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# 1 Problem Formulation

## 1.1 Introduction

The focus of section 1 is to define the objective of the team project and to model how the project will benefit the Eureka Discovery Museum. Figure 1-1 illustrates our objective.

## 1.2 Objective

The objective of Team The Three Engineers is to design a portable, safe, interactive number system using recycled materials for the Eureka Discovery Museum.

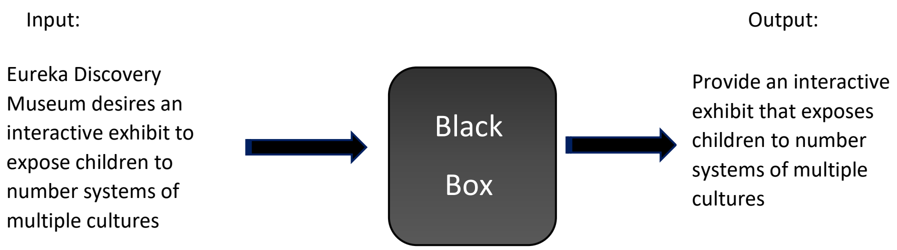


*Figure 1-1 The black box model provides a general overlook of what our design project aims to accomplish.*

# 2 Problem Analysis and Literature Review

## 2.1 Introduction

In the problem analysis the environmental challenges, requirements, and client desires for the exhibit are analyzed in detail. The literature review provides a brief summarization of the information and references studied while seeking to better understand the problem.

## 2.2 Specifications

The exhibit must be physically interactive and not include digital screens. Child safety must be ensured. Loose components small enough to be a choking hazard must be able to be easily assembled and removed in less than five minutes. The exhibit must educate children about different number systems.

## 2.3 Considerations

The client prefers the exhibit to be mobile within the museum as well as to math education fairs. There should be easily replaceable spare parts for small, loose components.

## 2.4 Criteria

In Table 2-1, below, we evaluate different criteria and constraints as well as their relative weighted importance.

*Table 2-1 Criteria and Constraints*

| Criteria | Constraint | Weight (0-10) |
|---|---|---|
| Easily Transportable | A component cannot exceed 30 lbs. | 6 |
| Educational Value | Must incorporate a minimum of two number systems. | 8 |
| Cost | Maximum cost must not exceed $350. | 3 |
| Ease of use for children | Able to be manipulated by children aged 4+. | 7 |
| Ease of Construction | Must be constructible by two people. | 7 |
| Safety | Must have relatively smoothed edges. | 9 |
| Durability | Must not be easily breakable by kids at Discovery Museum. | 10 |
| Aesthetics | Aesthetics must be appropriate for kids at Discovery Museum. | 6 |
| Interactivity | Must engage kids to interact with object. | 8 |

## 2.5 Usage

This exhibit could potentially be used by children of all ages as well as their attending adults. It has also been requested by the client that this exhibit is transportable within the museum as well as outside of the museum to math fairs and similar events. The exhibit must be able to withstand daily use for multiple years.

## 2.6 Production Volume

Only one final unit will be required for this project, with several intermediate prototypes. However, considering the high probability of damage to the exhibit, as well as the likelihood that any small components of the exhibit could go missing, it would be wise to build a more modular design, and supply spare components as well as instructions for repair and replacement of components.

## 2.7 Literature Review

### 2.7.1 Types of Number Systems

A basic understanding of the different number systems is necessary to understand the potential educational opportunities of the exhibit. This sub-section includes a brief survey of the world's number systems.

#### *2.7.1.1 Base systems*

The use of number systems historically emerged in different cultures to help practical communication. The different styles of systems seems to have been linked to the particular culture's methodology of counting. For example, the decimal system, which can be traced as far back as ancient Egypt, is based on counting groups of ten. Counting in groups of ten had practical roots in counting by the number of fingers on one's hand. Many different base systems have occurred historically and still have uses in present day. Base 12 systems still impact modernity when one considers the fact there are 12 months in a year, twice 12 hours in a day, 12 inches in a foot, and the common count measurement of a dozen. (Britannica, 2017)

#### *2.7.1.2 Written numerical systems*

Many different cultures developed a written numerical system at different points in history. The numerical system currently predominate in the west is thought to have originated in India, then further developed in ancient Arabic culture and is commonly termed the Hindu-Arabic system. See Figure 2-1 Evolution of Hindu-Arabic numerals.

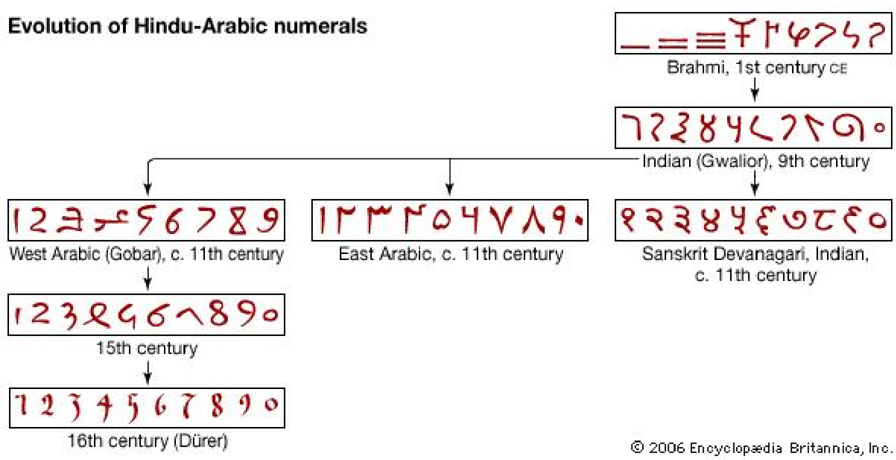


*Figure 2-1 Evolution of Hindu-Arabic numerals*

(Britannica, 2017)

#### *2.7.1.3 Native American systems*

Michael Krauss of the University of Alaska at Fairbanks published an article in the journal "Languages" in 1992 describing the alarming extinction rate of Native American languages. At the time he calculated that of 187 North American Native languages, 149 were no longer being learned by children. He also cited 90% linguistic destruction in the 'English-speaking world'. (Krauss 1992) Perhaps this information would provide greater urgency in including local native language number systems to encourage the preservation of these languages.

##### 2.7.1.3.1 Local Native American Number Systems

The below chart contains the words for numbers 1-10 in several local Native American languages.

*Table 2-2 Northern California indigenous language numbers.*

| Number | Karuk | Tolowa | Hupa |
|---|---|---|---|

| Number System | The Three Engineers | | |
|---|---|---|---|
| 1 | Yítha | Lla’ | La’ |
| 2 | Áxak | Naaxe | Nahx |
| 3 | Kuyraak | Taaxe | Ta:q |
| 4 | Piith | Dunchi | Dink’ |
| 5 | Itrôop | Srweela | Chwola’ |
| 6 | Ikrí vkih | K’weestąni | Xosta:n |
| 7 | Xakiní vkih | Shch’eet’e | Xohx’it |
| 8 | Kuyrakiní vkih | laanisrutnaatą | Ke:nim |
| 9 | itroopatíshaamnih | Lla’dui | Miq’ost’aw |
| 10 | itráhyar | neesan | minlung |
| Source | (Richardson 1993) | (Me’laashne et al. 1995) | (Golla 1994) |

### 2.7.2 Smithsonian Children’s Accessiblity Standards

The Smithsonian museum’s guidelines for accessible exhibit design has a children’s specific section with the following standards that may be pertinent to project:

- For single direction travel provide a 44 in. wide circulation route, 88 inches for 2 direction travel
- Provide passing spaces of at least 74 in. wide at no more than 100 ft. apart
- Select carpets that have a max pile height of 6mm
- Design interactives that are usable from a forward approach with a mx high reach of 36 in. and max low reach of 20 in.
- Side approach interactives have same standard as forward approach
- Extend protrusions from walls all the way to floor (for cane detection)
- A 6-9 year old wheelchair user’s eye level is approximately 41 in. above the floor.

Interesting non-children specific recommendations:

- People with cognitive disabilities have an easier time following instructions if there is an action after each instruction instead of after multiple steps of instructions.
- Written instructions in 70% contrast, sans serif or simple serif type, at least 3/16$^{th}$ in height, and at least 100 lux lighting are easiest to read.
- Avoid shadows on labels
- Print only on solid backgrounds
- Provide high contrast between text and background

(Smithsonian)

### 2.7.3 Number System Games

Number system games help to encourage learning in a fun way. There are many different number games ideas that could be incorporated.

#### *2.7.3.1 Clothes peg game*

Janice Davis has a simple design on how to incorporate basic math problems into a number system game. The game entails attaching clothes pegs with basic math equations to their corresponding numbers on a board. For example, a clothes peg with the equation 11-1 would be attached to the number 10 on the board. This design allows for repetitive use and has many variations of clothes peg equations (Davis 2012).

#### 2.7.3.2 DIY Number Puzzles

This design is aimed towards younger age groups. Matching outlines of numbers with number cutouts allows for a basic visual learning experience. This activity does not incorporate equations but rather the shapes of the numbers for first time learners. After matching the shapes with their corresponding numbers, objects are then placed on the numbers to indicate how many of something that number represents (Davis 2012).

#### 2.7.3.3 Count like an Egyptian Game Client Recommendation

The activity "Count Like an Egyptian" created by Claudia Zaslavsky aims to make children compare Egyptian hieroglyphs with the Arabic number system. Included are worksheets that ask students to write the corresponding Arabic number to an Egyptian hieroglyph. Zaslavsky also dives into other languages such as Mayan numerals and Chinese stick numerals. These games include adding numbers together and completing equations aimed at challenging a young brain. The Climb to the top of the pyramid game requires a set of 3 customized dice. The dice have Egyptian numbers drawn on their six sides in sharpie. Dice one has three ones drawn on, two tens, and one 100. Dice two has two ones, two tens, and two 100s. Dice three has one one, two tens, two 100s, and one 1000. The goal of the game is to reach a sum of 2000 first. All players must agree on the numbers rolled and roll all three dice when it is their turn. This game engages every player and is an excellent learning activity (Zaslavsky 1996).

### 2.7.4 Interactive Children Exhibits

#### 2.7.4.1 Goals of an exhibit

An interactive exhibit is one that engages a visitor in an activity, and makes them gather information and make choices. Exhibits then take results and provide the correct answer to the problem. This procedure allows for active learning through voluntary participation (Allen and Gutwill 2004). Interactivity between youth and an exhibit is essential in the encouragement of learning in children.

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#### 2.7.4.2 Downfalls of interactive exhibits

There are many downfalls in past museum exhibits. One of these downfalls is creating an exhibit that has too many features a user needs to focus on. Keeping it simple is often much more effective when trying to make the user retain what they have learned. Prioritizing one learning experience is essential.

Another downfall in exhibits is when having multiple users becomes a distraction in completing the activity. In creating an exhibit, it is necessary to avoid making an activity that could easily be disturbed by another's involvement. The example used by the Exploratorium was a past exhibit that spun a table with sand on it allowing guests to make patterns in the sand as it spun. The problem with this was that multiple users could create a pattern at the same time allowing for disruption in others designs (Allen and Gutwill 2004).

### 2.7.5 Methods of Engaging Kids

Child engagement is essential to this project. In order to fully engage a child with the exhibit, it must incorporate behavioral, emotional, and most importantly, cognitive engagement. It is important to implement all three of these elements when designing the project to ensure the user is actively learning about the number systems of various cultures.

#### *2.7.5.1 Behavioral Engagement*

Behavioral engagement can be thought of as positive or good behavior while a kid is interacting with the exhibit and with each other. In the "Handbook of Peer Interactions, Relationships, and Groups" psychologist K.C. Wentzel states, "when students work effectively with others, their engagement may be amplified as a result"(Wentzel, 2009). To achieve behavioral engagement, the exhibit could be a cooperation-based game, as opposed to a competition-based game. This is because in a competition, one participant may have an advantage over others, discouraging the less capable from engaging. Whereas when kids cooperate, they are encouraged to work together to accomplish a common goal.

#### *2.7.5.2 Emotional Engagement*

Emotional engagement is important to consider because it takes into account how the child is feeling about a given activity. "When teachers relinquish control to students, rather than prompting compliance with directions and commands, student engagement levels are likely to increase as a result"(Reeve, Jany, Carell, Jeon, and Barch, 2004). In this case the "teacher" will be the directions for the exhibit. This suggests the exhibit should have a more open-ended guideline for the rules and regulations to prevent disengagement. The exhibit should be fun and easy to grasp for kids while still prompting them to learn.

#### *2.7.5.3 Cognitive Engagement*

The most important of these three elements is cognitive engagement because it involves participant thinking. "When students pursue an activity because they want to learn and understand...their engagement is more likely to be full and thorough"(Anderman and Patrick, 2012). This can be accomplished by making the goal of the activity centered around uncovering a hidden number system. In this way kids can actively succeed and learn simultaneously.

### 2.7.6 How to Appeal to children

At first glance, math can be a menacing concept to grasp for younger people. Therefore, it is important for the project to have a mainstream appeal to the younger viewers. James Siegal, the president of the toy company KaBoom! Suggests, “Toys should encourage kids to be creative, challenge them to achieve mastery over time rather than in one sitting”. Given the exhibit requires no screens, it will be best to create a game that inspires imagination and creativity.

Many games that attempt to teach math to kids often fail to maintain the attention of the user. According to mathematician and playwright John Mighton, this often because adults make the game “overly complex”. He continues by revealing, “Children love repetition, exploring small variations on a theme and incrementally harder challenges” (Mighton, 2017). Incorporating a number of small variations to the game, will intrigue the user by the multiple possibilities they can explore. This must be accomplished while still maintaining simple, straightforward content.

### 2.7.7 Upcycle Techniques

Upcycling is a great, resourceful way to take old materials or furniture and transform them into a functional contraption. Useful Upcycle techniques include:

- Chalkboard paint: creating a writing surface on old mirror or desk.

- Clothes: Cut designs and patterns out of fabric
- Tea or coffee: die anything wooden
- Plasticizing paper: with silicon caulking
- Antique paper: paint coffee on paper
- Dry brushing: furniture
- Corks: make water resistant mats

There are several upcycling techniques that can be found at: https://www.pinterest.com/tickledpinktony/techniques-for-upcycling-recycling-reppurposing-di/?lp=true

#### 2.7.7.1 Upcycle Resources

There are a few local resources where upcycled materials can be sourced, such as:

- SCRAP
- Discovery museum
- Old projects from Sci D
- Old furniture
- Metal scrap yard

#### 2.7.7.2 Safety Standards

There is an outline of toy safety standards referred to as ASTM F963-13. Although the Discovery museum may not require all of these standards, utilizing this reference would ensure the product follows basic guidelines for safety. Basic things to remember:

- No small pieces or choking hazards
- Magnets and batteries must be labeled
- Must be accessible for disabled persons
- Prevent projectile objects from entering mouth

The significant changes to the ASTM F963-13 can be found at : https://www.asiainspection.com/astm-f963-16-toy-safety-standard?xtor=SEC-5&sc=ppc&lang=en&campaign=toys&gclid=CjwKCAjwu7LOBRBZEiwAQtfbGPKmQDaigtDFchhHUR4IgPp7PD5HpfaOHBtUeMWDxXxmRR4DnXELihoCDjgQAvD_BwE

# 3 Alternative Solutions

## 3.1 Introduction

In the Alternative Solutions phase of the design process previous research and detailed analysis of the problem is utilized to brainstorm potential solutions. The following section includes an overview of the brainstorming session as well as summaries of selected alternative solutions.

## 3.2 Brainstorming

Our team met on 10/06/2017 to brainstorm alternative solutions. We spent approximately the first thirty minutes in an unstructured, round robin-esque session focusing on producing and recording on a whiteboard as many different solutions as we could think of (See appendix, Figure 1). We then spent five minutes coalescing these ideas into a discrete list (See appendix, Figure 2). Next, we allotted two minutes to list the advantages and two minutes to list the disadvantages of each idea. We then allowed an additional free form ten minutes to further add to the list (See appendix, Figure 3). Finally, we each selected three ideas we liked to further investigate in detail.

## 3.3 Magnet Matcher

The Magnet Matcher game utilizes a 4ft by 3ft magnetic board and two sets of seven 5in tall individual magnets numbered 1 through 7. The magnetic board features 5 different culture groups in their own individual row across the top of the board. Directly under each culture is the corresponding number symbol and the word associated with that symbol. The number symbol and name will be in their own column in ascending order as seen in Figure 3-1. The movable number magnets will be layered with a fabric covering to ensure safety. This is an open-ended game where kids can match a number magnet to whatever culture group they like. There are no specific rules to this game so kids can interact with the board however they like. The only guidelines will be the reference board. The reference board will have a list of all the cultures numbers and their translations. This reference board will be customary for some of our alternative solutions.

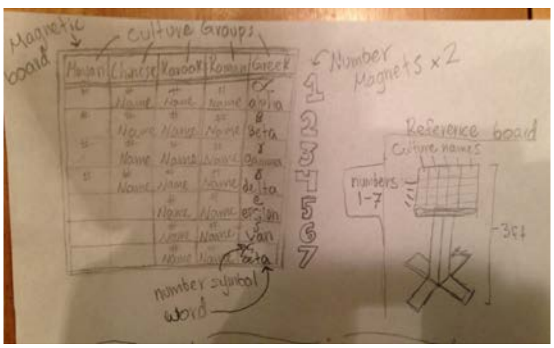


*Figure 3-1 Magnet Matcher Game*

## 3.4 Math in a Cornhole

Math in a Cornhole, is a cooperative game and kids are encouraged to work together. The game board is approximately 4ft by 4ft with 25 circular slots assorted into rows. Inside of each of these slots is a number from one to five from one of five culture groups. Each number will have a matching color to correspond. For example, all the number 1s from each culture will be red, all the 2s yellow, etc. The user is given two sets of five bean bags numbered one through five. The colors of the bean bags correspond with the colors of the culture groups on the board. The objective of the game is to throw the right color bean bag into the matching hole. The user must then identify what culture group the number in the hole originates. They do this by referencing the “number wall” as seen in Figure 3-2.

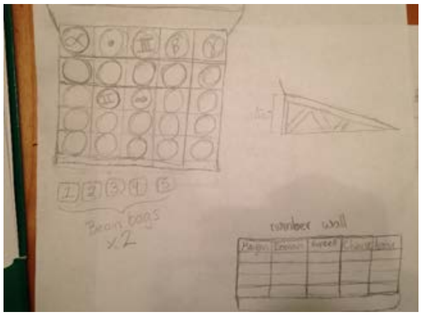

*Figure 3-2 Math in a Cornhole*

## 3.5 Pop Culture!

This is a hand-held game meant for 1-3 players. Similar to the game perfection, the goal of the game is to match all of the shapes to their corresponding sections before the time runs out. However, instead of random shapes, kids will have to match the numbers of different cultures. Instead of a reference board, this game will have a number guide across the top next to the timer as seen in Figure 3-3. To start the game, the user must push down on the board until it is secured by the latches. Then the game begins. The user is then given a minute and thirty seconds to get all the pieces to their designated areas. If time runs out, then the latches will unhinge and pop the board back to its original position. If the user gets all pieces in their respective areas before time runs out, then they hit the timer, stopping it.

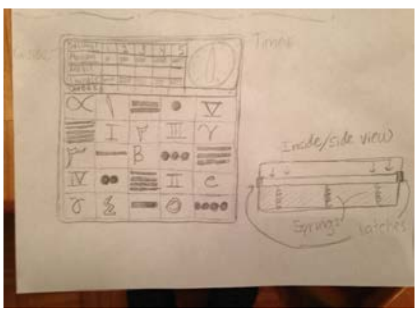

*Figure 3-3 Pop Culture!*

## 3.6 Blank Puzzles Adapted to Display Number Systems

There are several online companies that sell blank jigsaw puzzles, or will print custom designs onto puzzles. A simple jigsaw puzzle of 5-7 columns of 10 pieces displayed the numbers 1-10 in different number systems. The advantages of a puzzle game include being highly interactive, very easily portable, physical adaptability to varying sizes and abilities of children interacting with the puzzle, and cheap and easy construction. Disadvantages include the puzzle pieces potentially being a choking hazard. The individual pieces will be very easy to lose, though this problem could be mitigated by acquiring multiple copies of the puzzle to provide spares. There are also magnetic versions of blank puzzles available to allow for vertical mounting.


*Figure 3-4 Example of a blank puzzle onto which number systems could be painted or printed. http://www.createjigsawpuzzles.com/AttachFiles/WebsiteImages/Product_Show/FI_8437.jpg*

## 3.7 Wood Block Puzzle

The Wood Block Puzzle features a display of different number systems arranged in columns. Each individual number is either carved into or painted onto a wooden block affixed to the display. Several number blocks would be removable from the display. The removable blocks each have a unique shape on their rear portion (opposite the side of where the number is displayed). The unique shape fits into a corresponding uniquely carved slot in the display such that each removable block can only be placed back into the display in the location that correctly completes the column for that number system. Advantages of the Wood Block Puzzle include durability, interactivity, and instructiveness. Disadvantages include difficulty of replacing the removable wooden blocks if they are lost and more complex construction required. Wood Lab Designs of Arcata could potentially be hired to construct the blocks.

An alternate design for the Wood Block Puzzle could include having all the blocks be removable, but have their corresponding slots in the display be standardized with a reference chart of the correct arrangement hidden behind a flap. This alternative would be far easier to construct but would not force the user to learn the correct arrangements of the number system.

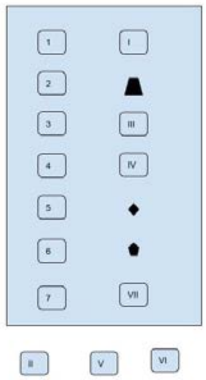


*Figure 3-5 Simplified Drawing of Wood Block Puzzle*

## 3.8 Math Equation Game

The Math Equation Game features a display of several number systems. Below the number system display is a series of math equations utilizing numbers from different systems. Correct solutions to the equations would be concealed beneath a liftable flap. Advantages of the Math Equation Game include a high level of instruction and mathematical challenge, easy constructability, and high durability. Disadvantages include a relative lack of physical interactivity, and a shorter age range of appeal.


*Figure 3-6 Simplified Drawing of Math Equation Game*

# 4 Decision Phase

## 4.1 Introduction

In this phase of the design process, alternative solutions from section III are evaluated against the criteria from section II and a final, best solution is chosen.

## 4.2 Criteria

Table 4-1 Criteria and Constraints displays the criteria utilized to examine the alternative solutions and the relative weights assigned to each criteria.

*Table 4-1 Criteria and Constraints*

| Criteria | Constraint | Weight (0-10) |
|---|---|---|
| Easily Transportable | A component cannot exceed 30 lbs. | 6 |
| Educational Value | Must incorporate a minimum of two number systems. | 8 |
| Cost | Maximum cost must not exceed $350. | 3 |
| Ease of use for children | Able to be manipulated by children aged 4+. | 7 |
| Ease of Construction | Must be constructible by two people. | 7 |
| Safety | Must have relatively smoothed edges. | 9 |
| Durability | Must not be easily breakable by kids at Discovery Museum. | 10 |
| Aesthetics | Aesthetics must be appropriate for kids at Discovery Museum. | 6 |
| Interactivity | Must engage kids to interact with object. | 8 |

## 4.3 Solutions

The final subset of alternative solutions from section III to be evaluated include “Math in a Cornhole”,“Pop Culture”, and a design called “Block Puzzle Matcher”, that seeks to combine the “Wood Block Puzzle”, “Blank Puzzle”, and “Magnet Matcher”. It was decided, in conjunction with the client, that the different interactive puzzle displays should each be explored as different prototypes of a single design effort. It was also determined that the “Math Equation Game” would best serve as a potential add-on to the final chosen design.

## 4.4 Decision Process

The final three solutions under consideration were shared with the client, Ken Pinkerton. Ken seemed to be most enthusiastic about the “Block Puzzle Matcher.” Additionally, each alternative solution was evaluated using a modified Delphi matrix, weighting each design's potential performance against the criteria from section II. Figure 4-1 displays the results of the Delphi Matrix.

| | | Alternative Solutions Weight (1-50) | | | | | |
|---|---|---|---|---|---|---|---|
| **Criteria** | **Weight(0-10)** | **Block Puzzle Matcher** | | **Math In a Cornhole** | | **Pop Culture** | |
| Transportable | 6 | 20 | 120 | 25 | 150 | 50 | 300 |
| Educational Value | 8 | 45 | 360 | 15 | 120 | 25 | 200 |
| Cost | 3 | 10 | 30 | 20 | 60 | 10 | 30 |
| Ease of Use For Children | 7 | 40 | 280 | 30 | 210 | 20 | 140 |
| Ease of Construction | 7 | 30 | 210 | 35 | 245 | 10 | 70 |
| Safty | 9 | 30 | 270 | 45 | 405 | 25 | 225 |
| Durability | 10 | 45 | 450 | 45 | 450 | 15 | 150 |
| Aesthetics | 6 | 45 | 270 | 45 | 270 | 35 | 210 |
| Interactivity | 8 | 40 | 320 | 45 | 360 | 35 | 280 |
| **Total** | | | 2310 | | 2270 | | 1605 |

*Figure 4-1 Delphi Matrix comparing the different solutions against a weighted criteria.*

The "Block Puzzle Matcher" secured the highest score in the Delphi Matrix exercise.

### 4.5 Final Decision Justification

The results of the Delphi Matrix, combined with a high level of client enthusiasm, propelled the "puzzle display" solution to be the final selection.

# 5 Design Specification

## 5.1 Introduction

Section 5 includes a detailed description of the final design for the number systems board game, now known as "Around the World in Twenty Digits", as well as the resources used to make it. The cost of the project is assessed by time invested, material cost, and expected maintenance cost.

## 5.2 Description of Solution

"Around the World in Twenty Digits" exposes the user to the numbers 1-5 of the Roman, Mayan, Chinese, and Greek number systems and is displayed below in Figure 5-1. The numbers 1-5 for each number system are laser engraved into the face of wooden puzzle pieces. The goal is to place each puzzle piece in the correct order in slots in the center of the board. To help guide and educate the user, each number system culture is labeled in a row at the top of the board and the numbers 1-5 in modern English are labeled in a column on the left side of the board. To further assist the user, the pieces of each cultural system have a unique shape and will only fit into slots in the correct culture column. In the lower right corner of the puzzle is a push button connected to a circuit that allows the user to test whether the pieces are correctly placed. When the button is pushed either a red or a green LED light at the bottom of each column will light up. If all the puzzle pieces of a specific culture are in the correct place, the green light below that column will illuminate. If there is a piece missing, or they are in the wrong order, the red light will illuminate (see Figure 5-2). The exhibit is designed to be placed on top of a stand or table at the Discovery Museum. The game board is 35" long, 31.25" wide and 5" tall. In the center of the board are four columns of five removable wooden puzzle pieces. In the face of each puzzle piece is a laser engraved number.

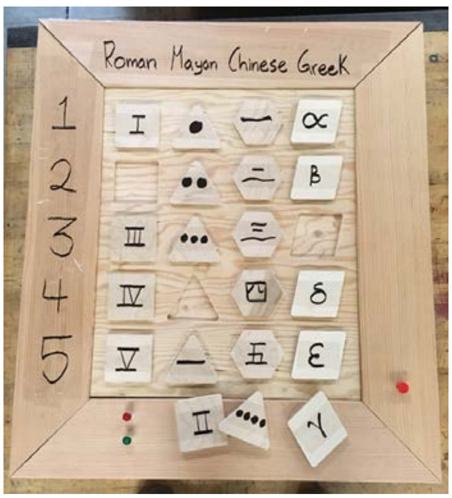


*Figure 5-1 "Around the World in Twenty Digits"*

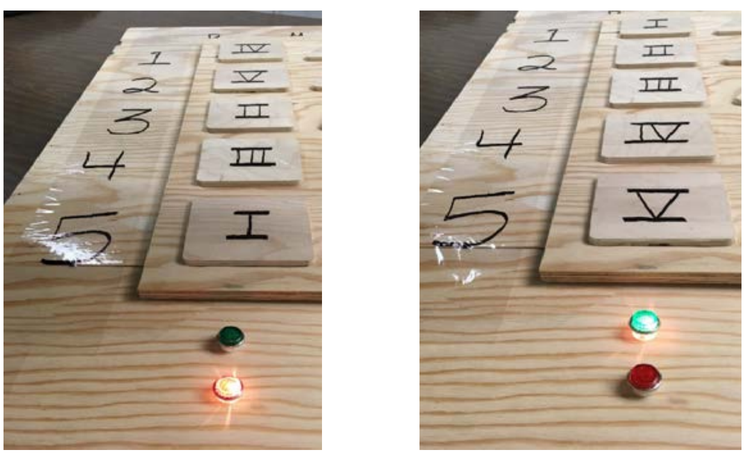


*Figure 5-2 Left Image: puzzle pieces are in incorrect order and red light illuminates. Right Image: Puzzle pieces in correct order and green light illuminates.*

### 5.2.1 Circuit Design

The electrical test circuit is powered by a 12 Volt DC power supply that plugs into a standard 120V AC outlet. The power supply is connected to the push button, which when pressed down, momentarily closes the circuit. When the circuit is closed by the momentary push button, current flows in parallel to four series of five magnetic reed switches. Each series of five switches corresponds to a specific number culture column and is glued to the underside of the puzzle board. The magnetic reed switches have both normally open and normally closed connections. The normally closed connection is connected to the red LED light at the bottom of its column. The normally open connections are strung in series to each successive magnetic reed switch in its column and then the final switch is connected to the green light. Imbedded on the back side of each puzzle are uniquely positioned neodymium magnets (see Figure 5-3).

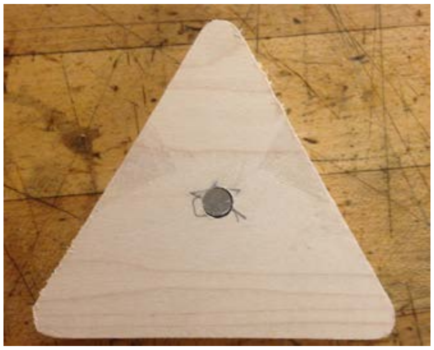

*Figure 5-3 Neodymium magnet imbedded in back of puzzle piece.*

The unique position of the magnets on the backside of puzzle pieces were selected such that the magnetic reed switches on the underside of the puzzle will only change state when the correct puzzle piece is placed in the overlying pocket. Only when all five puzzle pieces are inserted into the pockets in the correct order will the green light illuminate. A simplified circuit drawing is located in Figure 5-4 below.

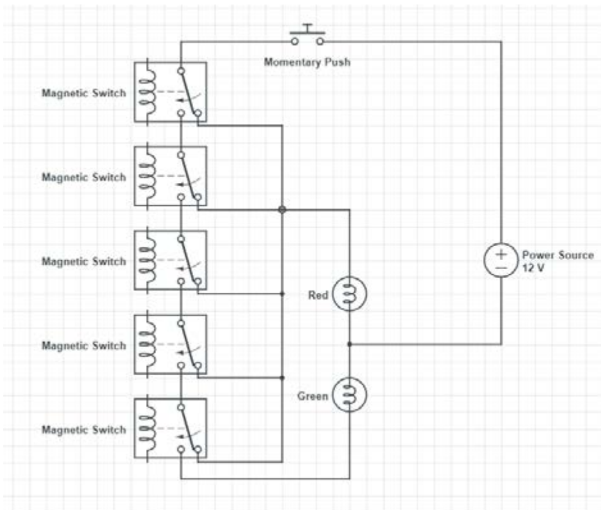


*Figure 5-4 Simplified drawing of test circuit.*

## 5.3 Costs

The project costs were calculated in both hours spent working on the project as well as the monetary cost of supplies.

### 5.3.1 Time Investment

Approximately 120 hours were invested in this project, divided into Problem Formulation, Research, Search for Solutions, Prototyping, and Construction phases. Figure 5-4 demonstrates the proportional expenditure of time on each phase.

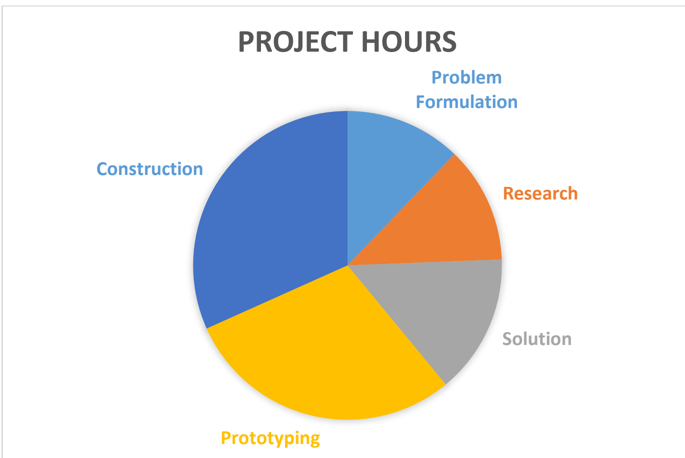


*Figure 5-5 Proportions of time spent on project.*

### 5.3.2 Material Cost

Table 5-1 depicts a list of each item purchased for the implementation of the number systems game. As well as the total cost of the design.

*Table 5-1 Items purchased for project.*

| Item | Price ($) |
|---|---|
| Plywood | 36.80 |
| Wire/Bulbs/ Button | 27.38 |
| 12 V Power Supply | 11.95 |
| 22 AWG wire 100' | 10.53 |
| crimp connectors | 8.95 |
| Green bulb | 2.95 |
| Red bulb | 3.50 |
| reed switches (5) | 19.81 |
| reed switches (24) | 119.35 |
| stain | 14.99 |

| | |
|---|---|
| utility knife | 7.99 |
| sanding sponge | 4.49 |
| sanding paper | 2.00 |
| paint brush | 4.99 |
| led bulbs | 65.00 |
| **Total** | **$ 340.68** |

### 5.3.3 Maintenance Costs

The maintenance costs of the number systems game is conservatively estimated to be roughly $15 and 2-4 hours annually. This estimation is based on an expected annual failure rate of one LED bulb or 1-2 reed switches as well as 1-2 hours required every 6 months to repair a small electrical connection or glued component due to wear and tear of daily use. A spare parts bag along with an electrical schematic will be included in the interior of the frame of puzzle with two red and two green LED bulbs and four replacement reed switches.

# 6 Appendices:

## 6.1 Brainstorming Session Photos

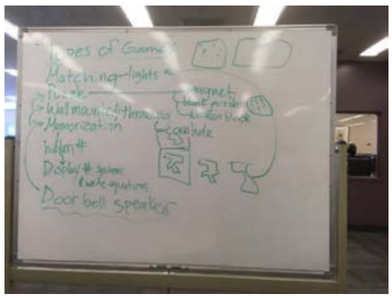

*Figure 6-1 Raw solutions brainstorm results.*

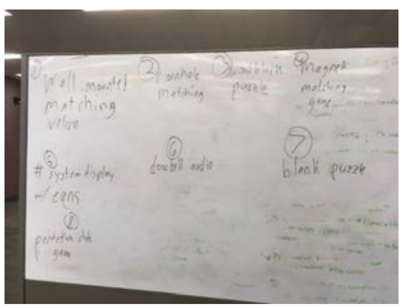

*Figure 6-2 Alternative Solutions Initial List*

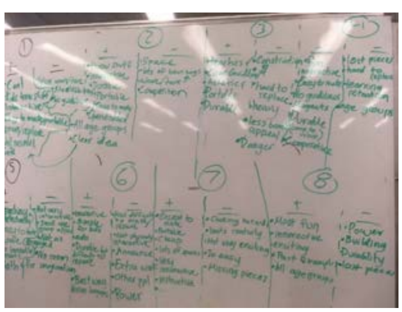

*Figure 6-3 Advantages/ Disadvantages of Alternative Solutions*