third most important customer needs were interactivity and durability. Interactivity was based on the feedback from the parents and durability was based on the feedback from the DSCP staff. The need to have an intuitive and interactive exhibit that effectively portrays scientific concepts is most important. The DSCP staff suggested that some of the exhibits were very interesting but had little educational value, and other exhibits were very educational, yet boring for the children. Achieving a balance between educational value and intuitive operation is an important challenge

Based on our experiences at the Discovery Space Museum, we have identified the following customer needs: safety, cost effective, durability, reliability, aesthetics, mobility, intuition, scientific concepts, maintenance, and interactivity. Descriptions and weighted percentages for all of these customer needs are shown in Table 1. The weighted percentages were determined by the Analytical Hierarchy Process (AHP) chart, which can be found in Appendix B.

Table 1: Customer needs description and weights

Need	Weight	Description
Safety	20%	The exhibit will have no potential risk or harm
Cost	5%	The exhibit will cost less than $100
Durability	15%	The exhibit will resist damage & wear The exhibit is incapable of causing the user harm
Reliability	10%	The exhibit will function properly on a daily basis
Aesthetics	10%	The exhibit will be visually attractive
Mobility	5%	The exhibit will be light & able to move throughout the museum
Intuitive	10%	The exhibit will be interesting, spark curiosity, easy to figure out, and require some thought by the user
Educational	10%	The exhibit will teach a scientific concept
Maintenance	5%	The exhibit will be easy to clean and take care of
Interactivity	15%	The exhibit will require input from the user

Transforming Customer Needs into Specifications

Engineering specifications were determined based on the customer needs. This process is aided by a Quality Function Deployment (QFD) Chart. The complete QFD chart can be found in Appendix C, and the results are summarized below in Table 2.

Table 2: Customer needs converted into engineering specifications

Customer Needs	Engineering Specifications
Safety	**Meets Toy Safety Standards**
Cost	**Total cost is less than $100**
Durability	**Does not fail under loading of 100 pounds**
Reliability	**The exhibit will consistently function properly**
Aesthetics	**Visually attractive and invites users**
Mobility	**Weighs less than 50 pounds**
Intuitive	**Holds a child's attention for at least 5 minutes**
Educational	**Incorporates at least 1 scientific concept**
Maintenance	**Requires under 1 hour of maintenance per month**
Interactivity	**A child can understand how to use the exhibit in under 30 seconds**

3 Concept Development

3.1 External Search

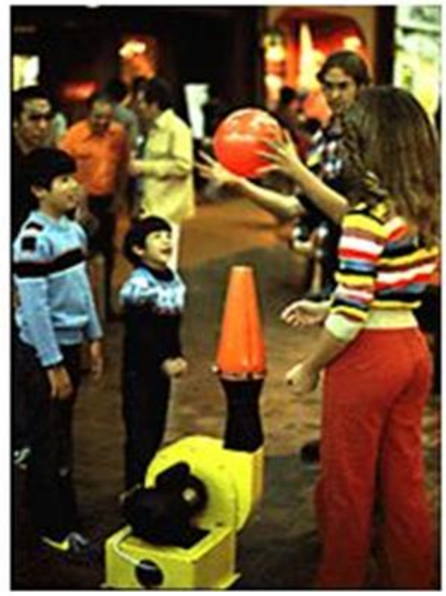


Figure 2: Bernoulli Blower [4]

The external search included an internet search of various museums. Many of the ideas sourced from recollections of exhibits that each member had seen or previously experienced. Our search also included an exploration of YouTube videos to find unique and intriguing ideas that are often not seen in everyday exhibits. They were then searched for on the internet to get more specific details on how other people have gotten these concepts to work. The team has also made many observations of the exhibits currently at the DSCP. Below are exhibits that were found to be interesting and successful.

3.1.1 Bernoulli Blower

The exhibit uses a fan to suspend a ball in the air. This is entertaining and eye catching. The scientific concept that it displays, Bernoulli's Principle, is easily visible to users of all ages, and sight of seeing a ball float in midair is very attractive. The exhibit shown in Figure 2 uses a cone to channel air from a fan into a concentrated stream [4]. This exhibit requires active participation by the user which prevents boredom and can be enjoyed by kids of all ages. The downside to this exhibit is that only one person can use it at a time. Also the use of a high powered fan or air pump may create undesired noise in the museum.

3.1.2 Gear Table

Figure 3: Gear Table [5]

Gear tables allow kids to experiment with different sized gears and see how they move relative to each other. The gears can be arranged for pure fun, or to achieve some task such as to move a flag. A previous group attempted to design a gear exhibit for DSCP, however their design failed due to the use of large foam gears that did not rotate properly. Figure 3 shows a successful gear table that uses smaller plastic gears that are more efficient, while still being kid friendly [5]. This exhibit is very popular, can be used by multiple children and encourages creativity.

3.1.3 Pulley Exhibit

This exhibit was designed by a previous ME 340 class and is relatively popular at the DSCP. Through the use of various pulley arrangements, users learn about mechanical advantages as they lift up weights. This exhibit and its corresponding report provide a great example of the attention to safety that groups must make when designing children's exhibits [6].The group that designed the exhibit built it to a high factor of safety and also examined nearly every possible way the exhibit could potentially harm the user. They then developed simple and effective ways of fixing potential problems. One such example of this is the addition of the wooden platform that prevents the exhibit from being tipped over and also acts as a step to allow shorter users to reach the handles as seen in Figure 4.

Figure 4: Pulley Exhibit at DSCP [6]

3.2 Problem Decomposition

The following black box model for a children's museum exhibit shows the inputs needed to reach the output goals. The inputs were determined from the external search and the background research, and the output goals are an influence of the customer needs and design specifications.

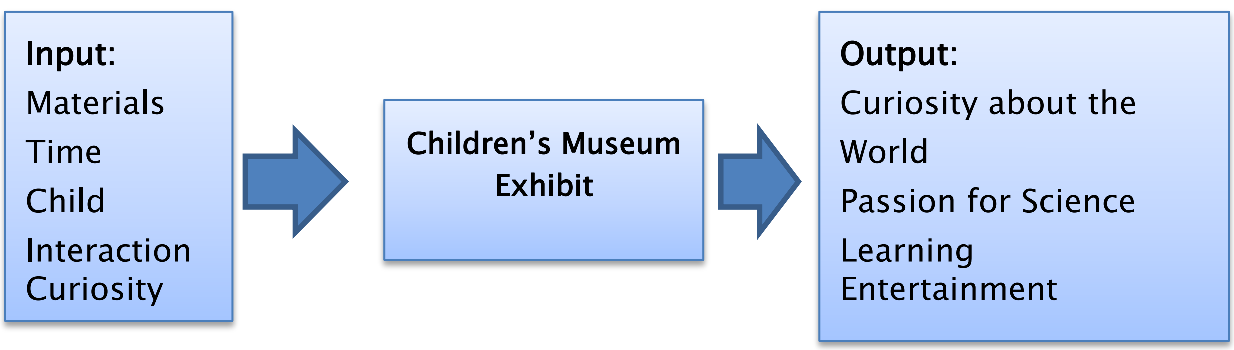


Figure 5: Black Box Model of a children's museum exhibit

3.3 Concept Generation

After analyzing the problem, each group member generated their own ideas that were discussed in a team meeting. This step in our concept generation resulted in thirteen ideas. Figures 6 through 9 show four concepts that were generated and considered as final design concepts.

3.3.1 Marble Machine

This exhibit demonstrates the principles of energy and momentum conservation through the movement of a marble through an intricate system of gears, tracks, screws, levers, and other gadgets. This idea was inspired by a YouTube video and the groups own fascination with the idea [7]. A great example of a marble machine is shown in Figure 6.

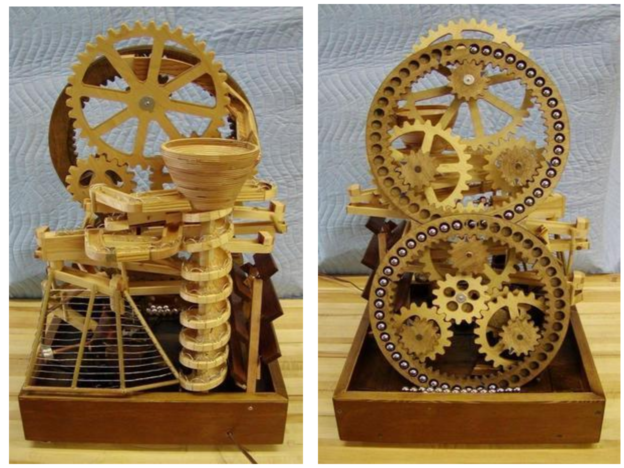


Figure 6: Wooden marble machines [7]

3.3.2 See Like a Fish

This exhibit allows the user to see the world as though they had eyes on the sides of their head, similar to that of a fish through the use of two sideways periscopes mounted in a fish head. By using this exhibit, children will learn why fish have eyes on the sides of their head, and also how mirrors and lenses work.

Figure 4: Potential fish head design [8]

3.3.3 Kinetic Art

Kinetic art is comprised of a series of pendulums whose length increases logarithmically. Due to their different lengths, the pendulums swing with different frequencies, which results in the formation of various wave forms as their phases synchronize. An example of this is shown in Figure 8. Through the use of this exhibit, the user will gain insight into pendulum motion and harmonics.

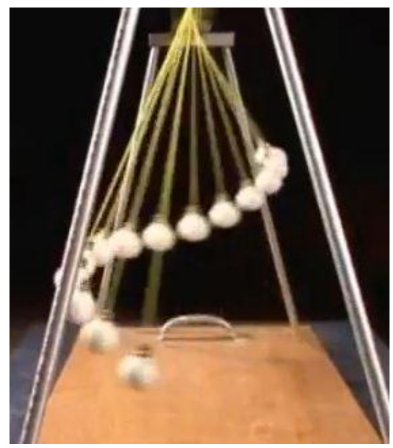


Figure 8: Pendulum wave patterns. [9]

3.3.4 Perpetual Motion

The concept of perpetual motion has long captured the minds of many famous scientists and inventors, such as Leonardo Da Vinci. This exhibit will consist of two perpetual motion machines such as da Vinci's overbalanced wheel, which is shown in Figure 9. Since perpetual motion is impossible to achieve, this exhibit will employ hidden switches and motors that give the appearance of perpetual motion. This idea was also inspired by a YouTube video [10]. The goal of this is to inspire children to question their surroundings as a scientist would, spark creative thought, and explain conservation of energy.

Figure 9: Da Vinci's overbalanced wheel. The motor is hidden beneath the white platform. [10]

3.4 Concept Combination

The potential ideas for the exhibit that were organized into groups based on their scientific concepts. During this process, the concepts were grouped, and repetitions of similar ideas were eliminated or combined. From here, each member voted on the ideas that they thought best taught their underlying scientific concept. While there were some repetitions of scientific concepts, this process resulted in thirteen ideas that each member thought would be a good exhibit.

3.5 Concept Selection

A structured method of analysis was used to help determine the best concept. The thirteen concepts that were generated went through concept screening where they were compared to the popular Sailboat Exhibit at the DSCP. This process resulted in six concepts, which went through a concept scoring process using the weights from the AHP matrix. The results can be found in Appendix D. Two hierarchal pairwise comparison charts were then constructed to evaluate the overall exhibit worth and ease of build. While the overall exhibit worth is important, the technical feasibility of each possibility needed to be considered, especially given the project time constraints. We then narrowed down our concepts to four ideas: Marble Machine, See Like A Fish, Perpetual Motion and Kinetic Art. In all of these analyses, the Kinetic Art concept excelled. These top four ideas were then presented to staff members of the DSCP. After this presentation and a meeting with their staff, it was decided that the See Like A Fish concept best suited the customer's needs and would be produced.

4 System Level Design

4.1 Overall Description

The See Like A Fish Exhibit is based on a similar exhibit in the Carnegie Science Center in Pittsburgh, PA [11]. This exhibit consists of an over-scaled fish head model that is mounted on a stand. Inside of the fish head model, there are two parallel periscopes extending to the eyes of the fish and turning in opposite directions exiting the sides of its head. The fish head is able to rotate about the stand on which it is mounted. The purpose of this exhibit is to allow the user to view the Discovery Space Museum as if his or her eyes were on the sides his or her head, like fish eyes.

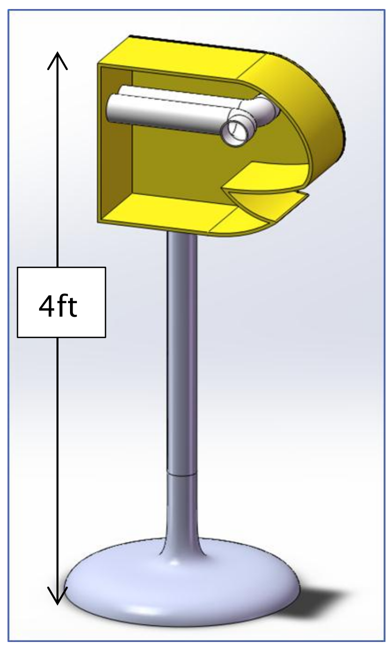


Figure 10: Computer model of exhibit

The See Like A Fish Exhibit was chosen because it relates to something that children already know about and have seen before. According to Mary Maher, Animal Exhibits have a universal acceptance by all age groups [12]. It was also chosen because it will complement the pre-existing fish tank at the museum. This exhibit has educational value because it teaches children about periscopes and how mirrors project different images. Even though it is very similar to the periscope currently in the DSCP, this exhibit is very unique because it the application of the anatomy of a fish.

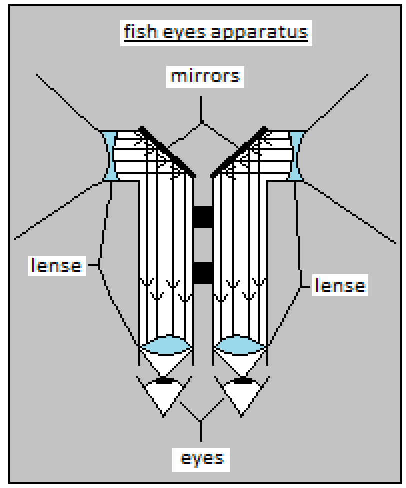
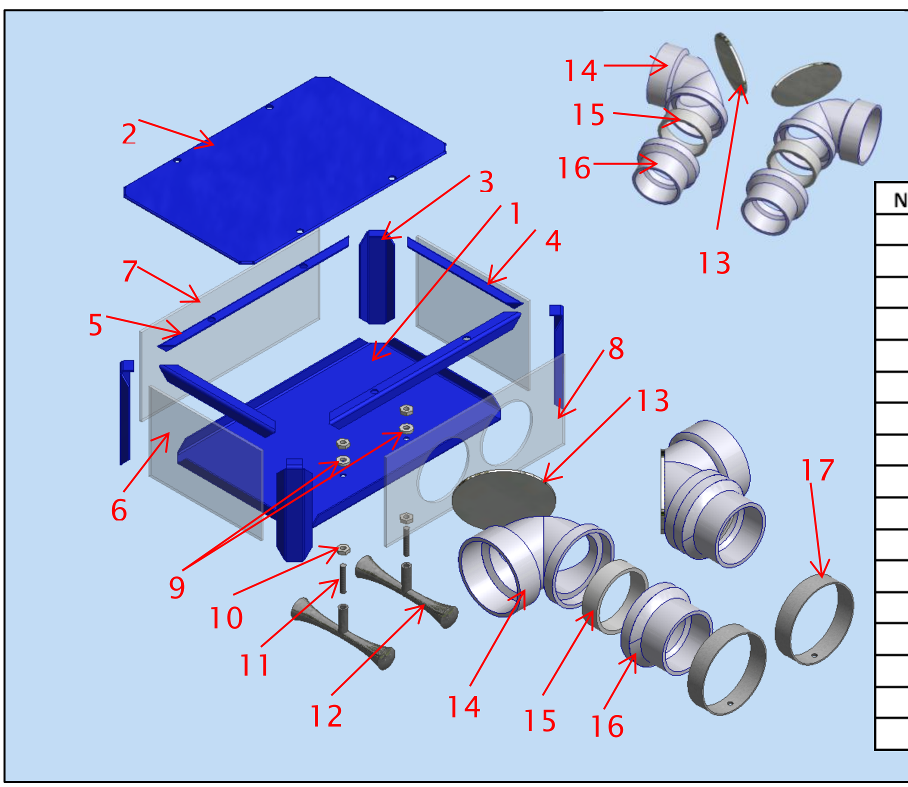


Figure 11: Optical diagram of See Like A Fish Exhibit

4.2 Theoretical Analysis

As shown in Figure 11 the project is mainly reliant on the application of periscopes and lenses to convert a human's vision into that of a fish. Most fish, because they cannot turn their heads, can see to the right and to the left at the same time. This gives them all-round vision. To allow fish to judge distances ahead of them, there is a small area in their front on which they can focus with both eyes.

5 Detailed Design



Number	Part
1	Bottom Plate
2	Top Plate
3	Side Wall x4
4	Top Component (Short) x2
5	Top Component (Long) x2
6	Side Window x2
7	Back Window
8	Front Window w/ Holes
9	Aluminum Washers x8
10	Steel Hex Nut x4
11	Threaded Rod x2
12	Stainless Steel Handle x2
13	Stainless Steel Mirror x4
14	PVC Elbow Joint x4
15	PVC Connector x4
16	PVC Adapter x4
17	Aluminum Hoop Brace x2

Figure 12: Exploded View of Aquarium Model & Handheld Periscopes

5.1 Modifications to Detailed Design Report

The overall design of the exhibit has changed significantly since the original proposal was submitted. Changes to the overall exhibit design arose after the alpha prototype was constructed. This prototype provided valuable proof of concept but also raised the question of the exhibit's purpose and usage. Preliminary plans involved having the user locate various objects throughout the museum while looking through the "fish eyes", similar to that of the periscope exhibit. Testing was carried out by our group to determine the feasibility of this idea. It was determined that locating objects in the museum was too difficult for the user. We found that most users focused on one periscope to find the object instead of using both, thus losing the fish eye concept. It was then determined that in order to give our exhibit more of a purpose and to allow for more interaction with the exhibit by the user, a major redesign was needed.

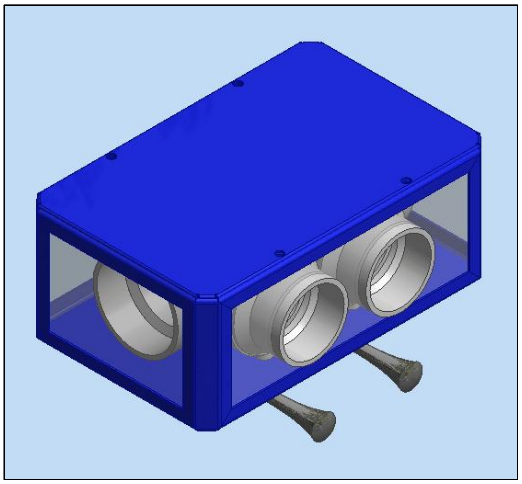


Figure 13: Aquarium Design

A meeting was arranged with Allayn Beck and Linda Bailey to discuss our findings and a potential redesign. At this meeting it was determined that producing a mobile, handheld exhibit would be more beneficial. This design would allow the children to navigate the museum, provide a better field of vision, and more closely mimic the eyes of a fish. The new design would feature two smaller periscopes mounted inside a protective rectangular box with handles mounted on the bottom to allow children to hold the exhibit. This new design is called the "Aquarium" because the fish eye periscopes will be mounted inside an aquarium styled box, thus giving the user the illusion of being a fish inside of an aquarium looking out into the world. Along with the "Aquarium" style exhibit, a pair of free floating periscopes will be constructed. The user will be able to place each periscope in their hands and move each periscope around as they please. This option will cater to smaller children who may not be strong enough to hold up the "Aquarium".

5.2 Educational Objectives

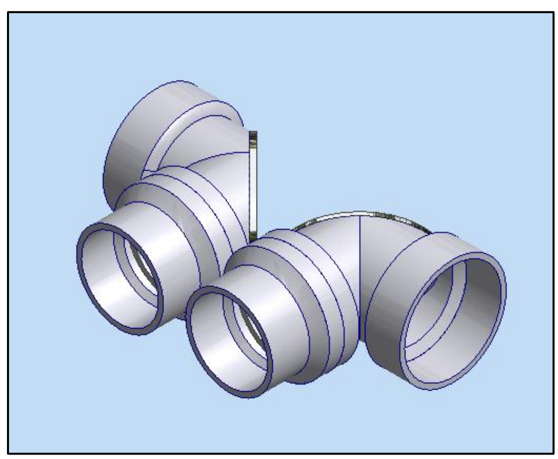


Figure 14: Handheld Periscope Design

Our exhibit focuses on the principles of mirrors and optics. Measuring a field of sight or the quality of an image can be difficult, and while there are some mathematical methods for calculating an approximate field of vision; it is best determined by testing. Mathematical approximations for the field of vision, and the degree of tunnel vision that is experienced when looking through a length of pipe can be found in Appendix E. Ultimately a large portion of our exhibit was analyzed quantitatively by testing various pipe sizes, lengths, and mirror angles, found in section Appendix E. One of our educational objectives is to teach kids the difference between the vision of a human and that of a fish. Because fish have eyes on the sides of their heads, their vision points sideways. Although the periscopes have a limited field of vision compared to a fish, this idea is demonstrated to a certain extent. The exhibit signage, which can be found in Appendix F, features images demonstrating the field of vision of a fish and that of a human. In addition to a basic understanding of fish vision, the exhibit teaches concepts about light. It shows that mirrors can reflect light in multiple directions. Children are assumed to have a general familiarity with mirrors because of everyday use. However, the periscopes enable the children to see objects to their sides as if the objects were in front of them. The exhibit signage also shows a diagram of incoming light being reflected from the side into a person's eyes, which demonstrates this phenomenon. The testing, questioning, and observations made while playing around with the periscopes will provide them with an intuitive sense of light, direction, and reflection. This is invaluable for a child studying these concepts later in life. Given these considerations, the exhibit helps make the museum a more effective informal learning environment [13].

5.3 Industrial Design

The exhibit has good aesthetic characteristics. The edges are rounded and smoothed over during the construction process. This increases safety because a child is less likely to get poked or scratched. The aluminum has been coated in a textured black rubber finish. The blue windows and stainless steel handles provide good contrast to the black. Ergonomics are good primarily due to the light weight of the binoculars. The stainless steel handles provide a smooth and comfortable grip that is under the mass. A child can comfortably hold the binoculars up to his or her eyes. In an emergency situation, the exhibit is safe because it is handheld, and can therefore be easily dropped. The proper use of the exhibit is self-explanatory. This is because the device compares to regular binoculars, with which most children have a general familiarity. From here the purpose of the exhibit can be understood. The signage for this exhibit provides helpful visual information so that a user can see the scientific concepts of the exhibit and how to use the exhibit. The complete signage can be found in Appendix F.

5.4 Safety

The See Like A Fish Exhibit is constructed with close attention to safety hazards, adhering to the ASTM F963-11 Standard Consumer Safety Specification for Toy Safety [14]. The edges of the aluminum box have been hemmed and the whole box has been covered with multiple layers of rubber coating to get rid of the sharp corners, satisfying the accessible edges safety requirement for metal toys in section 4.7.3. There is a threaded rod that attaches the elbow joints and the handles to the aluminum box, which is not exposed,

Figure 15: Blunt Corners

satisfying the accessible edges safety requirement for Exposed bolts and threaded rods section 4.7.5. There are acrylic windows in the box to prevent the user from contacting the thin edge of the aluminum box frame also satisfying section 4.7.3. The paint applied to the aluminum box is standard spray paint and is safe for application on any surface, thus complying with section 4.3.1. The rubber coating on the aluminum box along with the paint do not contain any amount of lead satisfying the heavy elements safety requirement for paint and similar surface-coating materials section 4.3.5.1. The mirrors are made of stainless steel and the side walls are made of Lexan to prevent shattering if the exhibit is dropped. The elbow joints are round and smooth on the edges that come in contact with the face of the user to prevent any harm to the user's eyes. Since the user will be holding the exhibit up to his or her face, we had to follow the simulated protective devices safety requirement for eye protection in section 4.19.1. Users should be very careful not to drop the exhibit on their foot as it may cause harm. The heavier of the two sets of periscopes has a weight of roughly 4 pounds. The user should also be careful not to fall on the exhibit because of the hard surfaces of the aluminum box. To minimize injury in the case of a child impacting the "Aquarium", the corners have been rounded and chamfered to reduce any sharp edges as seen in Figure 15.

5.5 Material & Component Selection

The construction of the aluminum box was challenging because the "Aquarium" had to be light weight, durable, and child proof. Preliminary plans called for a plastic frame that would provide the basic structure of the protective box. In order to achieve the high level of durability necessary for the exhibit, 3/8" plastic for the side walls and 1/2" plastic and baseplate was required. The size of these plastic pieces greatly increased the weight of the "Aquarium".

.050 inch Mill Aluminum 3003 series alloy was chosen for the frame because of it is lightweight, strong, and easy to fabricate. The thin gage of aluminum chosen provides a great balance of strength and slenderness to the frame. Constructing the frame out of aluminum also allows for the components to be welded together, which made the joints stronger than if the pieces were screwed together. Aluminum sheet metal is widely available and is used in many commercial applications. The aluminum frame has been coated in a rubber coating and painted to provide a soft, child friendly surface. Lexan will be used to create the windows of the "Aquarium" because it is stronger than Plexiglas, shatter-proof, and scratch proof.

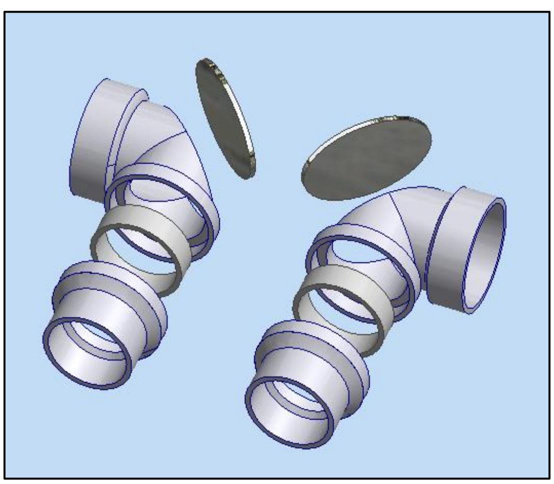


Figure 16: Exploded view of handheld periscopes

The periscopes for the exhibit have been constructed from off the shelf PVC pipe components as shown in Figure 16. These parts include two 2" T joints, which have been cut into

90 degree elbow joints, two 1.5” x 2” couplings, six inches of 2” inch pipe, and two 2” male couplings. These off the shelf components can easily be cut to size to fit the requirements of our design. Traditional glass mirrors were replaced with finely polished type 304 stainless steel sheet metal. The stainless steel mirrors are more durable than glass and will not shatter. The two periscopes have been attached to Aluminum mounts with epoxy. These mounts were then attached to the aluminum frame with threaded steel rod, washers and hex nuts. The ends of the threaded rod were attached to stainless steel handles. The threaded steel rod, washers, hex nuts, and stainless steel handles are all available off the shelf at any hardware store. A complete list of materials and where they can be purchased can be found in Appendix I.

5.6 Manufacture & Fabrication Processes

Fabrication of our exhibit can be divided into two distinct parts. The handheld periscope model can be easily constructed by someone with basic shop tools and building experience. It is highly possible that an individual could construct this design in their own home after a trip to their local hardware store.

Figure 17: See Like A Fish Exhibit - Aquarium Model

The “Aquarium” design is more difficult to fabricate due to its design. By choosing to construct the frame of custom Aluminum parts, fabrication is restricted to an experienced sheet metal worker, or fabricator who has access to many of the tools needed to cut out the parts, and the proper tools to weld the frame together. The fully constructed exhibit is shown in Figure 17. While this custom fabrication process is significantly more involved, a lighter, more durable product is produced than if the product was assembled with screws.

A complete description of fabrication and assembly for the full “See Like A Fish” exhibit can be found in in at the end of this report. A list of materials and tools required can also be found in Appendix H.

5.7 Detailed Drawings

See Appendix G for more detailed drawings.

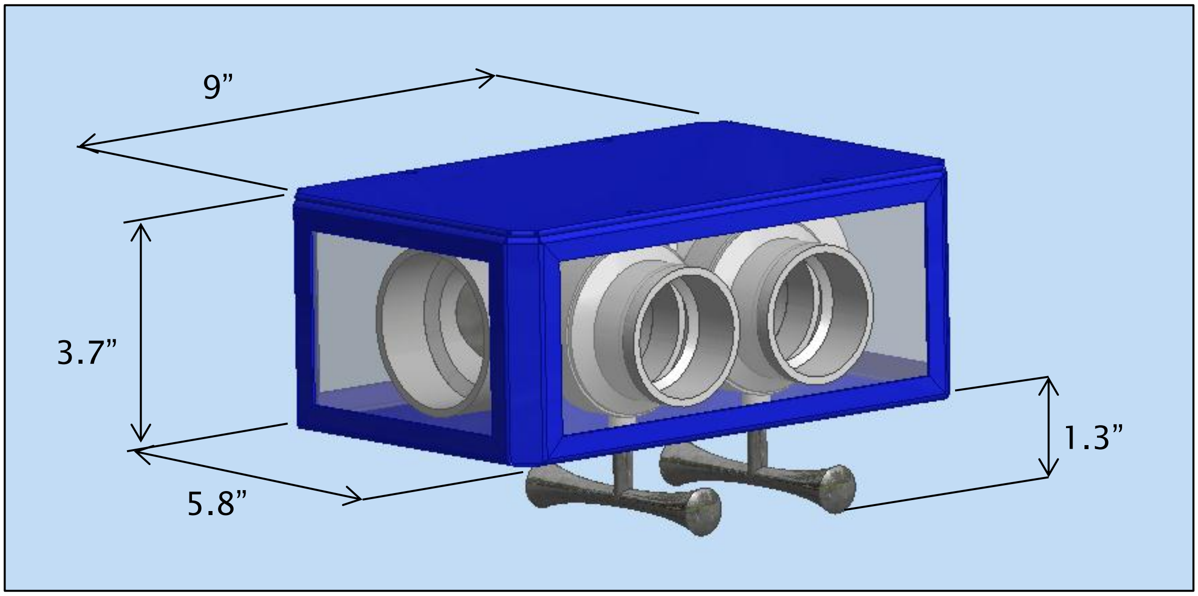


Figure 18: Aquarium Model

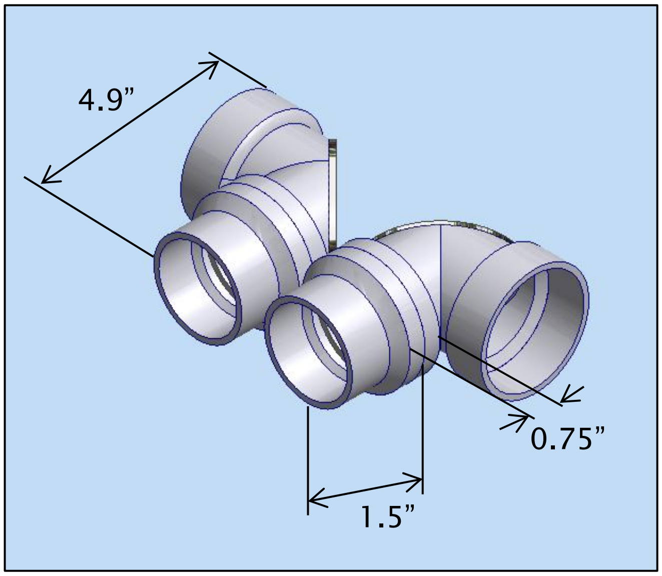


Figure 19: Handheld Periscopes

5.8 Economic Analysis

The cost to construct the See Like A Fish Exhibit includes materials for the frame, the periscopes, the mounts, the appearance, and the cost for labor and tooling. The materials totaled \$97.63 in cost. The labor costs \$60, assuming four hours of labor at a rate of \$15 per hour, making the total cost of construction \$157.63. While the projected cost of total construction is over budget, the labor costs for this project have been mitigated by providing our own labor in constructing the final exhibit. Therefore, the $100 budget is adhered to. The full bill of materials can be found in Appendix I.

The materials used and fabrication process are the result of a compromise between cost and quality. The PVC components used for the periscope construction are durable and low cost. They are also off the shelf parts that are easy to fit together, and must only be modified slightly to function in the exhibit. These components can be found at a local hardware store. Expensive components such as custom fabricated plastic may lead to a more aesthetic and effective exhibit, but given time and price constraints, the PVC offers sufficient quality without unnecessary expense. The same principle applies to the construction of the aluminum frame in place of a plastic frame. Other off the shelf parts are also chosen to minimize fabrication time. The stainless steel knobs used for handles are available at Home Depot. The threaded rod used has standardized dimensions. This also allows standardized fasteners to be used, which can be purchased directly from the manufacturer.

Through the selective use of materials, the safety and durability requirements were able to be satisfied with a low production cost and feasible construction. While the projected cost of total construction is over budget, the labor costs for this project have been mitigated by providing our own labor in constructing the final exhibit. Therefore, the $100 budget is adhered to.

6 Testing

6.1 Testing Procedure

The testing procedure will check the validity of the theoretical analysis, verify that the exhibit is durable, check for appropriate eye spacing, and check for ease of use. These tests are described in Appendix J. Also included are some testing completed for the previous prototype. Testing was done on the beta prototype on Thursday, December 6 at the Discovery Space Museum. The results for some of them can be interpreted from the feedback received from the staff and Dr. Lamancusa. Many of the tests also required the observation of child interaction with the exhibit. A complete description of each intended test is listed in Appendix J. In addition to the results of the prescribed tests, other important input was obtained throughout the session.

6.2 Testing Results & Discussion

The first test was a durability test that involved dropping the periscopes and aquarium at several different angles and a height of 4 feet. Observation of any damage would lead us to modify the exhibit as necessary. While the possibility remains that a child will intentionally or unintentionally drop the exhibit on the ground, this test was not conducted. Given our time constraints, if the exhibit were to break in the duration of this test, there is a possibility that Team C would be unable to repair the damage caused. The exhibit was designed to be durable, but the proposed durability test poses a risk not worth taking. Although this durability test was not enacted, the testing done at the museum provided useful input in this regard. At several points in the session, the stainless steel handles came unscrewed. This problem can be resolved by adding locknuts to screw against the edge of the handle threads.

The second test was for intuition. The aquarium model and the handheld periscopes were handed to children with no instructions given. It was observed that the children did not know the proper orientation to hold the "Aquarium" model such that their arms or hands would not block their vision. As a result, the signage was corrected with a diagram of how to use the "Aquarium" model. We also observed that some children connected the handheld periscopes to the aquarium model to see what would change. This shows that the children's curiosity was sparked by this unique use of mirrors. Despite the fact that kids do not intuitively use the periscopes in the intended manner, it is not necessarily the wrong way.

It is important consider that the ergonomics of the "Aquarium" had some flaws. The weight of the "Aquarium" model to an adult may not seem to be a lot, but a child may find it more difficult to manage while holding it from the bottom. None of the children held it in the intended position for very long before putting it down. It is also possible that the handles are too close together, decreasing balance. Test three was for eye spacing and ease of use. The free periscopes can be adjusted by the user for eye spacing, but "Aquarium" model appeared to have the proper eye spacing for all children. One child reacted when someone waved to them through either periscope, so he was able to see through both sides. When asked to navigate through the museum, some insisted that they couldn't do it, while others took a few steps, and then stopped. Our observations cannot conclude whether this was due to ergonomics or visual impairment caused by the exhibit. With the consideration that an adult might have difficulty moving about the museum using the periscopes, visual impairment is likely a primary cause of low usability.

Test four evaluates the theoretical analysis shown in Appendix J. Our experimental results have been compared to the results of the theoretical analysis using the same inputs. Experimental results and discussion are also shown in Appendix J.

One comment that a staff member noted was that some of the mirror edges on the handheld periscopes were too sharp. This has been corrected by grinding down the edges to make them round, eliminating the sharp corners. Dr. Lamancusa requested the mirrors be more permanently affixed to the periscopes. This has been accomplished with epoxy.

7 Maintenance and Operation Instructions

To uphold the safety and usability of the See Like A Fish exhibit, it must be maintained on a regular basis. Because this exhibit comes in contact with children's faces, it must be cleaned after each day of use. Use any form of glass cleaner to wipe down the mirrors and disinfectant wipes. The only official operation instructions of the exhibit are to look through the periscopes such that the ends are in the directions of the user's left and right peripherals. These instructions are displayed on the signage, which can be found in Appendix F. Any other operation of the exhibit is to be determined by the experimentation and curiosity of its users.

8 Conclusion & Recommendations

The See Like A Fish exhibit is a positive contribution to the Discovery Space Museum. It allows the user to experience the vision of a fish. This has been accomplished through the construction of PVC pipe elbows with the corners replaced by mirrors, which redirect light from the sides into the user's eyes. Two of these periscopes have been mounted into an aluminum box with handles on the bottom, resembling a mobile Aquarium. The See Like A Fish exhibit teaches the user about educational concepts such as mirrors, light rays, and the anatomy of a fish.

Although the exhibit may be considered a success, other possibilities exist for the same general concept. One flaw the periscopes have is their limited field of vision. This could be fixed with the use of larger mirrors and/or a concave lens. The time constraints and budget limitations we were given prevented us from resolving this issue when we came across it. The other issue that was noticed was that the children were not holding the Aquarium model upright. We believe that this is an issue having to do with the handles on the underside of the exhibit being too close together. Mounting the handles farther apart would improve the balance of the Aquarium model. The museum staff approves of the safety of the exhibit provided the completion of our final modifications.

The exhibit is fun to play with and teaches some fundamental scientific concepts. The two primary takeaways are the understanding of how a fish sees and an intuitive sense of mirrors and light. Curious children will wonder why they see what they do when looking into either the aquarium or free periscopes. The creative ways that children choose to use the exhibit may even provide education beyond what is intended.

Although we were successful in the completion of this project, some conflicts were encountered. Miscommunications and interpersonal issues interfered with the enthusiasm of designing a deliverable science museum exhibit for the educational benefit of children. Despite all of our struggles, we all gained team building skills that enabled us to overcome this challenge.

The course could be improved if it did not have so much emphasis on writing. Although it is understood that effective writing will be essential in any engineering career, it caused this course to consume much more time than other three credit courses. Additionally, we could have used more time to develop prototypes, resolve conflicts, and ultimately yield a better product to the Discovery Space Museum. It also seems that much of the semester time is spent externally searching and developing concepts. Expediting this process somehow could reduce some of the much needed time working later in the semester. At the same time, it is understood that teamwork often involves conflicting interests and interpersonal conflict. Overall, this course has given us an experience of a practical engineering project as well as skills that can be used in our careers after graduation.

9 References

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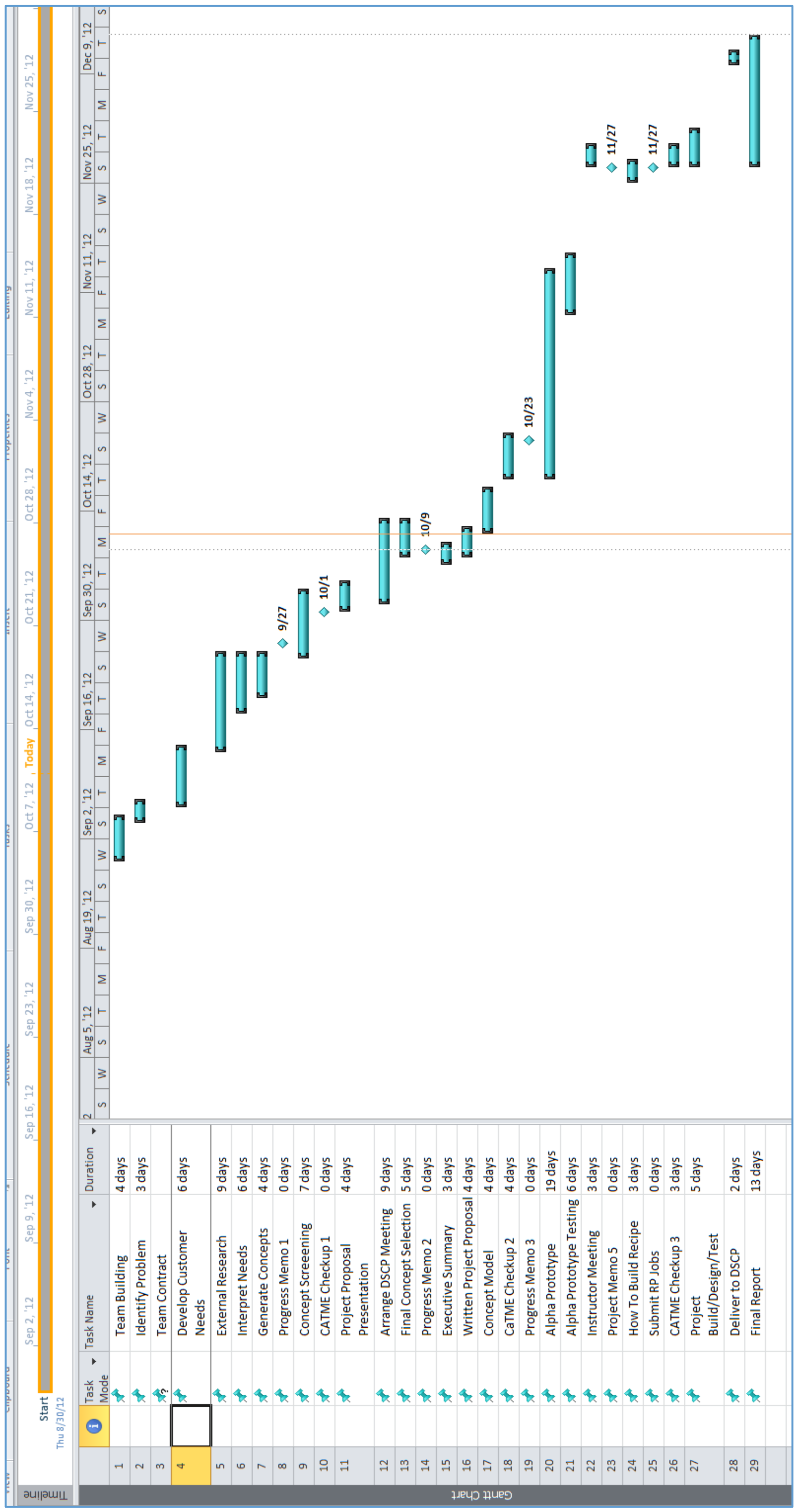
10 Appendices

Appendix A: Gantt Chart



Appendix B: AHP Matrix

Evaluated	Safety	Cost	Durability	Reliability	Aesthetics	Mobility	Intuitive	Scientific Concepts	Maintenance	Interactivity	Total	Weight	Corrected Weights	Rank
Safety	1	5	3	2	3	4	3	2	3	3	28	0.20	20%	1
Cost	0.2	1	0.33	0.33	0.5	2	0.5	0.33	1	0.25	5.44	0.04	5%	8
Durability	0.33	3	1	1	4	3	2	1	3	3	20.33	0.14	15%	3
Reliability	0.5	3	1	1	2	1	0.33	0.33	1	1	10.16	0.07	10%	7
Aesthetics	0.33	2	0.25	0.5	1	3	2	3	4	0.5	15.58	0.11	10%	5
Mobility	0.25	0.5	0.33	1	0.33	1	0.33	0.33	1	0.25	4.32	0.03	5%	10
Intuitive	0.33	2	0.5	3	0.5	3	1	3	4	1	17.33	0.12	10%	4
Scientific Concepts	0.5	3	1	3	0.33	3	0.33	1	3	0.33	14.49	0.10	10%	6
Maintenance	0.33	1	0.33	1	0.25	1	0.25	0.33	1	0.2	4.69	0.03	5%	9
Interactivity	0.33	4	0.33	1	2	4	1	3	5	1	20.66	0.15	15%	2

Weighting scale: 1= Equal

2= Moderately Important

3= Strong Importance

4= Very Strong

5= Extreme Importance

Appendix C: QFD Chart

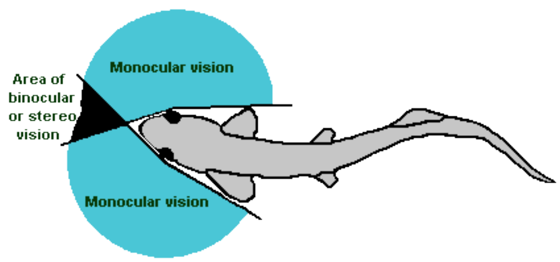
Customer Needs	Meets Toy Safety Standards	Total cost is less than $100	Does not fail under loading of 100 pounds	Children use the exhibit at least once every visit	Holds a child's attention for at least 5 minutes	Incorporates at least 1 scientific concept	Weighs less than 50 pounds	Requires under 1 hour of maintenance per month	A child can understand how to use the exhibit in under 30 seconds
	Product Specifications								
Safety	X								
Cost		X							
Durability			X					X	
Reliability			X					X	
Aesthetics									X
Mobility							X		
Intuitive					X				
Educational						X			X
Maintenance								X	
Interactivity				X	X				X

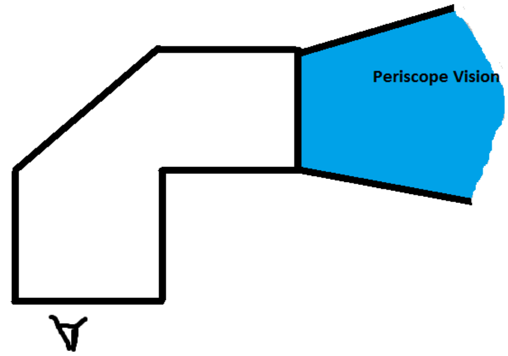
Appendix D: Concept Scoring

		Kinetic Art		Perpetual Motion		Compass		Fish		Airplane		Marble	
Selection Criteria	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Safety	0.20	4	0.79	4	0.79	5	0.99	4	0.79	5	0.99	3	0.60
Cost	0.05	5	0.25	3	0.15	3	0.15	2	0.10	2	0.10	2	0.10
Durability	0.15	4	0.60	3	0.45	3	0.45	4	0.60	4	0.60	3	0.45
Reliability	0.10	3	0.30	3	0.30	4	0.40	5	0.50	3	0.30	3	0.30
Aesthetics	0.10	5	0.50	5	0.50	2	0.20	3	0.30	4	0.40	5	0.50
Mobility	0.05	5	0.25	3	0.15	4	0.20	5	0.25	3	0.15	3	0.15
Intuitive	0.10	4	0.40	5	0.50	3	0.30	3	0.30	2	0.20	3	0.30
Scientific Concepts	0.10	3	0.31	3	0.31	4	0.41	4	0.41	4	0.41	4	0.41
Maintenance	0.05	4	0.20	3	0.15	3	0.15	3	0.15	3	0.15	4	0.20
Interactivity	0.15	4	0.59	3	0.44	2	0.29	5	0.73	3	0.44	5	0.73
Total			4.19		3.74		3.55		4.14		3.74		3.74
Rank			1		3		6		2		5		4

Appendix E: Theoretical Analysis

One important consideration to be made is how much the viewer will be able to see looking into the device. When the viewer looks into the periscopes, he sees a circular image that is shrouded by the edges of the pipe fitting. Therefore he cannot have the wide field of sight that a fish sees out of its eyes.





Ideally, the viewer would be able to see as if his or her eyes were located at the sides of it. Then they could truly see like a fish. Unfortunately, this will not be the case because of the limited scope of the periscopes. The image that the viewer can see will be referred to as the field of vision. This is the diameter (f) of the image seen by the viewer. This measurement will be calculated at distance (d) perpendicular the side of the periscope. The following shows how the length and diameter of a straight pipe affects the field of vision if one were to hypothetically look through it. After that, this model will be related to the periscopes used in the device. The model for the straight pipe is shown in Figure A. This is looking from the top down, showing the horizontal angles at which the viewer can see.

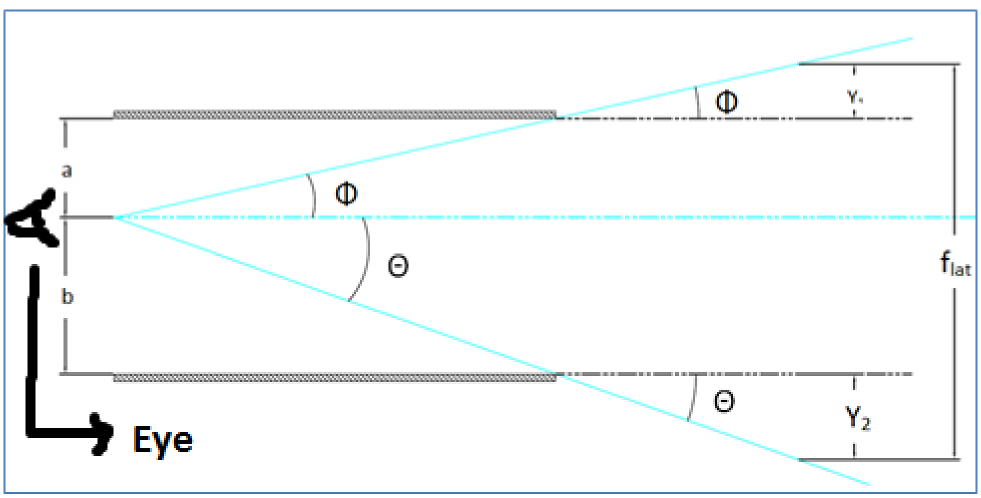


Figure A: Top view of looking through a straight pipe

Assumptions:

- The pipe is of constant diameter
- The eye is even with the end of the pipe

For angle ϕ, the expansion of the field of vision y_1 is calculated as

$$y_1 = d\tan(\phi) = d\left(\frac{b}{l}\right)$$

Similarly, for angle θ,

$$y_2 = d\tan(\theta) = d\left(\frac{a}{l}\right)$$

In summation, the lateral field of vision is

$$f_{lat} = (a+b) + y_1 + y_2 = (a+b) + d\left(\frac{a}{l} + \frac{b}{l}\right) = (a+b) + d\frac{(a+b)}{l}$$

Note that $(a+b)$ = the diameter of the pipe.

Figure B shows the same model from the side. Using the same equations, f_{lat} in the vertical field of vision is shown to be the same as that in the horizontal. Since the pipe is long enough, it can be assumed that the off center position of the eye has little effect on vertical field of vision. This is assumed to be true from any perspective. Therefore f is approximately the same all around. This shows that the field of vision is approximately circle.

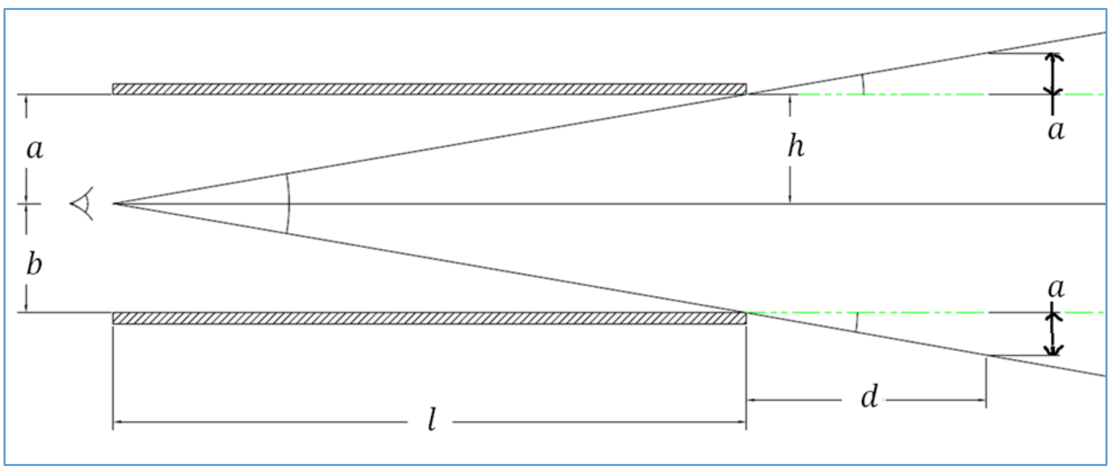


Figure B: Side view of looking through a pipe

To translate this analysis to the elbows, consider first the comparison of the elbow and straight pipe in figure c. Assuming these have the same diameter and the mirror is oriented so that each end point forms a right triangle with the mirror as the hypotenuse, as is shown in figure c, it can be shown that the field of vision for both the straight pipe and the elbow is the same.

Figure d demonstrates this pictorially. This representation does not prove the conclusions drawn, but shows strong evidence that supports them. In Figures C and D, it is assumed that

$$l_1 + l_2 + l_3 = l_s$$

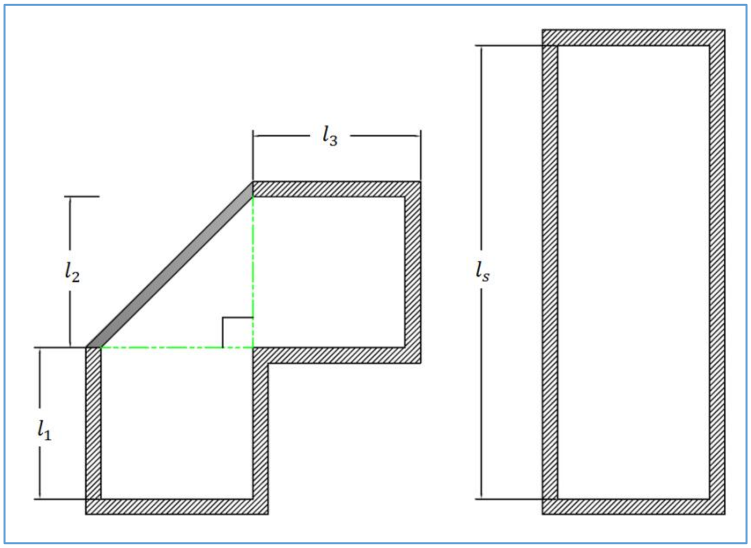


Figure C: Comparison of straight vs. angled pipe

The angles that form the outer border of sight for the straight pipe were first drawn on the elbow. Then two lines are constructed from the points of intersection with the mirror to the edges of the sideways facing pipe. This is truly the path the light follows because the angles of incidence on the mirror appear to be the same for the light rays. If two construction lines are drawn from the point of incidence, one vertical and one horizontal, it is shown that the angle of the incoming light is equal to the angle of the light interpreted by the viewer.

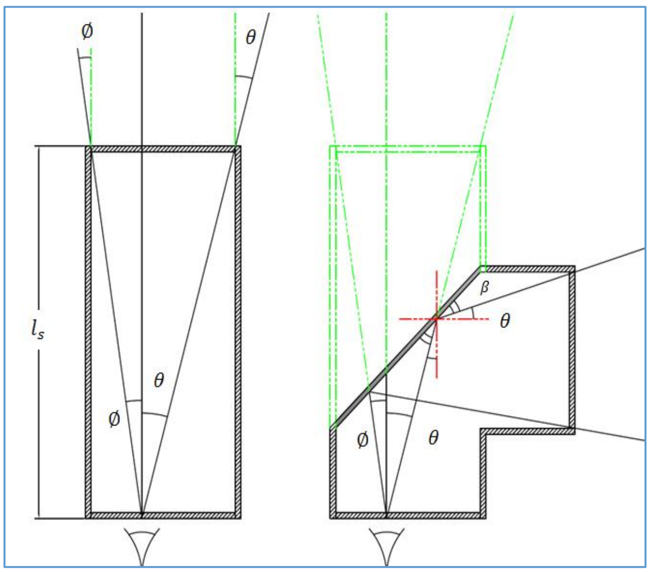


Figure D: Line of sight of straight pipe vs. an elbowed pipe

$$\beta + \phi = 45°$$

β is the same on either side of the point of incidence. Therefore ϕ is also the same. If a similar model is made using a side view of the periscope, the vertical field of vision is shown to be the same as a straight pipe with the similar dimensions. If the eye were to look at the upper edge in either pipe, the light would enter the eye from

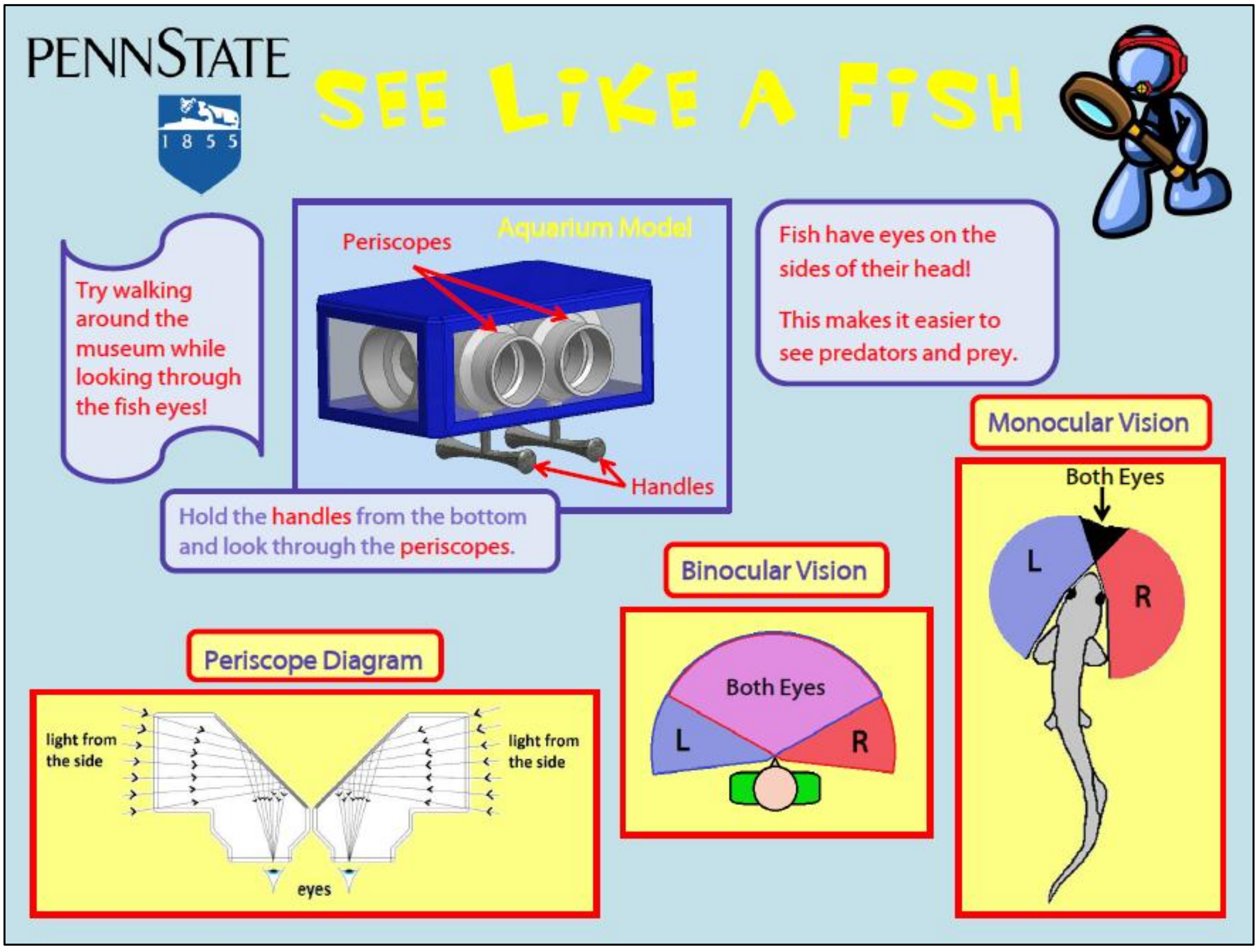
$$\theta = \tan^{-1}(\frac{h}{l})$$

if y is the vertical distance between the eye and pipe edge and l is the length of the pipe in Figure B. If a line with this angle is observed in the elbow, the horizontal projection of the line is as long as the horizontal projection of the line in the straight pipe. This is assumed based on the symmetry about the mirror in figure d. Note that the light reflects of the mirror with the angle θ between the line and the horizontal plane. The vertical distance in the elbow is

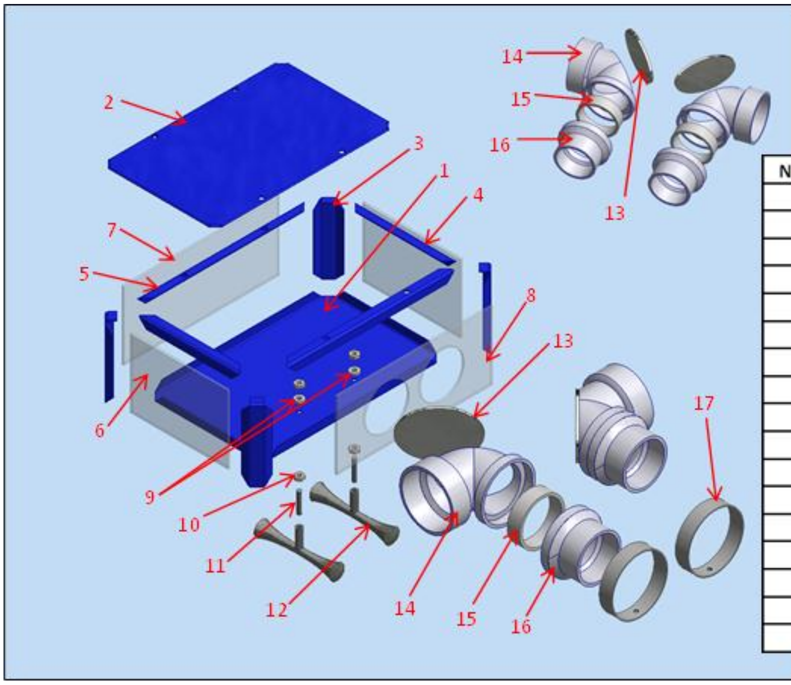
$$h' = l' \tan\theta = l \tan\theta = h$$

So the boarder of the incoming light enters the periscope and eye at the same angle as in the straight pipe. Thus, the field of vision for an elbow can be calculated using the same equations as a straight pipe when $l_1 + l_2 + l_3 = l_s$.

Appendix F: Exhibit Signage



Appendix G: Detailed Drawings



Number	Part
1	Bottom Plate
2	Top Plate
3	Side Wall x4
4	Top Component (Short) x2
5	Top Component (Long) x2
6	Side Window x2
7	Back Window
8	Front Window w/ Holes
9	Aluminum Washers x8
10	Steel Hex Nut x4
11	Threaded Rod x2
12	Stainless Steel Handle x2
13	Stainless Steel Mirror x4
14	PVC Elbow Joint x4
15	PVC Connector x4
16	PVC Adapter x4
17	Aluminum Hoop Brace x2

Figure 1: Exploded assembly drawing of the Aquarium model. Pieces are attached via welds of epoxy as stated in the How To Build Recipe

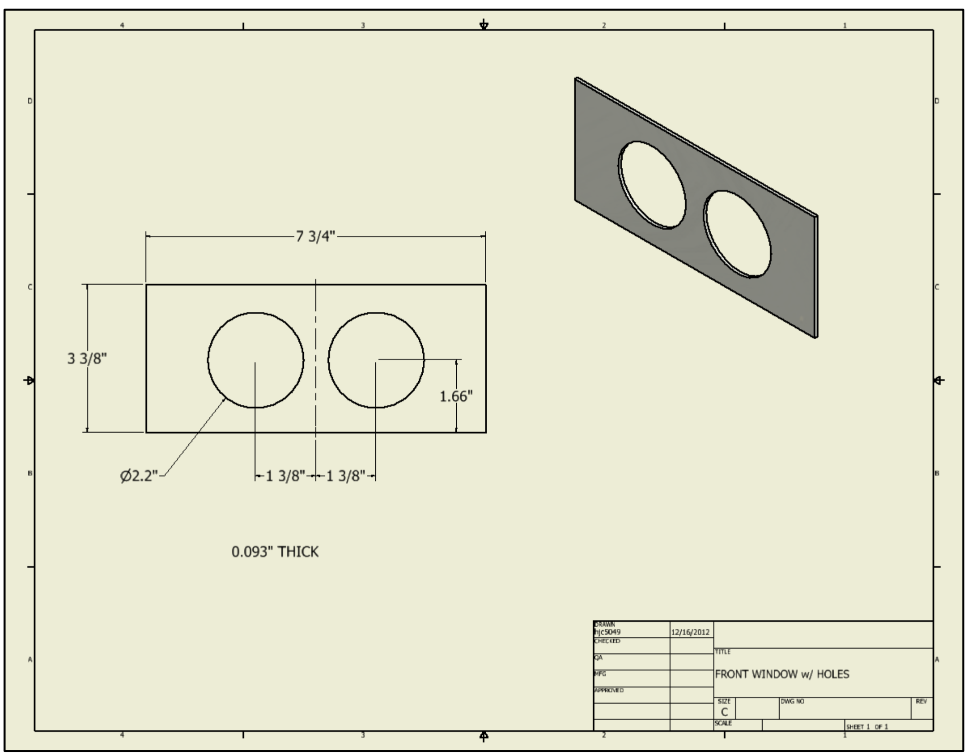


Figure 2: Front Window with Holes

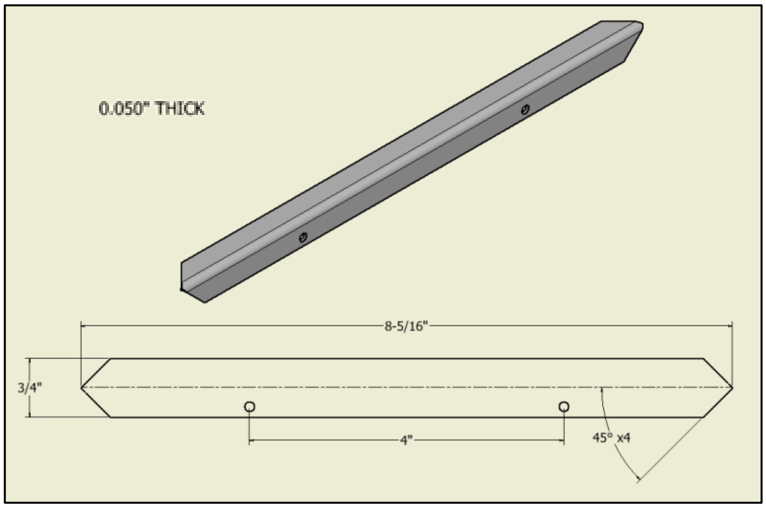


Figure 3: Aluminum Frame Top Piece (Long)

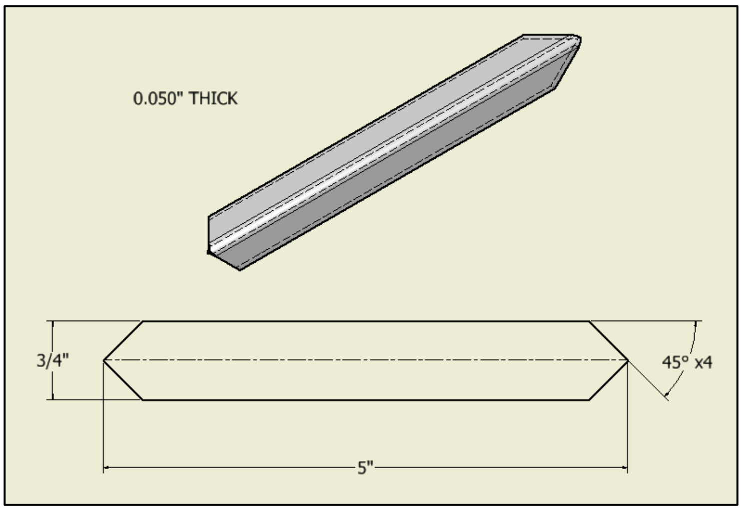


Figure 4: Aluminum Frame Top Piece (Short)

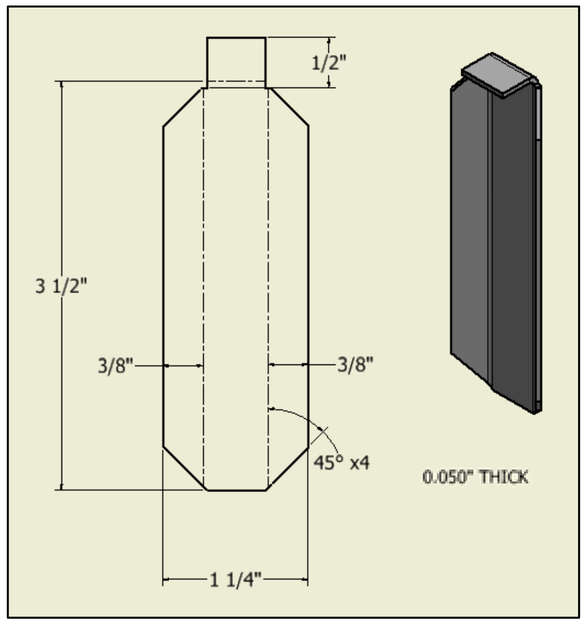


Figure 5: Aluminum Frame Side Wall

Figure 5: Lexan sheet with cutouts for eyepieces

Appendix H: Fabrication

Complete Instructions can be found in at the end of this report.

Materials needed:
1 sq ft .050 Mill Aluminum sheet metal 3003 Series ASTM B209
Rust-Oleum leak seal flexible rubber coating
12”x24” sheet of clear Lexan
4 2” diameter PVC T joints
4 1.5” to 2” diameter PVC joints
1’ PVC pipe 2” diameter
4 2” Male pipe adapters
2 Brushed stainless steel handles
3/16” diameter threaded rod 6” long
6 steel 3/16” hex nuts
2 Aluminum 3/16” hex nuts
8 Aluminum 3/16” washers
4”x6” Stainless steel sheet metal
Blue spray paint
1 tube Clear epoxy
3’ Aluminum Welding rod

Tools needed:
Pair of shears
Ruler
Square
Metal scribe
TIG Arc Welder
Welding gloves
Welding shield
Press brake
Hand brake
Tap for 3/16” threaded hole
Razor blade
Band saw
Drill
Buffing pads and compounds
2.5” hole saw

Appendix I: Bill of Materials

Item	Cost	Quantity	Subtotal	Vendor
Frame				
0.050 Mill Aluminum 3003 Series ASTM B209	$3.00/ sq. ft	1 sq ft	$3.00	ALCOA
Lexan Sheet (12"x 24"x .093")	$12.98	1	$12.98	Home Depot
Rust-Oleum Rubber Coating	$9.96	1	$9.96	Home Depot
Aluminum Welding Rod	$3.00/ ft	1 ft	$3.00	Jackson Welding Supply
3/16 x 1/4 in. Aluminum Machine Screws w/ Binding Post	$1.18	4	$4.72	Home Depot
Subtotal			$33.66	
Periscopes				
Type 304 Stainless Steel 2b Finish ASTM A240	$2.50	1 sq ft	$2.50	Samuels Metals
2" PVC Tee Joint	$3.54	4	$14.16	Home Depot
2"x 2' PVC Pipe	$3.81	1	$3.81	Home Depot
2"x 1-1/2" Reducer/Increaser	$1.23	4	$4.92	Home Depot
2" Male Adapter	$1.29	4	$5.16	Home Depot
Plastic Expoxy	$5.47	1	$5.47	Home Depot
Buffing Kit	$9.97	1	$9.97	Home Depot
Subtotal			$45.99	
Mounts				
Stainless Steel knobs	$3.99	2	$7.98	Home Depot
10/24x 24" 3/16" Threaded Rod	$1.46	1	$1.46	Home Depot
Aluminum Hex nuts	$0.08	2	$0.16	American Fastener
Steel Hex Nuts	$0.04	4	$0.16	American Fastener
Aluminum Washers	$0.06	8	$0.48	American Fastener
Subtotal			$10.24	
Appearance				
Blue Spray Paint	$3.87	1	$3.87	Home Depot
Grey Spray Paint	$3.87	1	$3.87	Home Depot
Subtotal			$7.74	
Labor				
Labor	$15.00	4	$60.00	N/A
Total				
			$157.63	

Appendix J: Testing Procedure

The materials needed are a tape measure and a yard stick.

Test 1: Durability Test

The impacts that the exhibit may be exposed to must be foreseen and prepared for. Given that this toy is hand held, it is prone to be thrown, dropped on the ground, and accidentally slammed into other objects. While it may not be possible to make the toy indestructible, measures should be taken to prevent damage when exposed to these impacts.

1) Drop the Aquarium model with the handles sticking straight up from approximately 4 feet above the ground.
2) Drop the Aquarium model so that one of its corners takes the impact
3) Drop the Aquarium model from a position in which one of the Lexan windows is parallel to the ground from approximately 4 feet high
4) Observe any damage to components

Test 2: Intuitiveness

1) Hand the child the exhibit and give no instructions and give no instructions
2) Observe what the child does with it
3) Give the child assistance as necessary
4) Observe how much assistance the child needs to properly use the exhibit.

Test 3: Eye Spacing and Ease of Use

The exhibit must be tested with children for overall effectiveness

1) Have the child hold the toy up to his or her eyes
2) Make preliminary observations about the eye position relative to the periscopes
3) Pick an object across the room and ask the child to navigate to that object using the binoculars.
4) Assist the child if necessary to ensure safety
5) Write down any observations about how easily the child could navigate and any possible safety hazards

Test 4: Theoretical Analysis Test

The device will be tested to verify the theoretical calculations. Variables in the formulas developed are taken from dimensions of the prototype. The test will proceed as follows:

1) Measure and record the inner diameter of the periscope end where light enters, or the input end.
2) Measure and record the distance from the end of the pipe to the closest mirror edge. Do this for the input end and the output end.
3) One person looks into one of the output ends, while the output end faces sideways, parallel to the ground. Another person holds a yard stick right next to the input end of the periscope.
4) The yard stick is gradually moved away from the periscope. It is held parallel to the eyepiece end of the periscope and the ground. The height of the meter stick is the same

as the periscope height. The viewer should see the meter stick span the across the approximately circular image at all times. If an edge of the meter stick is seen, the viewer and holder coordinate the forward or backward position of the stick so that it crosses the entire circle.

5) The holder continues moving and adjusting the stick until both ends of the stick can be seen in through the periscope.
6) Place the stick on the ground and use a tape measure to measure the distance from the meter stick to the periscope.
7) Substitute the periscope dimensions from steps 1 and 2 and the distance from step 6 into the formulas in section 5.2 to calculate theoretical field of vision.
8) Compare the theoretical result to the experimental result. Discuss why these results are or are not the same. If they are not the same, try to explain why. Review the formula development and note all assumptions made that were not true in the actual model. Explain how these false assumptions affected the disparity of the results.

Testing will be done on Saturday, December 1 at the museum, and the analysis of the results will be completed by Tuesday, December 4.

Testing of Alpha Prototype:
Some preliminary testing was done to assess how different sized tubes would affect the field of vision of the periscopes.
Materials Needed

- Two periscopes with end diameters of 2”
- 2 6” lengths of 2” pipe
- 2 12” lengths of 2” pipe

1) Look through the periscopes with the ends pointed out to the side.
2) Make subjective observations of how much can be seen
3) Look through one of the periscopes while another person aligns various combinations of pipe lengths in front of the end the eye looks into and the other end.
4) Make observations about how much can be seen

Observations
It is difficult to perceive both images from the periscopes when they are both held up to the eyes. This can be corrected by angling the periscopes slightly outward relative to the eyes. When this is done, two concise images can be seen. These observations led to the inclusion of a rotating feature for the two periscopes in the binoculars. The user can slightly manipulate the angles, changing how much can be seen.

The area that could be seen though the periscope varied based on how long the pipes were held up to the outer and viewing ends. The longer the combination of pipes was, the less could be seen. This led to a goal of keeping the periscope tubes as short as possible to maximize the viewing area.

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How to Build Recipe: See Like A Fish Exhibit

The “See Like A Fish” exhibit provides children with an excellent opportunity to view the world around them as if they were a fish. The exhibit utilizes two sideways mounted periscopes that can be handheld, or mounted in an aquarium like protective box. To use the exhibit, children simply look through the periscopes or the Aquarium model, and are then able to explore their surroundings. The exhibit teaches the principles of mirrors and why fish have eyes on the sides of their head.

This recipe includes the step by step instructions to create the Aquarium model and the handheld periscopes from the materials listed in the Fabrication section in Appendix H and in the Bill of Materials located in Appendix I. Fabrication will require the use of special tools that are commonly located in a sheet metal fabrication shop, or at a welding shop. Preliminary construction can take place at home by substituting shears for the press brake, and using a smaller handheld hand brake. After the parts are made, they can be taken to a local welding shop to be assembled. From there assembly of the rest of the exhibit can take place at home, or in a regular shop.

WARNING: It is recommended that professional help is sought when welding is required to prevent injury.

Aquarium Model

Bottom Plate

1. From the stock aluminum, cut out a 9-3/4”x 6 7/16” piece using the press brake.
2. Use scribe, ruler, and square to layout the pattern A, at the end of these instructions, on the piece of sheet metal.
3. Using a pair of metal shears, make cuts into the corners of the metal following the blue lines.
4. Using the razor blade and a ruler, etch the metal along the red line
5. Etching the metal creates a stress concentration that will allow you to bend off the resulting corners of the plate. Apply upward and downward force onto the corner until it breaks off. Repeat for all four corners
6. Using metal shears, cut each corner to roughly a 45 degree angle, following green lines on pattern
7. Following the etched lines, use the hand break bend all four sides upward at a 90 degree angle, creating the sidewalls for the base of the Aquarium

Top Plate

1. From the stock aluminum, cut out a 9-3/4”x 6 7/16” pieces using the press brake
2. Use scribe, ruler, and square to layout the pattern B, at the end of these instructions, on the piece of sheet metal
3. Using a pair of metal shears, make cuts into the corners of the metal following the blue lines.
4. Using metal shears, cut each corner to roughly a 45 degree angle, following green lines on pattern
5. Hem metal along etched lines, and file and smooth the edges

Side walls

1. Using press brake, cut out a 1.25"x 15" piece of aluminum
2. Using ruler, square and scribe, mark off two parallel lines. Each 3/8" away from each edge
3. Set press brake to cut 3.5" long sections
4. Using press brake, cut 4 pieces.
5. Starting from the etched lines, trim each corner at roughly a 45 degree angle
6. Using hand brake, bend each piece upward along the etched lines at a 45 degree angle

Top Pieces

1. Using press brake cut 2 aluminum strips measuring ¾" x 8-5/16"
2. Using press brake cut 2 aluminum strips measuring ¾" x 5"
3. Using ruler and scribe, mark a centerline on each piece
4. Using hand brake, bend each piece to a 90 degree angle on the centerline
5. Using shears, trim each corner to a 45 degree angle

Frame Assembly

WARNING: Assembly requires welding and should be done by a trained professional.

1. Using TIG arc welder, weld each sidewall to the corners of the bottom plate, using a square to make sure the pieces remain perpendicular
2. After the side walls have set and cooled, weld top pieces on to the tops of the sidewalls, thus creating a frame on which to mount the Plexiglas windows
3. After the welds have cooled, file and debur edges and welds until a smooth appearance is achieved

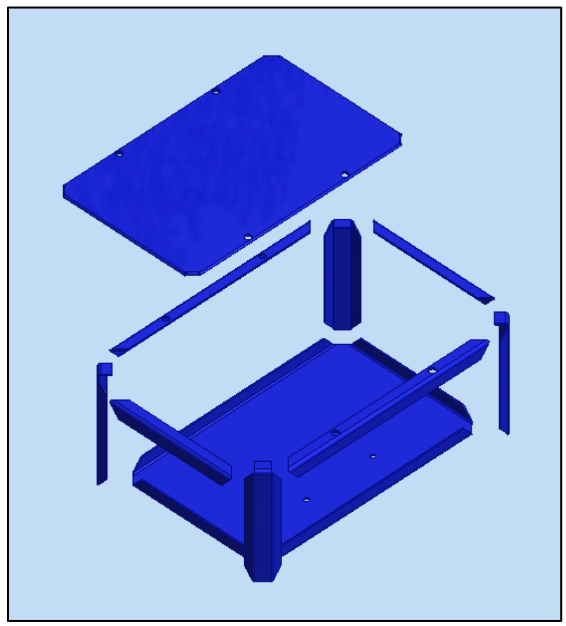


Figure A: Aluminum Frame

Periscopes

1. Using a band saw, cut T joint to form a 90 degree angle. Repeat for second T joint. This will create two 90 degree elbows with a missing corner for the mirror
2. Using ruler, mark a line ½" in from edge of the non-threaded end of each newly cut elbow
3. Using band saw, cut along this line
4. Remove ½" of pipe from the 2" diameter end of the 1.5" to 2" pipe adapter
5. Use band saw to cut 2 5/8" wide sections of 2" pipe
6. Press fit 5/8" wide pipe into the non-threaded end of both elbows

7. Press fit the 1.5" x 2" pipe adapters onto the 2" pipe
8. Using drill press, drill two ¼" diameter holes to a depth of ¼" into the bottom of the periscope joints to allow for clearance of the threaded rod
9. Using rollers, roll two 5/8" wide strips of aluminum into a 2" diameter hoop
10. Weld aluminum hex nuts to the aluminum hoops
11. Wrap aluminum hoops around the joint of the PVC piping
12. Fill the hole drilled in the bottom of each joint in the PVC piping with epoxy

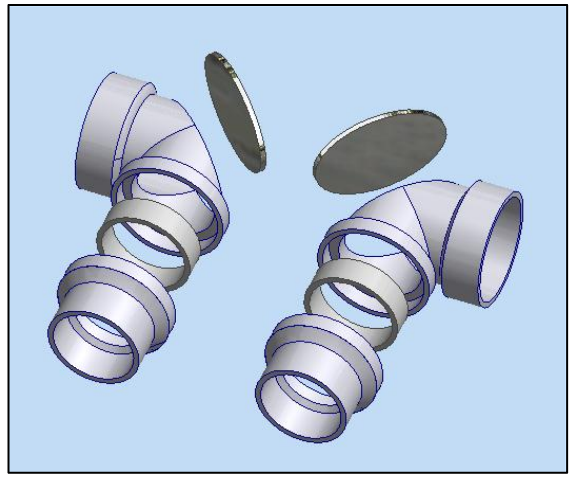


Figure B: Handheld Periscopes

13. Using a 1" section of threaded rod, screw the rod into the aluminum nut welded to the aluminum hoop and into the hole in the PVC joint
14. Apply epoxy to aluminum hoop and PVC pipe to create a strong bond
15. Using a drill and a buffing compound to begin shining the stainless steel to a mirror finish. Start off with the brown compound and move the wheel along the steel in straight lines. Continue with this combination until it no longer has an effect on the metal. Repeat with black and finally white buffing compounds until a mirror finish is achieved
16. Using cut elbow, trace the mirror size on the stainless steel. Also allow for 2 tabs on the end of each mirror to allow for attachment to the PVC pipe. Cut them out using metal shears
17. Attach mirrors to the elbows using epoxy. Apply epoxy to the tabs and around the edges of the mirror
18. Allow time for the epoxy to dry
19. Repeat steps 1-18 and omit steps 8-14 for the handheld periscopes

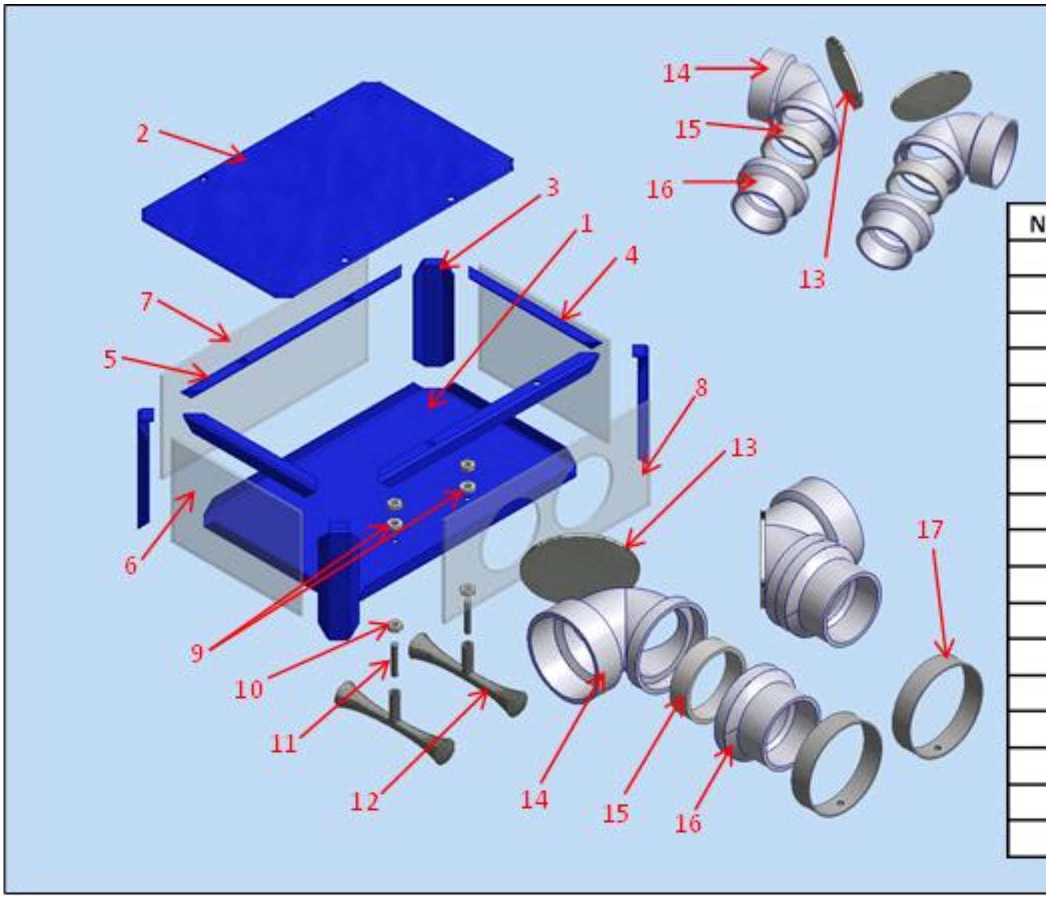
Windows

1. Using band saw, cut out two 3-3/8" x 4-7/8" pieces of Lexan. DO NOT REMOVE PLASTIC COATING
2. Using band saw, cut out two 7-3/4"x 3-3/8" pieces of Lexan. DO NOT REMOVE PLASTIC COATING
3. Using hole saw, cut out two holes in one piece of 7-3/4"x 3-3/8" Lexan that are 3/8" apart from center
4. Using epoxy, attach Plexiglas to inside of aluminum frame
5. Allow time for epoxy to dry

Coating

1. Apply 2 coats of rubber coating to all surfaces of the aquarium structure, paying special attention to avoiding overspray onto the Plexiglas as much as possible
2. Apply 2 coats of blue paint to the inside of the aquarium
3. Apply 2 coats of blue paint to the PVC periscopes, avoiding the threaded metal rod
4. Apply 2 coats of gray paint to the outer edges of the metal frame

Final Assembly

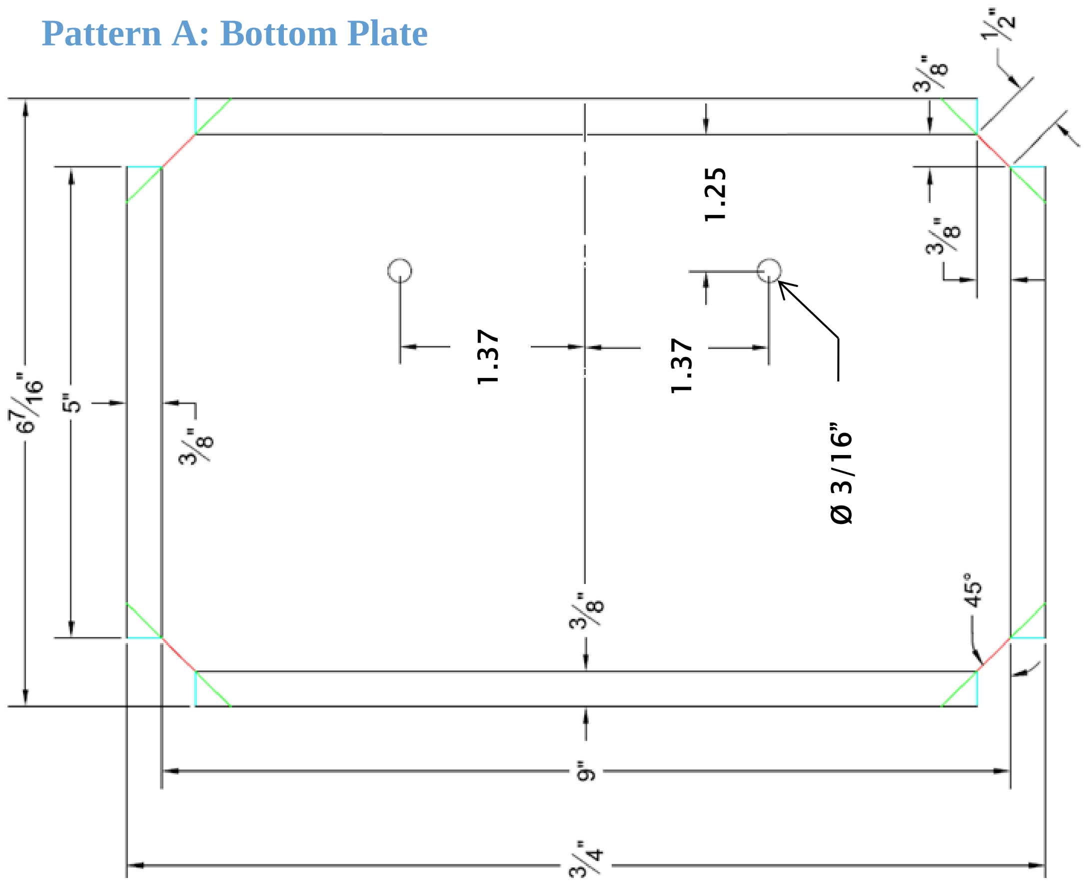


Number	Part
1	Bottom Plate
2	Top Plate
3	Side Wall x4
4	Top Component (Short) x2
5	Top Component (Long) x2
6	Side Window x2
7	Back Window
8	Front Window w/ Holes
9	Aluminum Washers x8
10	Steel Hex Nut x4
11	Threaded Rod x2
12	Stainless Steel Handle x2
13	Stainless Steel Mirror x4
14	PVC Elbow Joint x4
15	PVC Connector x4
16	PVC Adapter x4
17	Aluminum Hoop Brace x2

1. Using ruler find centerline of aquarium structure. It should be perpendicular to the longer edges
2. Drill two holes on the top plate and top edge of the frame that are 4” apart from center and 1/8” away from the edge with a 1/4” drill bit. Repeat for other side
3. Using drill press, drill two holes on the bottom plate that are3/4” away from center and 1” away from the leading edge with a 3/16” drill bit
4. Insert periscopes into aquarium frame and insert metal rods into the drilled holes. Apply metal washers as needed to ensure clearance over the sidewalls of the aluminum frame and proper height relative to the holes drilled in the Lexan
5. Attach an assembly of a washer, hex nut and stainless steel handle to the exposed metal threads
6. Cross tighten hex nut and stainless steel handles
7. Insert crown bolts and binding posts into the top part of frame
8. Screw on top cover
9. Remove protective plastic from Plexiglas

The exhibit is now ready to use!

Pattern A: Bottom Plate



Pattern B: Top Plate