SAN LUIS OBISPO CHILDREN'S MUSEUM:
THE CIRCUIT LAB

by

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Executive Summary

Over a nine month period, the senior project team worked closely with the San Luis Obispo Children’s Museum to develop a new interactive exhibit for the museum’s Science, Technology, Engineering, and Mathematics (STEM) floor. The initial budget given for this project was $3,000. The museum’s requirements for a new exhibit were that it must be safe for young children to use, require minimal supervision, is interactive, has learning objectives, and is economically feasible and sustainable. The team chose to build an exhibit that would teach young children about simple circuitry and electronics.

First, extensive research of circuits, children’s museums, children's safety laws and practices, attention span of the relevant age group of children, and existing solutions was completed in order to build a strong background on the topic. An observational time study was also done at the SLO Children’s Museum to gather more information about the end user. Next, a conceptual model of the exhibit was formed.

Through an iterative design process, the team developed multiple functional prototypes and conducted electronic testing to reach a final design. The exhibit is made up of three interactive stations that each teaches a unique concept. The stations include an interface that requires user input to cause a response. The first station teaches how different resistance affects a circuit, namely, Ohm’s Law. At this station, the user compares the effect a big resistor and a small resistor would have on a circuit involving an LED fan. The second station teaches the concept of completing a circuit in order to function correctly. Here, the user builds a circuit using childproofed custom pieces that will, if done correctly, illuminate an electroluminescent (EL) wire that is outlined in the shape of a volcano. The third station teaches the idea of electronics and circuits being a part of everyday life. This station is a plexi-glass display that includes

everyday devices opened up to show their internal circuitry and wiring. In addition, the team also worked with the museum to construct effective and simplified signage that would instruct the user on how to interact with the exhibit.

The exhibit is scheduled to be open by July of 2015. Furthermore, in order for the exhibit to be maintained, the team has built numerous, interchangeable spare parts and have given design specifications and a build manual to the museum to refer to. Ultimately, the team was successful in staying within the budget by only spending $388.62 overall.

Introduction/Background

The San Luis Obispo Children’s Museum (SLOCM) first opened in 1990. A major reconstruction occurred from 2005-2008 causing the museum to temporarily close. Finally complete in 2009, the SLOCM officially opened as the three-floor facility that can be visited today. Each floor of the museum is designed with a specific focus and audience in mind. The first floor of the museum has a focus on science, technology, engineering, and mathematics (STEM) and is intended for children ages 6-10. The second floor of the museum is meant to represent San Luis Obispo with areas such as bubblegum alley, a city trolley and farmers’ market. The audience of the second floor is approximately ages 3-6. The third and final floor is designed for safe toddler play, focusing on activities that are appropriate for 1-3 year olds.

The objective of this project is to design an interactive and educational engineering exhibit for the first floor of the SLOCM. The project is sponsored and overseen by the museum’s executive director, Michelle Jenkins. This new exhibit will promote the child's understanding of the concepts of electrical engineering, focusing specially on circuits. The project will consist of three parts that will teach children the concept of completing a circuit, the effects of resistors and the relevance of circuits in everyday life.

Designing a circuit exhibit required knowledge from electrical engineering courses such as *Electric Circuit Theory* and *Electronics*. It also called for an understanding of manufacturing processes such as designing, rapid prototyping, and casting.

This report begins with a literature review. It then continues into the body, which is divided into the design, methodology, and results. The report then ends with concluding remarks.

Literature Review

The literature review for designing a museum exhibit focuses on five main topics. The first topic researched will be the history of children's museums. It will also review the intention and design guidelines of a scientific exhibit for children. The second segment of the literature review discusses the attention spans and experimentation capabilities of the ages using the museum exhibit. The third segment focuses on electricity and concepts relevant to a circuitry exhibit. The concepts discussed are completing the circuit and electrical resistance. The literature review then discusses the materials associated with these electrical circuits. The fourth segment focuses on safe designs for children including labeling, as well as, mechanical and electrical safety requirements. The fifth topic researched will be existing solutions for teaching circuits to children. Existing solutions are the consumer products little bits, snap circuits, circuit scribe, and squishy circuits.

Children's Museums

The exhibits on the first floor of the San Luis Obispo Children's Museum focus specifically on science, technology, engineering and mathematics (S.T.E.M.). To understand how to design an exhibit with this focus, it is helpful to first understand the history and purpose of children's museums as a whole before narrowing the focus to S.T.E.M. exhibits.

The first Children's Museum was opened in December 1899 at the Brooklyn Institute of Arts and Sciences (Schofield-Bodt, 1987). Created during the same era as the establishment of child labor laws, childhood was being "recognized as an important life stage itself, rather than simply a precursor to adulthood" (Schofield-Bodt, 1987, p 4). Traditionally museums were and still are known for their exhibit's historical value, however, the Brooklyn Children's Museum's "priority switched to education" due to the need to create an environment to appeal to and benefit

the life stage of childhood (Schofield-Bodt, 1987, p 4). The museum's founders determined their museum "would be experience rather than object oriented" (Schofield-Bodt, 1987, p 4). Originally, the expected age of museum attendees was elementary through high school but by the mid-1970s the audience was expanded to include preschoolers (Schofield-Bodt, 1987, p 5).

With the widespread growth and support of children's museum, it is apparent that the Brooklyn Institute of Arts and Sciences made the right decision to invest in designing an establishment for children. Part of the success of children's museums is that they were created "not to be miniaturizations of the adult genre, but specifically designed spaces and buildings that were at once extensions of both the classroom and the playroom" (Heller and Guarnaccia, 1994, p 33). Without the restrictions of historical content, museum exhibits can focus on subjects like science where "each interactive exhibit embodies a single scientific principle that visitors are encouraged to work out for themselves" (Owens, Lecrubier, and Breithaupt, 2002, p 507). A strong focus of exhibit design became balancing "simply having fun" with the "need to effectively transmit knowledge and enthusiasm" (Owens, Lecrubier, and Breithaupt, 2002, p 510).

The rapid growth of technology leads to children being exposed to technology before they are ever educated on it. "Today's children represent the first generation totally born into computer literacy" (Heller and Guarnaccia, 1994, p 99).   Teaching children science earlier is becoming essential and "what is often overlooked or underestimated in the potential for science learning in non-school settings" (*Learning Science,* 2009, p 1). Children's museums provide an environment "to learn about science and nature through discovery and inquiry" (Schrementi, 2011, p 1). They are effective learning centers "where people can pursue and develop science

interests, engage in science inquiry and reflect on their experiences through sense making conversations" (*Learning Science*, 2009, p 2).

An exhibit's design influences how effectively its intended message will be received. The design determines "what aspects of science are reflected in learning experiences, how learners engage with science and with one another, and the type and quality of educational materials that learners use" (*Learning Science*, 2009, p 6). In *Learning Science in Informal Environments*, a national research council summarized guidelines that apply to creating an exhibit. It states that the "informal environments should:

- be designed with specific learning goals in mind (e.g., the strands of science learning)
- be interactive
- provide multiple ways for learners to engage with concepts, practices, and phenomena within a particular setting
- facilitate science learning across multiple settings
- prompt and support participants to interpret their learning experiences in light of relevant prior knowledge, experiences, and interests
- support and encourage learners to extend their learning over time"

(Learning Science, 2009, p 6).

Science exhibits promote S.T.E.M. learning in children outside the classroom. The following section will discuss the age group represented by the children visiting the San Luis Obispo Children Museum, focusing on attention spans and California's science learning standards.

Relevant Age Group

The age group of focus for this project is 6 to 10 years old. It is essential to understand the attention span capacity of this age group in order to design knowing the audiences limitations and abilities. Attention span is defined as "an individual's ability to attend to a stimulus or object over a period of time" (Levin and Bernier, 2011, p 161). Research published in The *Encyclopedia of Child Behavior and Development* reports "attention span develops rapidly between the age of 4 and 6 years, then stabilizes between ages 7 and 8, improving gradually until the age of 16" (Levin and Bernier, 2011, p 161-162). The younger the child the more likely he/she is to have a shorter attention span. Therefore, to design an exhibit that will hold its intended audience's attention, it is important to focus on the attention span of the youngest members, the 6 and 7 year olds. *Standards for Technological Literacy* reports that students, especially those in Kindergarten through second grade, require "a wide variety of activities because they have short attention spans and tire easily," (*Standards*, 2000, p 216). A study conducted by Kenneth E. Moyer and B. Von Haller Gilmer sought to evaluate attention spans for the same age group in non-classroom environments. They noted that in teaching situations the attention span of preschool and primary children are limited to spans of ten to fifteen minutes (Moyer and Gilmer, 1954). After three stages of evaluations, Moyer and Gilmer concluded attention spans may be increased through "providing the right toy for a particular age" and that "attention spans tend to be lower when measured in group situations" (1954, p 465). Furthermore, their research concluded that "a toy specifically designed to help the child learn number concepts held the child's attention three times as long as did the act of having him work with numbers in a more conventional way" (Moyer and Gilmer, 1954, p 466).

Designing an educational exhibit requires an understanding of the academic guidelines for children. *Science Content Standards for California Public Schools* divides science requirements into the varying types of sciences, such as physical and earth, and then provides a list of each grade level's investigation and experimentation capacities. In Kindergarten, students learn to make observations using the five senses and then sort objects based on a single property. First graders will learn to further observe objects and determine differences occurring in two objects that are the same. During second grade, students learn to form predictions from analyzing observational patterns and begin using basic measuring tools like a ruler or thermometer to collect data. Third graders learn to make a hypothesis, record and analyze data, and then establish a conclusion from the data that they can compare to their original hypothesis. In fourth grade, students study cause and effect relationships and use these relationships to understand connections between their predictions of what will happen and what actually happens. Lastly, fifth grade students begin designing, conducting and reporting their own basic experiments using dependent, independent and control variables.

Electricity

Electricity makes possible tasks that are difficult, time-consuming, or even impossible to do manually. Take for example, a calculator. We can perform mathematical operations using a pen and pencil but a calculator makes the task a lot faster and easier (Williams, 1979). On the other hand, it's not possible to make a phone call or browse the internet without electronics. Electricity, either directly or indirectly, influences almost everything we interact with on a daily basis.

Though we are surrounded by electricity everyday much about it is misunderstood. Linda Froschauer in "It's Electrifying," claims that the concept of electricity is

difficult to teach for two reasons; it is difficult to classify, and it is complex and not intuitive. Electricity is difficult to classify because it is not something that can be seen or held. Often students equate electricity with energy, but the problem with this model is that students end up believing that electricity can be “exhausted” or used up (Bauman, 1990). To address this problem Froschauer suggests associating electricity with other scientific concepts, such as physics or optics.

The lack of tangible experiences to explain electricity is also related to the concept being unintuitive. It’s very difficult to explain electricity without relating it to something tangible, yet it doesn’t behave exactly like anything in the physical world. A common physical analogy used to explain electricity is the flow of water. In “Analogies: Handle with Care,” Kerry Parker describes how the water flow analogy leads to many problem and misconceptions. The sections below

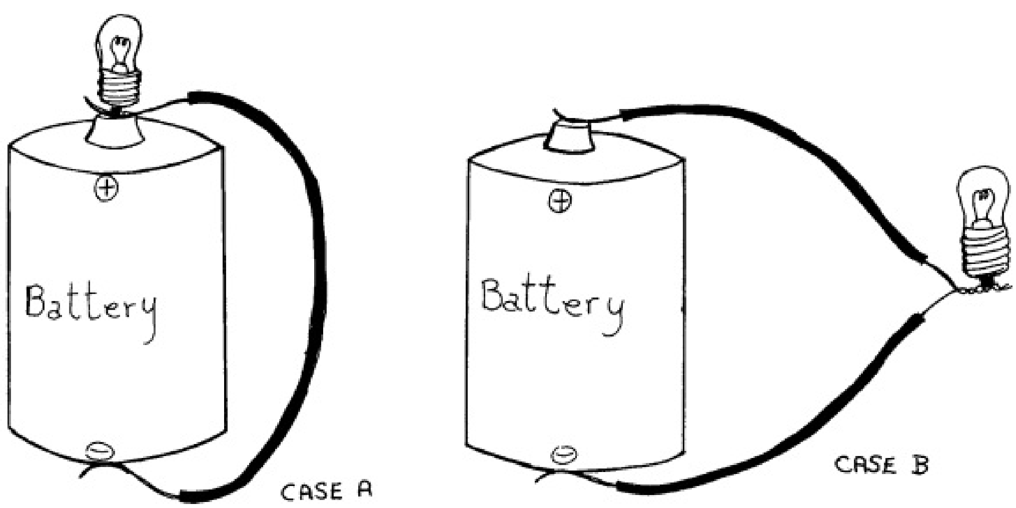
Completing a circuit

Electricity is defined as the flow of negatively charged particles, called electrons, through a conductive material (Bridgman, 1993). In order for electricity to exist there must be a complete circuit that allows the electrons to flow. The most basic model of a complete circuit consist of three components; a power source, a load, and conductive material. It’s from this model that we get the simple circuit most people are familiar with; a battery, bulb, and wire. The battery acts as the power source, the bulb as the load, and the wire as the conductive material.

The ability to understand this simple circuit has been the subject of much research. The earliest of which was a study done by James Evans tiled “Teaching Electricity with Batteries and Bulbs.” In this study he gave high school students, university student, and university graduates a battery, a lightbulb, and wire and found that half of the were unable to make the bulb light up.

Though this study was performed over 30 years ago and education standards have drastically change, one facet of this study is still very relevant. Evans observed that students who have been exposed to circuits were able to complete the circuit and make the bulb light up immediately, while those who have no prior experience struggled.

Another study, completed in 1980 by Norman Fredette and John Lochhead, expanded on Evans research. In this study Fredette and Lochhead gave freshmen engineering students a survey with two incorrect circuits and asked students if the bulb would light. As seen in Figure 1 below a majority of students answered the survey incorrectly. From this study it can be seen that even at a college level students have difficulties with the concept of completing a circuit.



The Questionnaire

The sketches shown above are two possible ways to connect a light bulb to a battery.
For each case, describe whether the bulb will light or not and explain your answer.

Case a) Will it light? Yes No
Why?

Case b) Will it light? Yes No
Why?

The results of the checked-off responses were as follows:

The bulb of case a will light	The bulb of case b will light	Both will light	Neither will light	No response	Total
5	19	12	18	3	57

Figure 1: Fredette and Lochhead Questionnaire (*Fredette, Norman, and John Lochhead. "Student Conceptions of Simple Circuits." The Physics Teacher, 18.3 (1980): 194.*)

Electrical Resistance

Another important, but more abstract electrical concept is resistance. The concept itself is difficult to define. In "Teaching Electrical Resistance," Mario Iona analyzes the different approaches used to define and explain electrical resistance in textbooks. Iona found that there were four main approaches; using defining equations, making analogies, using an atomic perspective, and an experimental approach

The most common and widely accepted definition of electrical resistance is based Ohm's Law, which is a mathematic equation that defines the relationship between voltage (V), current (I) and resistance (R) (Figure 2).

$$R = \frac{V}{I}$$

Figure 2: Ohm's Law Equation

This definition states that resistance is the ratio between the voltage and the current through a conductor. The problem with this definition is that it is abstract and it doesn't indicate anything about the nature of resistance. Eric McIldowie claims in "Some Thought on Law and

Order," that introducing Ohm's Law first when explaining the concept of resistance actually makes the concept more difficult for students to understand.

The second approach to defining and explaining resistance relies on the uses of analogies. The most common analogy used is that of fluid flow, as mentioned above. The problem with this approach is that it often leads to misconceptions, because fluid flow and electricity are not directly related.

Materials

An important part of the design process is deciding on what types of materials to use for this project. This includes understanding all of the materials going into the exhibit. Material choice significantly determines a number of important factors for the project, such as the functionality of the circuits, design cost, space, size of individual parts, durability, replicability, ease of use, and, most importantly, safety to the user. The following section will discuss the considerations that go into choosing the correct materials to use for this project as well as potential material choices.

Circuitry Materials

The basic components of a circuit include a power source, insulated electrical wires, and a load. Other mentionable parts include a silicon PCB board, PCB components, a mount to secure the circuit, a switch, and an insulated case to block contact between the user and the electrical components.

For a power source, modern batteries that are likely candidates for this project are made of Zinc-carbon, Alkaline, or lithium-ion batteries. In their commercial sizes, these types of batteries can produce a voltage range of 1.25V to 5V which is ideal for limiting the risk of

electric shock. An existing safety issue with batteries according to the EPA includes the exposure of Lead, Cadmium and/or Mercury due to leakage after long time use (*Batteries, Common Wastes & Materials).*

Insulated wires are used as the connection between a power source and a load, often having other components in between. The numerical value of a wire's electrical conductivity is the measurement used to determine how conductive it is. The equation to determine this value is Ohm's Law (*Charles and Sadiku, 30*):

$$\sigma = 1/\rho$$

where σ *is electrical conductivity (measured in Siemens per meter)*

ρ is electrical resistivity (measured in ohms * meters)

$$\rho = R * (A/L)$$

where R is electrical resistance of the material (measured in ohms)

A is the cross-sectional area of the specific piece of material (measured in square meters)

L is the length of the material (measured in meters)

According to Chrales and Sadiku, authors of the book *Fundamentals of Electric Circuits*, resistivity is how much a certain material opposes current flow when current is run through it (30). It is also the inverse of conductivity. Therefore, conductivity of metal wire is determined by how resistive to current it is; the less resistive, the more conductive. A commonly used material for conductive wires is copper. Specific useful properties of copper include "high tensile strength, ductility, deformation resistance, corrosion resistance, low thermal expansion, high

thermal conductivity, and solderability” (*Pops, Introduction*). Aluminum wire is another material used for wire conductivity, having similar properties as copper and but is slightly less conductive. The conductivity value for aluminum is 3.57×10^{7} Ω*m while the conductivity value for copper is 5.81×10^{7}Ω*m (*Charles and Sadiku, 30).* Aluminum is often used for electrical power transmission for large voltage sources, such as power lines that run through cities (*Pops, Conductor Requirements*). Aluminum is also notably less dense than copper having a density of 2.70 g/cm^3, compared to copper’s density of 8.96 g/cm^3 (*Charles and Sadiku, 30*). This allows aluminum to be used instead of copper in situations where the weight of the metal wire is significant.

The load of a circuit is essentially what the power source is powering, for instance a light bulb. For this project, the load serves as a response the user receives after successfully interacting with the exhibit’s circuits. The important factors here include immediate response, simplicity of use, and flashiness. The following products meet the requirements of a load for the exhibit.

Safe-for-kids Design

In order to ensure the safety of the user through effective material choice decisions, all the factors of safety must be accounted for. This section will discuss potential safety hazards and regulations relevant to the project. Standard regulations under the *Child Safety Protection Act* of the *Consumer Product Safety Commission (CPSC)* are referred to in this section as a basis for relevant safety precautions. In addition, under the *Federal Hazardous Substances Act* of CPSC, these safety regulations specify manufacturing, construction and performance requirements intended to reduce the risk of injury from consumer products. Specific regulations discussed in

the following section are safety warnings and labels for the consumer, and design regulations for electronic and mechanical products.

Labeling

Using safety warnings and labels is crucial to user safety, especially when supervision is limited. A common hazard for products meant for children is choking. Given that the target user for the museum as a whole is children of all ages, it is completely possible that some users may attempt to place the product in their mouth. The CPSC require under the *Child Safety Protection* Act that "Toys and games with small parts intended for use by children at least 3 years old but under 6 years must be labeled as follows:

/!\ WARNING:

CHOKING HAZARD - Small parts

Not for children under 3 years"

Figure 3: Warning label for small parts

Electrical Design Safety

Understanding safety regulations for interactions between children and electronics is important for material decisions and overall exhibit design. Under the CPSC, electronics operated by children must ensure that all electrical components have been securely enclosed and unable to be opened with household tools. Switches, motors, transformers, and other relatable component must also be securely mounted as well, to prevent unnecessary moving and damage of internal components. In relation to this project, physical access to the electronic components will be restricted completely. All electronic components will be mounted securely. Continuing, the CPSC states that any part requiring heating or the emission of heat must be prevented from

making contact with other parts that may result in electric shock (*Child Protection Act)*. Given that the exhibit will likely become dirty after use, the exhibit must be designed in a way in which cleaning with a wet cloth will not seep into the electrical components leading to corrosion and electrical hazard. If the exhibit includes any electrical plugs, the plug must have a finger/thumb grasping area and a safety shield on it to prevent accidental contact with the live prongs on the electrical plug.

Mechanical Design Safety

Another potential hazard for the user is physical injury due to poor mechanical design. On the physical design of a product, the CPSC states that "enclosures must be strong and rigid to preserve the safety and integrity of the electrical components, even when the [product] is subjected to foreseeable abuse" (*Child Protection Act*). This means that any casing used to prevent the physical contact between the user and the electrical components must be secured strongly even after sufficient wear and tear. This also applies to the integrity of the insulation used for the electrical wires in the circuits. Additionally, the mechanical design of the exhibit must be exclusive of any sharp areas, such as corners, or snapping parts that can lead to injury. The exhibit will be generating heat due to the use of electricity in the parts. On thermal regulation, the CPSC states that "products must not exceed maximum surface temperature requirements. These temperatures are determined on the basis of accessibility of a particular surface, its function, and the material from which it is made. For example, a surface which a child cannot gain access to, is allowed to reach a higher temperature than a knob or a carrying handle" (*Child Protection Act*). Also, given that slight heat will be present within the circuits; all materials used must be able to withstand deformation from heat exposure and temperature

change. Another factor is weight, which is both a material and safety issue. If a heavy object is being used by children, it could lead to injury if the product is dropped or thrown.

Inspiration (Existing Solutions)

Currently, there exist a number of educational products on the market meant to teach and expose children to circuitry. This section will reveal what existing products are offered currently and gave inspiration to the design of the final exhibit.

Little Bits

Little bits started in 2011 and produces small electronic components that connect together using magnets to create a functional circuit. The concept of Little Bits is to combine individual components that have small functions, such as rotate, lift, spin, electronically power, and heat, in order to produce a more complex function, such as play music, be a timer, turn on another electronic product, and transport an object.

Figure 4: Little Bits Product (*Little Bits product image. Digital image. LittleBits. LittleBits. Web. 22 December 2014)*

Snap circuits

Snap Circuits takes a unique approach to teaching people about the fundamentals of circuitry. The products of Snap Circuits use magnetically-connecting components that mimic the basic components of a circuit, such as resistors, capacitors, power sources, and switches. Snap Circuits uses a magnetic board as a mount where the individual component pieces snap onto. Once the individual pieces form a completed circuit, the combined pieces will function as designed. Some functions include creating a noise-activated alarm, operating an AM radio, and controlling the speed of a fan. This product is used to teach beginners and children how simple circuits work.

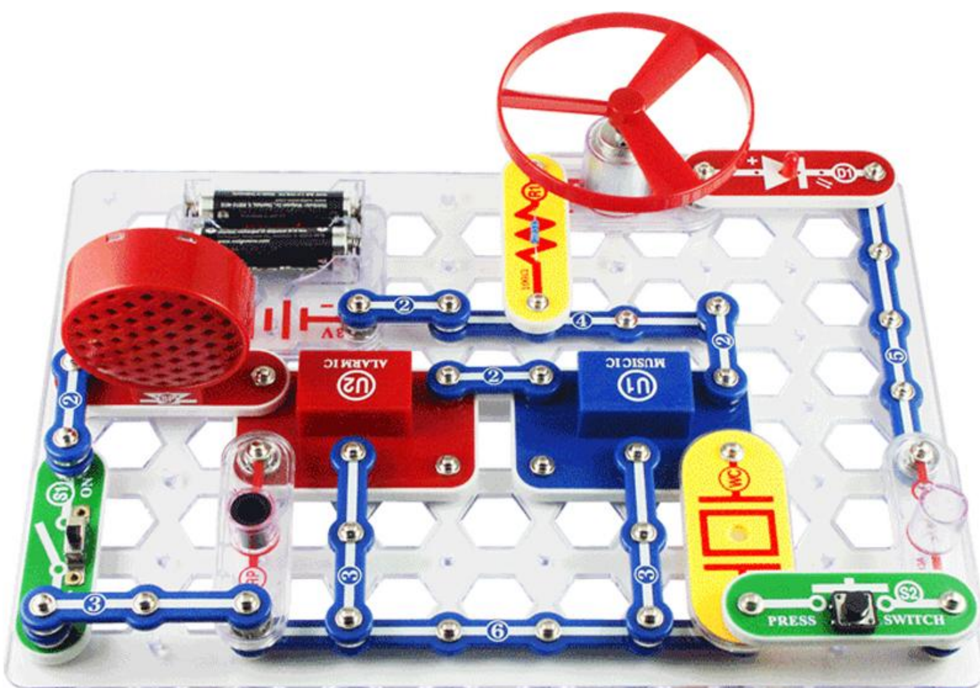


Figure 5: Snap Circuits Product (*Snap Circuits product image. Digital image. Snap Circuits. Snap Circuits. Web. 22 December 2014*)

Circuit Scribe

The Circuit Scribe is a recent development by a team of electrical and chemical engineers in 2013. The concept of Circuit Scribe is to allow users to create working circuit on a piece of

paper using conductive ink instead of wires. Electronic components such as a resistor or a battery are placed on the designated areas of the drawn circuit. The circuit will electronically conduct using the conductive ink on the paper and operate as if wires were used to connect the components together. Circuit Scribe provides a unique approach to teaching circuitry in an educational matter by creating a working circuit using just pen and paper.

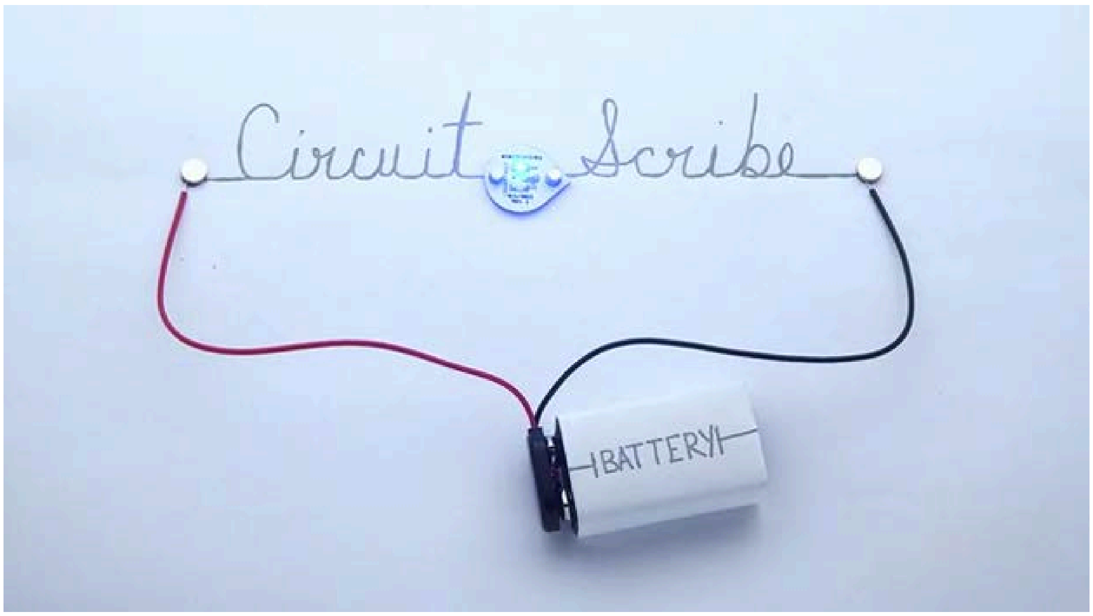


Figure 6: Circuit Scribe Product *(Circuit Scribe* product image. Digital image. Circuit Scribe. Circuit Scribe. Web. 22 December 2014).

Squishy Circuits

Squishy Circuits uses homemade conductive clay and insulating dough as a component to a circuit. Squishy Circuits simply teaches beginners the concept of how and why insulators and conductors work. The conductive clay is a mixture of water, flour, salt, cream of tartar, vegetable oil, and food coloring. The insulating dough is a mixture of flour, sugar, vegetable oil, and deionized or distilled water.

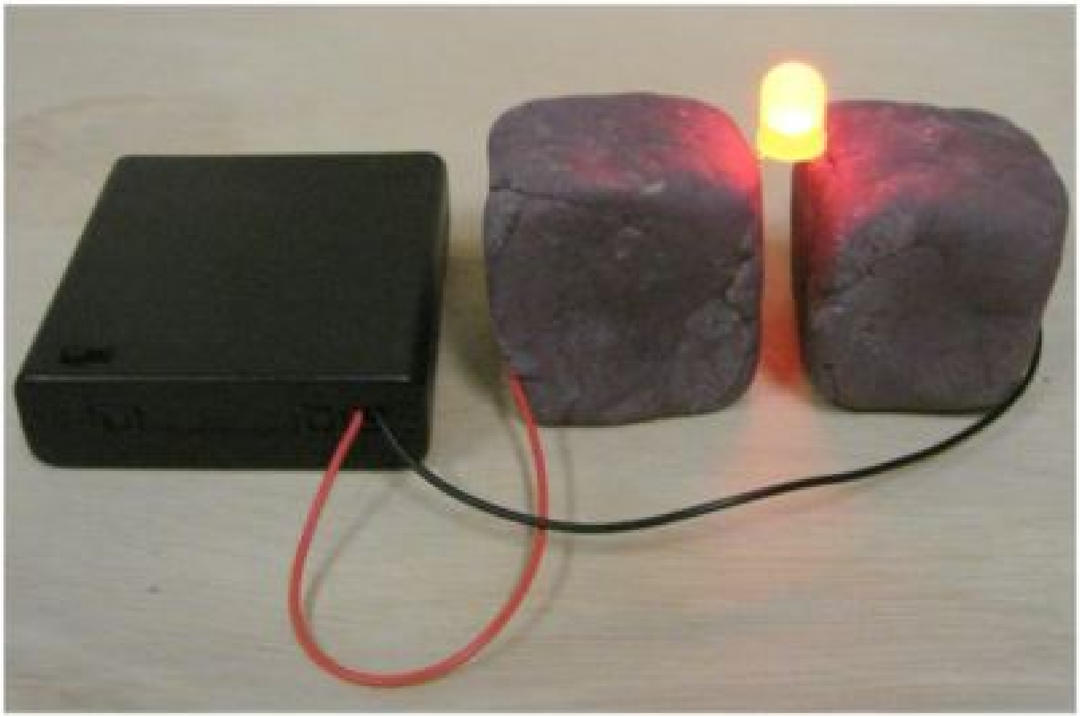


Figure 7: Squishy Circuits Product *(Squishy Circuits* image. *Digital image. University of St. Thomas. Web. 22 December 2014)*

Design

The design section of this report will discuss the many steps that were taken to achieve the project solution. It begins by presenting the initial requirements of the project and the various tools utilized to determine what the final project would be.

The report then discusses each physical component and their prototyping processes that are required for the exhibit. This includes the boards, component pieces, and response electrical wiring. Finally, the section concludes with refined project requirements and exhibit signage.

Initial Requirements

Basic requirements were given that must be followed in a SLOCM exhibit. First, the exhibit would have to be safe for children meaning that it could contain any sharp, heavy, or

easily breakable parts. All parts that can be removed from the exhibit would have to pass a choke tube test. The content of the exhibit needs to be educational and interactive, specifically focusing on engineering. Although the museum asks parents to stay with their children at all times while in the museum, that is not always the case. This fact mixed with a minimal museum floor staff requires that the exhibit be self-explanatory and need minimal supervision. Next, the exhibit design, prototyping and implementation process could cost no more than $3000 combined. Any signage, table or exhibit structure building fees were not included in this budget. Finally, a plan for the long-term maintenance of the exhibit must be designed.

Deciding on Exhibit Idea

The museum presented the project team with a list of potential exhibits. A decision matrix (Table 1), was used to determine which project would be pursued. Each potential exhibit was scored according to how well the option would meet the initial project requirements. The team added an additional requirement that the project option must be major applicable. The scores varied from integer values one to five, one representing the best fit and five representing the worst. The weighted average was then taken to determine which project would be the best choice. The outcome, highlighted in yellow was a circuit block exhibit.

Table 1: Decision Matrix ad Project Decision

	Option		1	2	3	4	5	6	7	8	9	10	11
Requirements	Weight (Score)	Weight (%)	Scores										
Safe	1	0.05	1	2	1	1	2	1	1	2	3	2	5
Interactive	3	0.14	5	1	3	1	1	1	1	1	1	1	1
Economical	5	0.23	2	4	3	1	1	1	4	2	3	3	2
Educational	4	0.18	5	2	5	5	3	4	1	1	1	1	1
Minimal Supervision	2	0.09	1	2	2	1	1	1	1	2	5	1	5
Sustainable	5	0.23	1	4	1	1	2	2	3	2	1	1	2
Major Applicable	2	0.09	5	1	2	2	2	2	1	1	1	1	1

Option #	Option Title	Weighted Score
1	Trolley	2.9
2	Airways	2.7
3	Motorcycle	2.6
4	Firetruck	1.8
5	Litebright	1.7
6	Magnet Wall	1.9
7	Rube Goldberg Machines	2.1
8	Circuit Writers	1.6
9	Conductive Bracelet	1.9
10	Circuit Blocks	1.5
11	Snap Circuits	2.0

Observations and Time Study

On January 15, 2015 from 5 pm to 8 pm, the senior project team observed various aspects of the first floor of the SLOCM. This was the third Thursday of the month meaning the team would be visiting during the museum's Moonlight Hours. Moonlight hours are when the museum offers free admittance for the evening. Michelle Jenkins informed the team that these hours are generally the museum's busiest because the time overlaps with the city's weekly farmers' market. The team's purpose in visiting the museum was to note the immediate surroundings of where the new circuit exhibit would be located, to take time studies on the attention span of children at current exhibits, and to record any observational data that would give further insight to understanding the children who visit the museum.

The surroundings of the new circuit exhibit can be found in Table 2 below**.** Due to these observations, a new exhibit should not involve sound and no changes need to be made to the current lighting.

Table 2: Observation of Exhibit Surroundings

Category	Observations Taken
Noise	• Humming noise heard from bernouli blower and spin table (consistent medium) • Additional noise occurs from the actual children visiting (varying levels low to high)
Lighting	• moderate

The average attention span of a museum exhibit was calculated to be 2.58 minutes with a range from .22 minutes to 6.7 minutes. These values were determined by analyzing the data

found in Table 3**.** Thus, the team should aim to create a new exhibit that can hold attention for 2.58 minutes.

Table 3: Time Study Data

Exhibit	Average Time Span	# of samples observed
Volcano Movie Maker	6.7 min	3
Bernouli blower	27.5 s	1
Snap on color shapes	13.21s	2
Spin table	3.0 min	1
Shake up (Earthquake simulator)	2.3 min	5
Magnetic bolt table	2 min 45s	3
RFID color lab	30.47 s	15
Augmented Sandbox	4.7 min	3

Some additional observations were:

- Children climb on top of exhibits (6 occurrences noted)
- Short attention span, will move from exhibit to exhibit quickly
- Like to touch and move from exhibit to exhibit
- Child was hurt when tries magnetic bolt table (snapped by bolt on finger)
- Estimated height of children was about 2 ½ feet (estimated)
- Children often ignored signage
- Run to colors/anything touchable
- Some parents dictate where they let the children play

An exhibit height greater than 3 feet can help prevent children younger than 6 from using the circuit exhibit. A new exhibit will have to be evaluated to make sure small body parts such as

fingers will not be harmed. Finally, exhibit instructions must be concise and anesthetic to promote actual reading of them.

Exhibit Concepts

The project design involves a three-part circuit exhibit. Each part focuses on teaching a different circuitry concept. The exhibit will teach children the effects of resistors, the concept of completing a circuit, and the relevance of circuits in everyday life.

The Resistor board will be equipped with two resistor shaped blocks, one large and one small. The size of the block will relate to its relative resistance, meaning the bigger resistor with have a larger resistance and vise versa. When the resistor shaped block is plugged into the board a fan will turn on. The fan will move faster when the smaller resistor is plugged in, and slower when the larger resistor is plugged it thus demonstrating the effect of resistance in a circuit.

The second part of the exhibit is the Complete the Circuit station. At this station children will have to complete the circuit by plugging in six blocks to connect the battery to the light. Lines on the board will simulate a wire connection between the blocks. The light in the circuit will be made of EL wire in the shape of the children's museum logo. The blocks at this station will be a different size and shape than the ones at the Resistor station to prevent the blocks from being plugged into the wrong board.

The third part of the exhibit is a plexi-glass display where children will be able to see the circuits that make up some of their familiar electronic devices. One of the circuits used is from a power supply because many of its components, such as batteries and resistors, are easily visible. The display will also include circuits for devices that are more familiar to kids such as cell phones and tablets.

Prototyping

Before beginning to build, the team first constructed a conceptual model of the design. The idea was to have an interactive exhibit that taught young children about basic circuitry and electronics. From research on existing children's toys on the market that taught circuitry, the most common teaching model involved the user being able to place an input and then trigger a response. This served as the basis for the first prototype.

Design Requirements

Mutual understanding of the requirements of the customer was established first. The team compiled a list of design factors based on customer needs and requirements. The first and most important design factor for the end user is safety. To ensure the complete safety of the end user, the design was aimed to be child-proof. This meant that no sharp edges, heavy falling parts, snapping objects, hot surfaces, small chokable objects, fragile/brittle parts, and electrical contact points existed within the exhibit. Standing as the number one priority, safety is a big influential factor in the design process. The second design factor is that the exhibit must require minimal supervision by museum staff or parental figures. As observed by the team, children have a tendency to stray from supervision while in the museum. Signage is used to address the issue of instruction and guidance while using the exhibit. Signage, meaning textual and graphical instructions, is located directly in front of the user at each circuit station. The signage content is written in colorful and attractive style with simple wording to match the target user age group. The rest of the design factors are that the exhibit must be interactive, have educational purposes, and be economically and sustainably feasible.

Prototyping Stage 1

After establishing the design requirements, the team was ready to initiate prototyping. Figure 15 below is an image of the first and most primitive prototype built by the team. This prototype is a simple circuit made up of a 9V battery and an LED light.

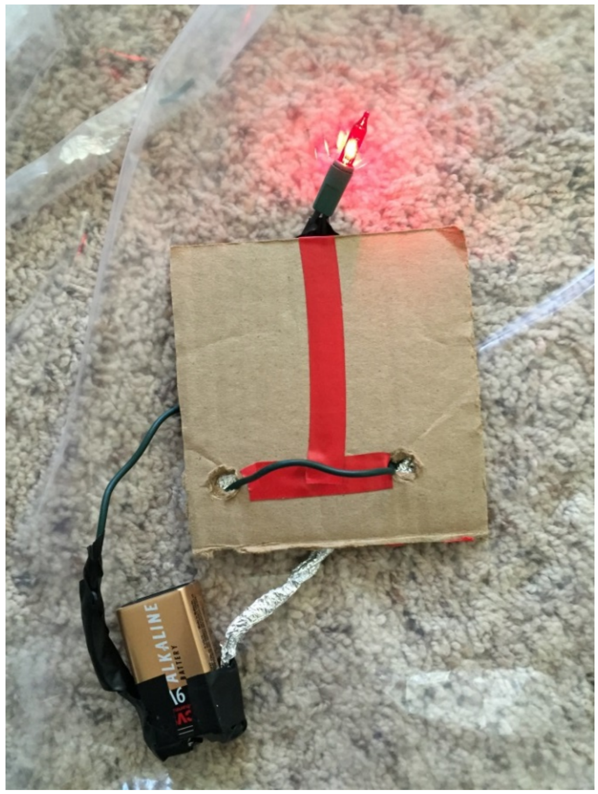


Figure 8: Basic prototype to test functionality

The positive end of the battery is connected directly to one of the two wires coming from the LED. The negative end of the battery is connected to a thin foil strip that is taped to the right hole going through the cardboard. The other wire coming from the LED is taped to another thin strip of foil that is taped to the left hole on the cardboard. By placing a wire on top of the cardboard to connect the left and right holes, as shown in the picture, an electrical connection is

made between the battery and LED thus causing the LED to illuminate. This stage of prototyping tested for basic functionality and established a proof of concept for the design.

Prototyping Stage 2

In the next stage of prototyping, a prototype input part and board was designed. Instead of bare wiring, the input part would have a casing around it. The prototype board tested for peg hole dimensions and spacing. Figure 16 below depicts the type of interaction the user would have with the board interface.

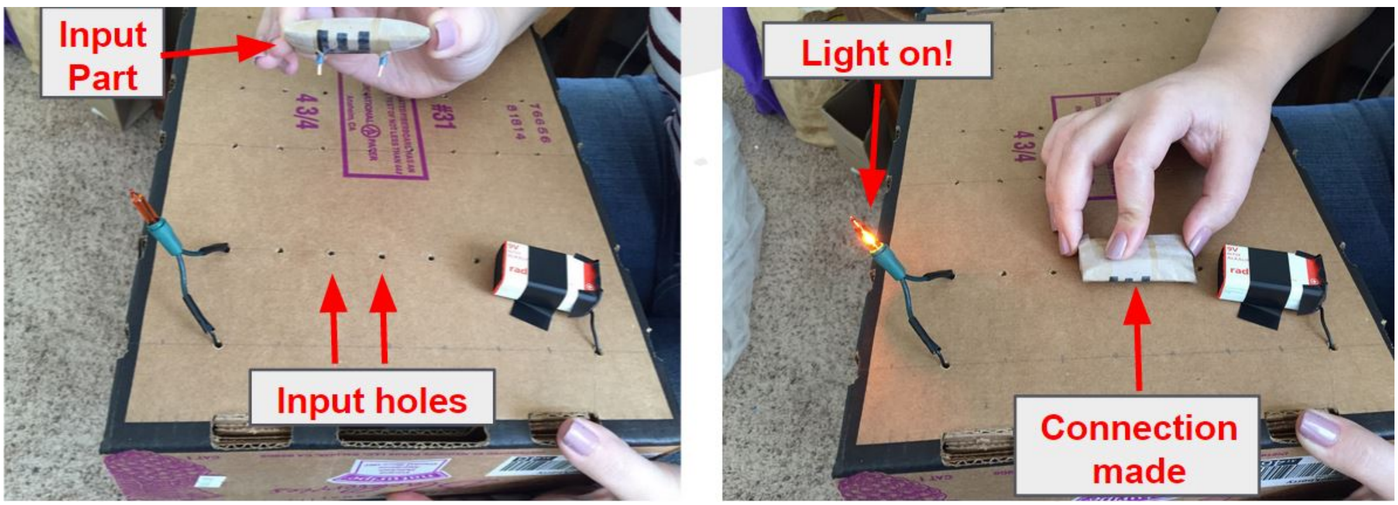


Figure 9: Second prototype of input part and board

Important takeaways from this prototype:

- The electronic components, such as all the wiring, resistors, and breadboard, would all be hidden from and inaccessible by the user. This serves both as a way to prevent any damage to the electronic components and also as a safety precaution to prevent electric shock.

- The placement and spacing of the input holes on the board must allow multiple input parts to be inserted on top of the board at one time.
- The peg length of the input part must be long enough to create contact with the wiring inside the board.

Creating the components

Of the three different stations the circuit exhibit, two of them needed separate pieces for children to pick up and interact with; the Resistor exhibit, and the Complete the Circuit exhibit. For each of these exhibits, the pieces were designed to visually reflect components found in circuits while still adhering to safety and durability requirements.

The Resistor Components

The design of the pieces for the Resistor exhibit was closely tied to the concept it teaches. In a circuit the relationship between voltage and resistance is inversely proportionate. This means that the larger the resistance in a circuit, the smaller the voltage across the load. In order to convey this concept to children, two pieces were designed with the size of the piece relating to the amount of resistance. Both pieces were designed in the shape and color of a typical resistor so that children would be able to recognize the piece if seen in a circuit (see Figure 17).

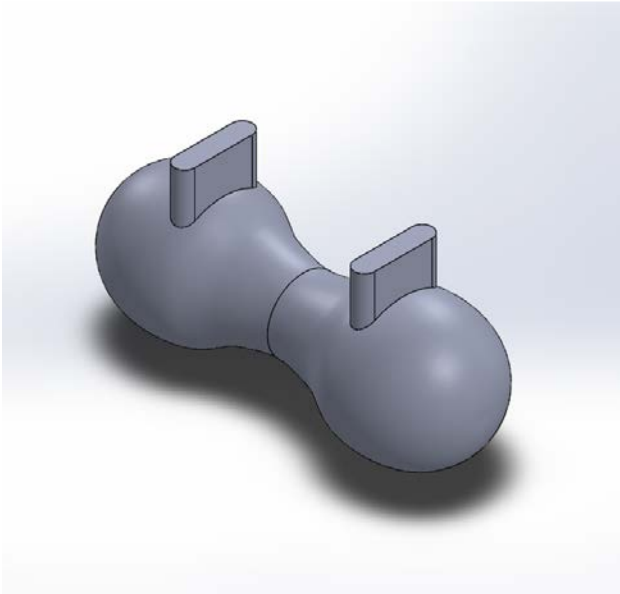


Figure 10: Solidworks model of resistor piece

Complete the Circuit Components

The pieces for the Complete the Circuit exhibit were designed to be much simpler because a larger quantity was needed. The pieces are a basic rectangular shape with rounded edges to make them easier to hold (see Figure 18).

When determining the size of the exhibit pieces there were two main considerations. The first was that the pieces had to be large enough so that they could not be easily lost or misplace. The second was that the pieces could not be so large that they wouldn't fit on the exhibit board. After weighing these considerations the final size of the pieces was decided to be 3" X 2" X ½" with ½" pegs.

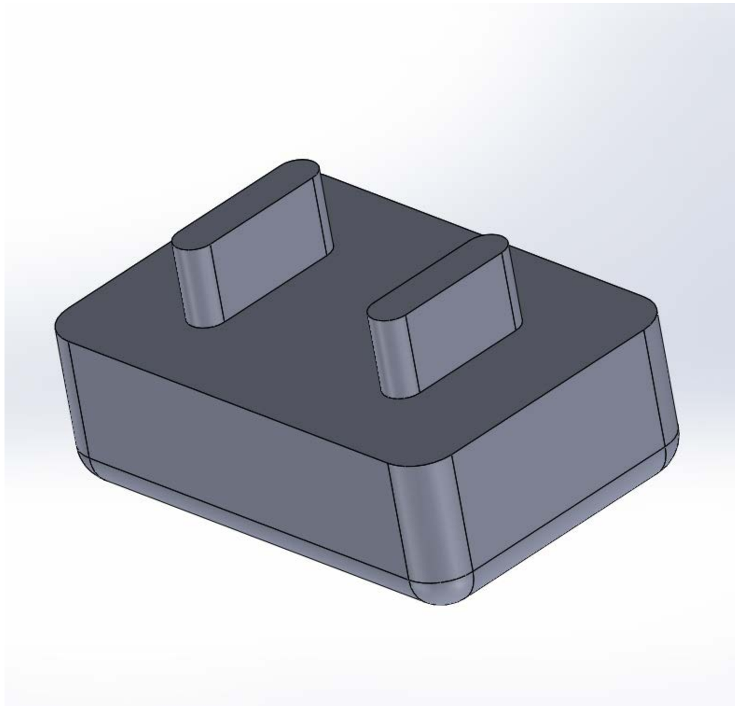


Figure 11: Solidworks model of Complete the Circuit piece

Connectivity

In order for the pieces to function in the exhibit and simulate a circuit they need to conduct electricity. To achieve this there were two options considered. The first was to create a hollow piece in which wire could be run from peg to peg. The second option was to manufacture a piece so that the wire would run between the two pegs but be completely encapsulated during the manufacturing process. After considering different possible manufacturing processes it was decided that the best possible option was to complete encapsulated the wire.

Manufacturing Process for Components

There were three possible methods considered for manufacturing the component; injection molding, 3D Printing, and resin casting.

Injection Molding involves machining a mold out of metal, then injecting it with a plastic in an injection press. The initial investment to set up this process is high, but the benefit is that additional parts can be made quickly and with little effort. The parts that result from injection molding have high durability and a high quality finish.

3D Printing is an additive process that makes a 3 dimensional part from a digital model. The benefit of using this process is that there are no set-up costs and the initial time investment is minimal. Some drawbacks of this process are that parts have a rough finish and are not as durable.

Resin casting is a process that involves creating a silicon mold from a 3 dimensional pattern, then filling the mold with a thermoplastic resin. There is some initial investment involved, though not as high as with injection molding. The finished parts are highly durable and the finish is a direct reflection of the pattern used.

In order to determine the best process for manufacturing the board component each processes was evaluated based on five categories; initial set-up, cost per part, time per part, part finish, and part durability. Initial setup includes the time and cost involved in creating the tools need to make the parts. Cost per part and time per part include only the cost and time involved in making each individual piece. The part finish refers to the quality of the surface of the part with regards to texture and aesthetic. The part durability refers to how well the parts will be able to withstand wear from repeated use.

Based on these five categories, it was decided that resin casting would be the best method to use. Though 3D printing was determined not to be an effective method for manufacturing the exhibit components this method was utilized to create the pattern for making the silicone mold.

Once it was decided that resin casting would be used to manufacture the parts another important decision had to be made. In resin casting, the type of resin used has a considerable effect on the outcome of the part.

Prototyping the Component

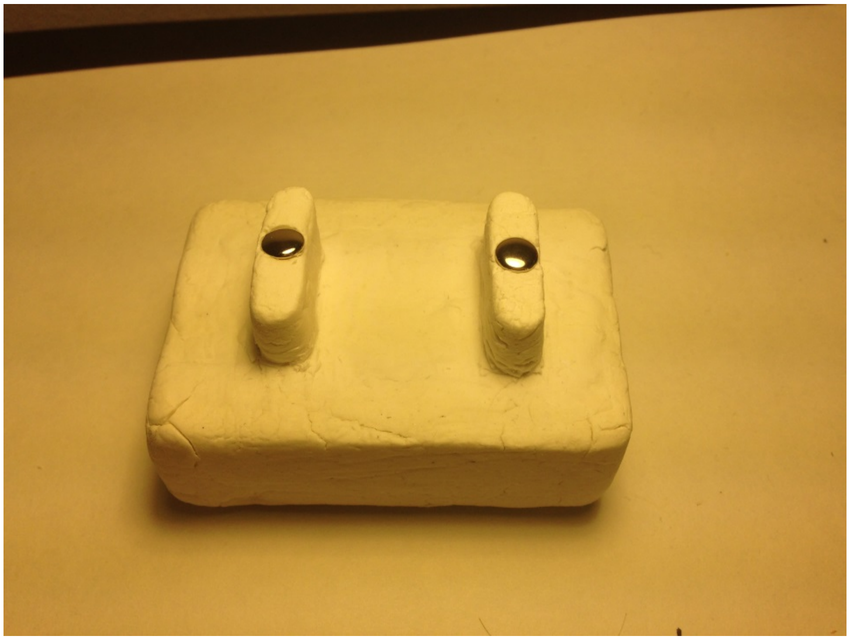


Figure 12: Clay molded prototype

The first prototype of the board component was sculpted out of clay (see Figure 19) and used to test hardness, weight, and conductivity. Flat rivets were soldered to a length of wire, and then clay was shaped around this assembly. This model allowed for better understanding of material choice, feasibility of the shape, and gave a better physical representation of the model.

3D Printed Input Parts

This section will discuss the manufacturing of the input parts. A different input part was designed for each of the two interaction stations, Resistor and Completing the Circuit. Using

Solidworks, a 3D conceptual model of the parts was made. Safety, durability, size, weight, and maintenance were influential factors in the conceptual design of the input parts. Using 3D printing technology, prototype input parts were manufactured to specification. The 3D printer used was the Makerbot Replicator 2X printer using ABS material. Initially, the team considered to use the 3D printed parts as the final parts. However, the ABS plastic parts did not meet the required hardness needed to withstand constant long term use. Instead, these parts served as patterns for casting the final parts out of a stronger plastic. Due to the unique shape of the parts, it is easier to cast the final parts rather than machining it to the desired shape. Figure 20 shows the 3D printed ABS parts for the Resistor and Complete the Circuit Stations.

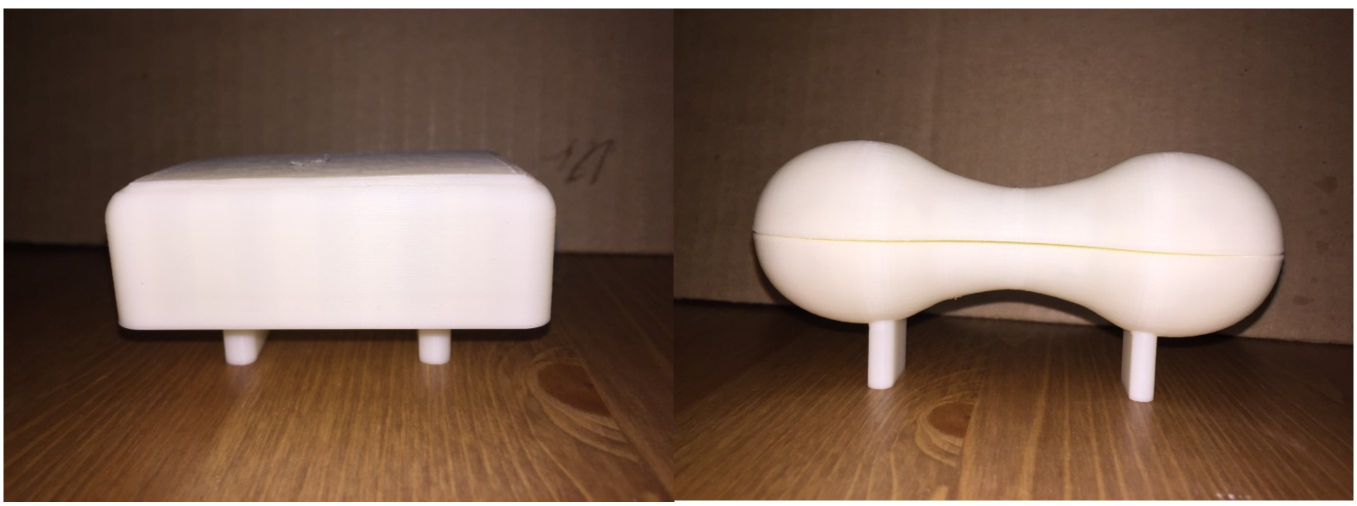


Figure 13: 3D printed prototype of Circuitblock (left) and Resistorblock (right)

The casting procedure first involved making a mold of the pattern. Oomoo 30 is a silicone rubber mixture from Reynolds Advanced Materials' mold catalog that was chosen to be the mold material. Reynolds Advanced Materials is a supplier of numerous mold rubber and casting resins. Oomoo 30 is comparitively inexpensive and easy to use, meaning not requiring any special equipment to use. The cure time for this mixture is 6 hours. The next step after making the molds from the 3D printed patterns was to cast the final parts. In regards to material choice, the team narrowed down the casting material to two thermoplastic resins from the Reynolds Advanced Materials' plastics catalog. The two options were between the Task 9 plastic from the Task Performance Plastic series and the Smooth-Cast 300 from the Smooth-Cast 300 Series. Task 9 is a urethane casting resin orinally used for impact resistant tooling, color accuracy, and durabity. Notable specifications of Task 9, found in the Reynolds Advanced Materials catalog, include a $7{,}800^{psi}$ ultimate tensile strength, $11{,}000^{psi}$ compressive stregnth, and a cure time of 1 hour. Task 9 also requires using a gas vacuum chamber during curing to remove harmful gases emitted during cure. The Smooth-Cast 300 resin is a low viscosity resin that is used for detailed models, props, and cast effect pieces. Notable specifications of the Smooth-Cast 300 include a $3{,}000^{psi}$ tensile strength, $4{,}000^{psi}$ compressive strength, $0.01^{in./in.}$ shrinkage rate, and a cure time of 10 minutes. The Smooth-Cast 300 also does not need gas vacuuming during curing. Given careful discussion, the team chose the Smooth-Cast 300 resin over the Task 9 resin because of the shorter cure time and not requiring gas vacuuming. Though the Task 9 plastic provided a higher tensile and compressive strengths, this added hardness and durability is redundant for it's needed purpose. Furthermore, the Smooth-Cast 300 resin passes hardness and durability requirements, provides a smooth finish, and has a convinient casting procedure.

The next step, before pouring the plastic into the mold, is to place a wire with two conductive rivets soldered to its ends into the mold. The rivets are placed into the peg area of the mold and will end up on the outside of the peg after curing. Figure 21 below shows the rivets attached on the ends of the pegs after a part is casted. The wire inside connects the rivets together to allow current to flow through the part when plugged into the board. Figure 22 is an image of the final casted part next to its silcone mold and the plastic container it was casted in.

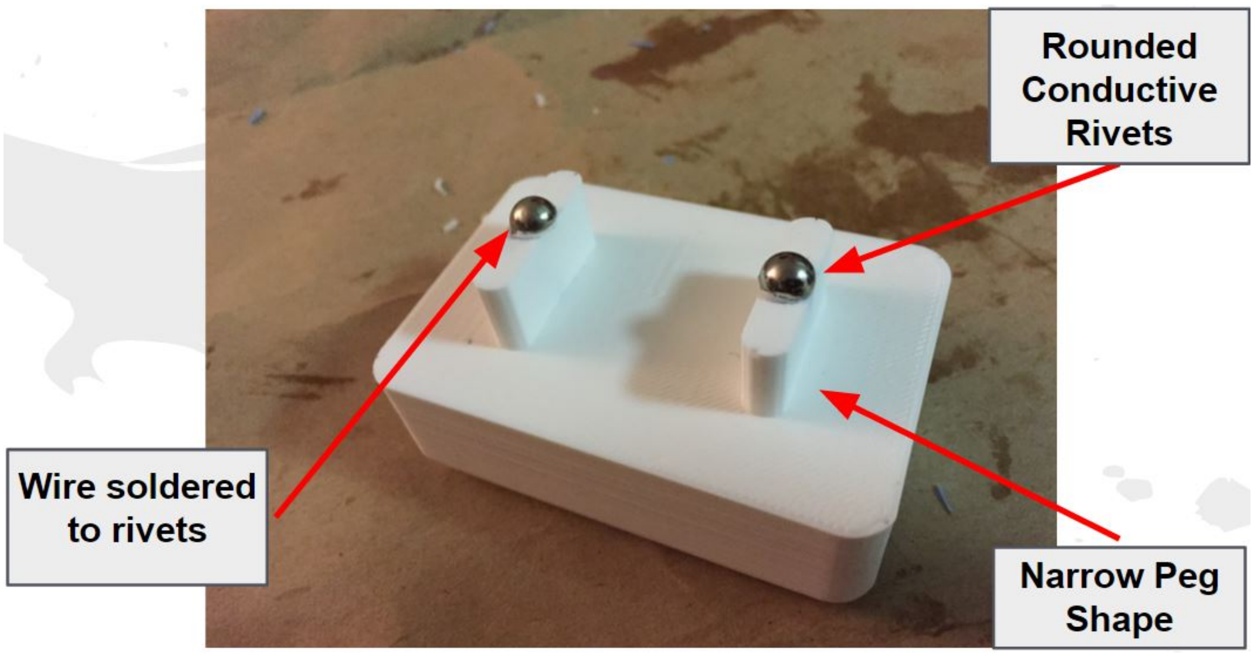


Figure 14: Close up of plastic casted part

Figure 15: Plastic molded part and mold

Electronic Design

Responses

The design of the electrical circuits for the exhibits began with deciding on which devices would best demonstrate the chosen electrical concepts for each station. A fan was chosen as the device for the Resistor exhibit because it would allow children to both see and feel the effect of resistance in that circuit. A picture of the specific fan is located in Figure 23 below. For the Complete the Circuit station it was decided that el wire would work best because it would allow children to trace the entire circuit from the board and through the lighted wire itself. The neon luminescence of the wire would make the exhibit very visible from any part of the first floor.

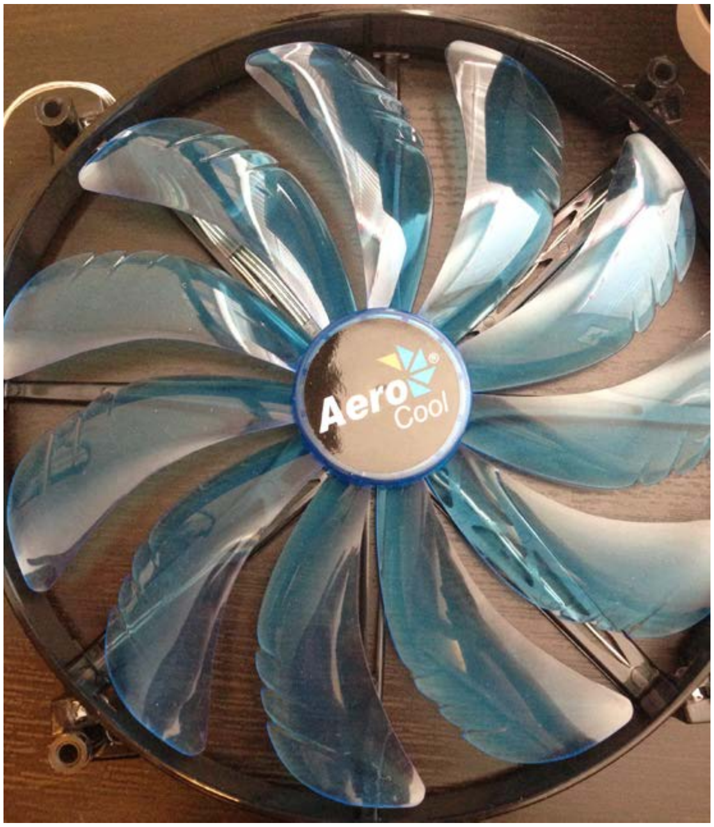


Figure 16: Resistor station fan

Power Source

Both the fan and the el wire require a 12VDC power source. To eliminate the waste in time and money that would go along with the use of rechargeable batteries, we decided to use a 12V power source that could be plugged in directly to a wall outlet. However, two double A batteries are still place in the bottom front slot of each board so that children can trace the complete circuit from the batter to the responding device.

Safety and Circuit design

An important consideration in detailing with any kind of electricity is safety. As stated above, both of the chosen response devices require a 12V power source. Though 12VDC is generally not considered a dangerous operating voltage, it is preferred that the least possible

voltage and current be running through the areas where children can potentially have access to. In order to connect a lower power board with higher powered devices the electrical design relies on the use of relays, or electro mechanical switches.

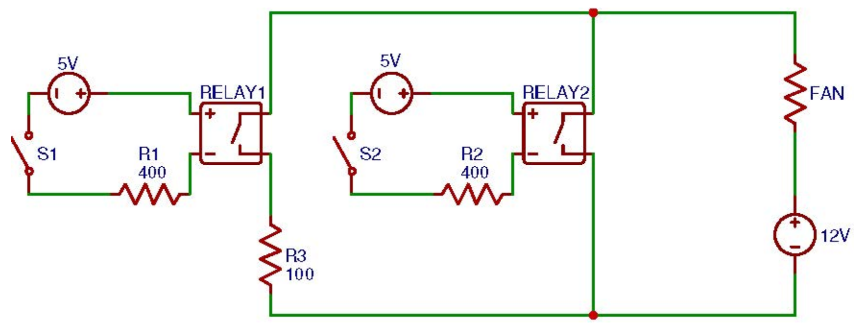


Figure 17: Resistor Station Schematic

Figure 24 above is the schematic for the Resistor station. In this schematic the The internal resistance of the relay coils are modeled by resistor R1 and R2. The Resistorblocks are represented by switches S1 and S2. The connection on the pegs of each Resistorblock will be located in different positions so that each block will connect a different circuit. When the circuit in the board is connected a relay will be activated, closing the circuit between the 12v power source and the fan. The circuit with the larger resistor will have an extra 100 ohm resistor which will slow down the fan.

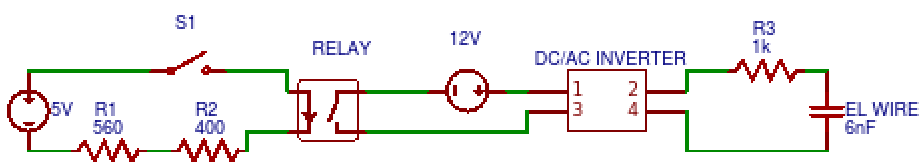


Figure 18: Complete the Circuit Station Schematic

Figure 25 is the schematic for the Complete the Circuit station. All six circuit blocks are modeled by a single switch, S1. The internal resistance of the relay coil is modeled by a 400 ohm

resistor, R1, and the el wire is modeled as a capacitor in series with a 1k resistor. To reduce the current through the board an additional 560 ohm resistor is added to the left side of the relay. When all six circuit components are plugged into the board the relay switch will be activated, closing the 12V circuit and turning on the el wire.

Electronic prototyping

For the Resistor station testing was required to determine the resistance necessary to create a discernable difference in the fan for the Resistor station. Testing began by first assembling the circuit using a breadboard. To establish the base speed for the fan it was connected to power without a resistor. Next, resistors of different values were added in series with the fan. Observations for the various values of resistance are located in Table 4 below. From these observations it was determined that a resistance of 100 ohm would create the most discernable difference in fan speed and LED brightness while still allowing the fan to run. Photos of the fan at full speed and at the slowed speed are shown in Figures 26 and 27 below.

Table 4: Fan Responses at Various Resistance

Resistance	Observation
0	Fan at full speed and LED at full brightness
680	Neither fan nor LED turn on
200	Not enough power for fan to start from a static state, but fan turns slowly if already in motion. LEDs turns on but very dim
100	Fan speed slowed slightly, and LEDs appear dimmer.
50	No discernable difference in speed or LED brightness that without a resistor.

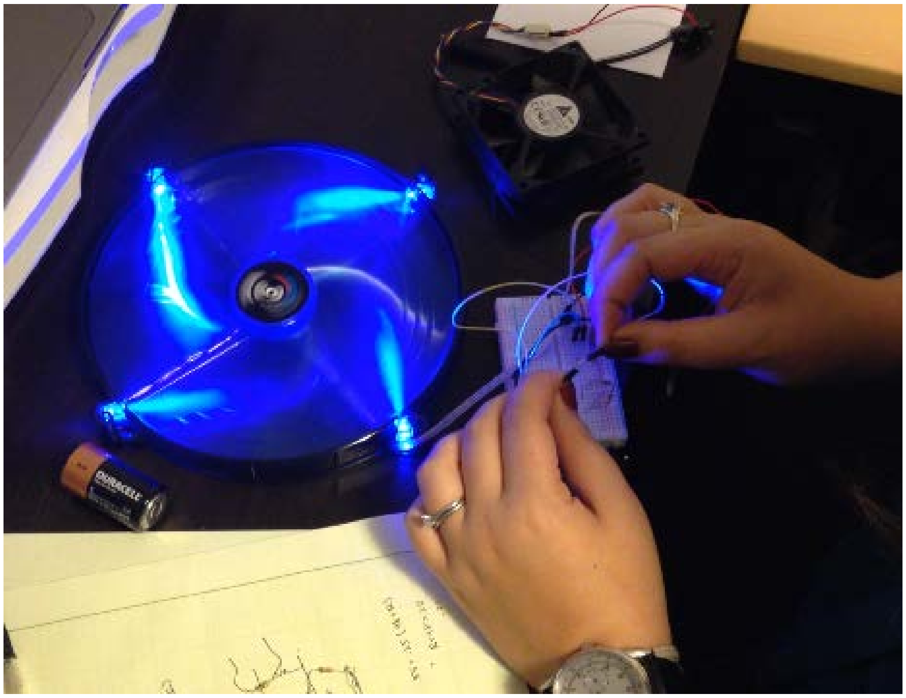


Figure 19: Fan circuit without added resistance

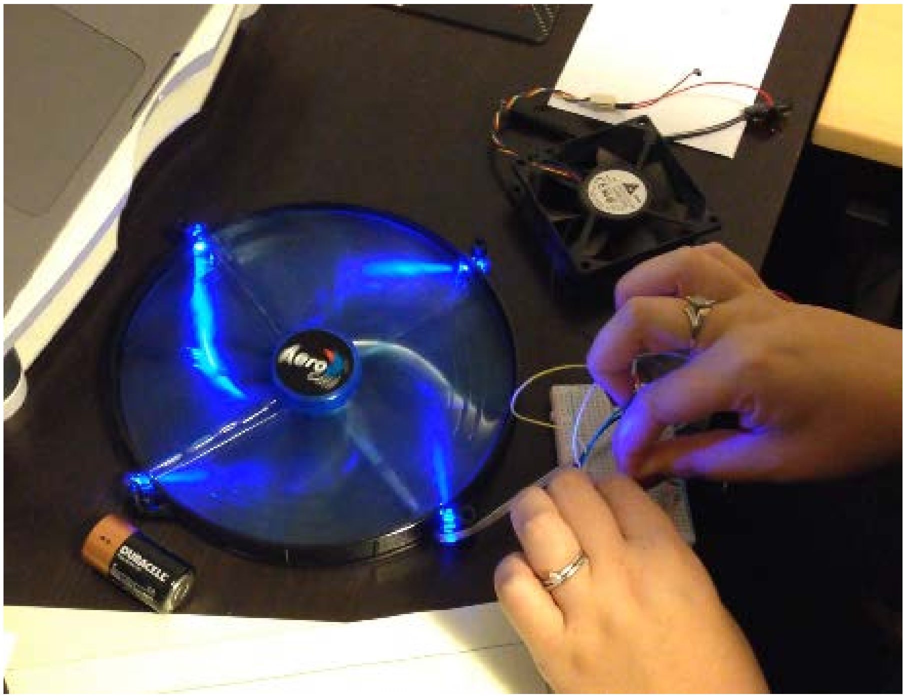


Figure 20: Fan with 100 ohm resistor

For the Complete the Circuit station a prototype of the circuit was created to test the functioning or the relay and to see if the el wire would respond to the circuit. To test the relay a 5 V power source was connected to the relay coil while 12V was connected to the switch side. When the relay switch was activated a multimeter was us to verify that 12VDC was running through the switch side of the relay. Figure 28 is a picture of the set up.

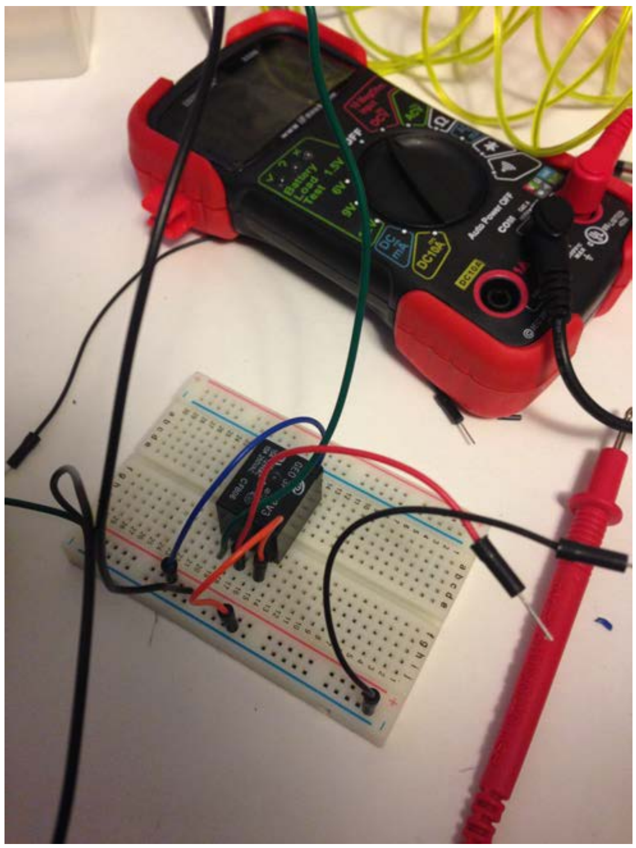


Figure 21: Set-up for relay testing

Refined Requirements

The museum decided that it would be best for the boards and display signs to be built and printed by contractors previously used by the museum. This decision would bring uniformity to the exhibits on the first floor of the museum providing a more anesthetically pleasing product.

Signage

The aspects of exhibit signage that the team was responsible for were the text explaining the exhibit, the dimensions of the sign, and the location where the sign would be placed. The museum's contractor, Ashala, would determine all other decisions such as font style, text size and color.

The audience of the display signs is the children who use the exhibit. Therefore, the text on the signs must be written using terms and logic that would make sense for six to ten year olds. This requirement meant that the language used could not be too scientific and examples relevant to a child should be utilized in the explanation. All text needed to be approved by Michelle Jenkins before being sent to the contractor. Figure 29 demonstrates the first attempt of the text for the Resistor board exhibit. The text used for the other boards can be found in Figure 31 and Figure 32 of the Appendix**.**

When riding a bike, if there is a big rock in your path you have to slow down to avoid it. The more rocks in your way, the slower you will have to ride.

Just like your bike, electricity can travel at different speeds. Resistors are the "big rocks" to electricity traveling through the wire.

What do you think will happen to the speed of the fan when you use a larger versus a smaller resistor?

Figure 22: Resistor board signage

Next, the location and dimensions of the signs had to be determined. To promote the best anesthetic set-up while also remaining in location that is easily seen, the signage would be placed flat on the table directly in front of the board that it was related to. The signage would be the same length as the board it was in front of, which was 12 inches. After printing samples of

various width options, the team decided on a width value of 4 inches. The orientation of the dimensions can be seen in Figure 30.

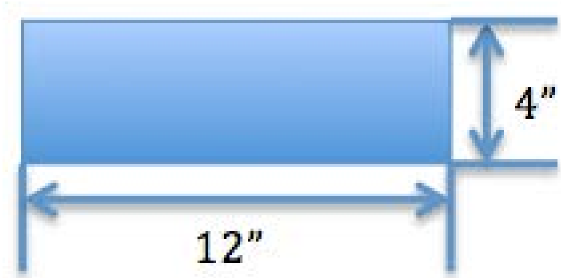


Figure 23: Sign Dimensions

Boards

This section will discuss the board-interfaces of the exhibit in regards to safety, functionality, specifications, and manufacturing.

In order to convey the three educational concepts mentioned earlier in the report, the exhibit will be made of three stations, each teaching one of the concepts. Below is a Sketch Up model of the three stations that the user will interact with.

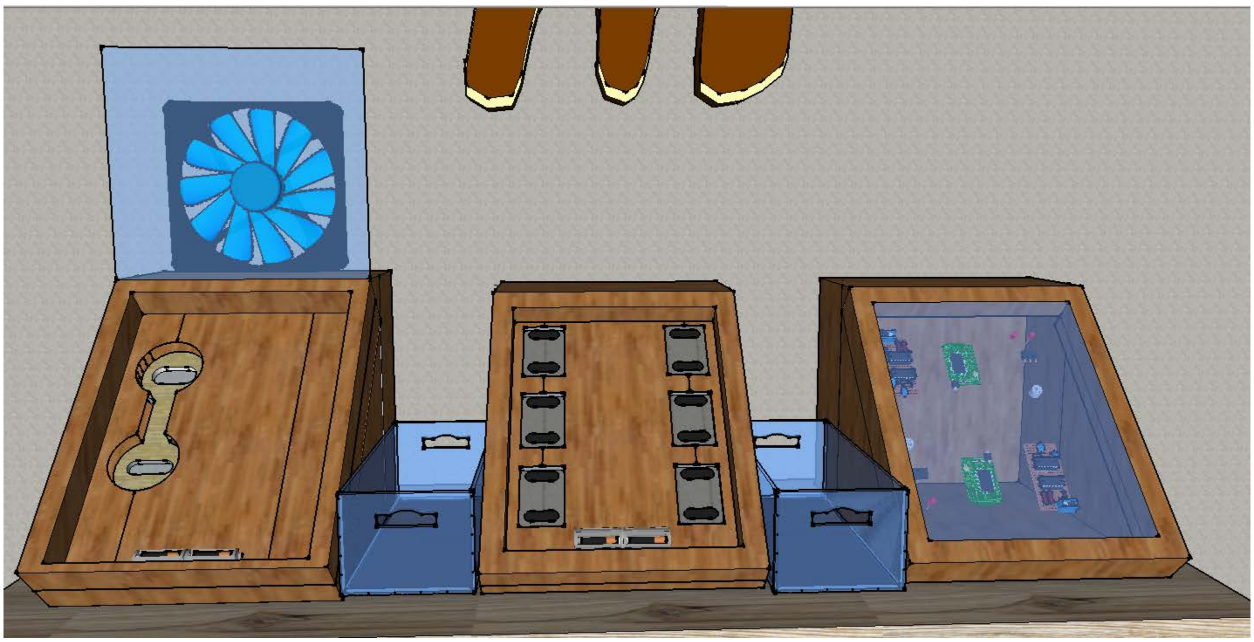


Figure 24: Sketch-Up model of exhibit

For the rest of the report, the three stations will further be referred to as the Resistor Board, the Complete the Circuit Board (CTC), and the Display Case, respectively, from right to left. In addition, the words station, interface, and exhibit will hence be used interchangeably.

Safety

The boards are designed to meet the safety and educational requirements set by the museum. Since users interact directly with the boards, it is critical to cover all potential safety hazards that may arise. The first safety issue is the hazard of physical harm or injury to the user. To address this, all edges of the boards and all sharp points that exist within the exhibit have been rounded off. The boards are bolted down onto the flat top of a table to prevent any unwanted movement and slippage of the boards or the electronic components cased within them.

The next major safety issue is preventing the risk of electric shock. To address this issue, the boards and table are designed to prevent any contact between the user and the internal electric components. The electric components are housed inside the boards without any access from the outside. For the Display Case, there is a surrounding plexi-glass screen that prevents the user coming into contact with the internal components of the display. For maintenance purposes, the inside components of the boards can be accessed by museum staff through removing a restricted panel located at back of the boards. To remove any possibility of electrical conduction from the internal components through the boards, the choice of material for the boards is wood. The boards are sanded and polished to ensure a smooth surface.

Functionality of boards

The Resistor Board (see Figure 9) seeks to teach the concept of resistance and how changing resistance impacts a load. For this board, the user will have two resistor pieces, one larger and one small, to choose from. The signage will advise the user to test out the effect that both resistor pieces will have on a fan. A fan has been chosen to be the load for this circuit because it allows both a tactile and visual response to changing resistance.

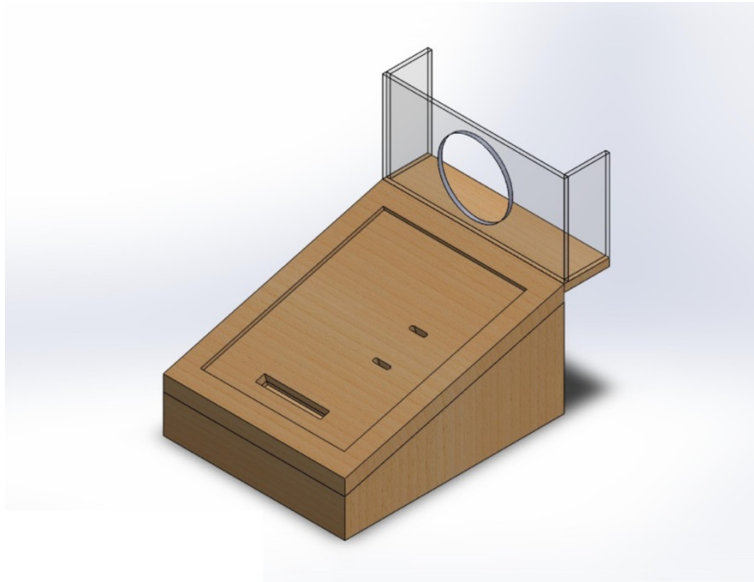


Figure 25: Solidworks Model of Resistor Station

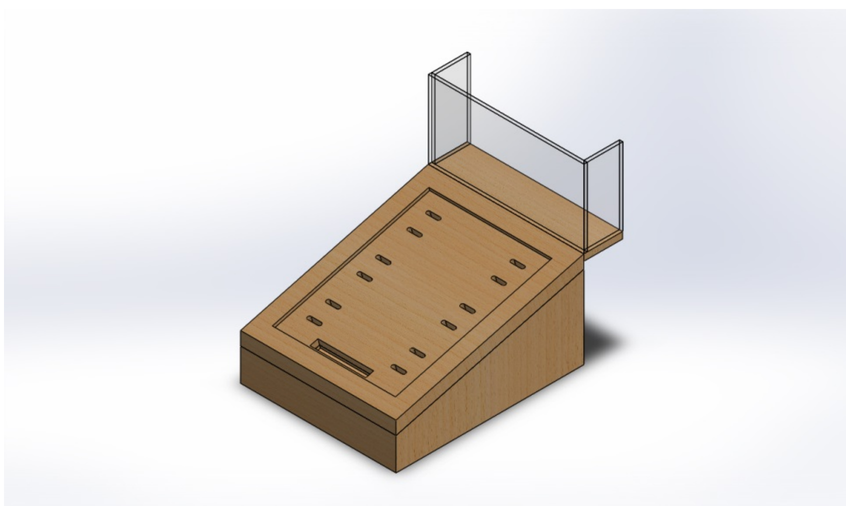


Figure 26: Solidworks Model of Complete the Circuit Station

The Complete the Circuit board (see Figure 10) seeks to teach the concept of, as the name of the board suggests, the necessity of a circuit to be complete in order for it to function correctly. For this board, the user must figure out that they need to connect six Circuitblock pieces to the board in order to fully complete the circuit and activate the load. The load for this

board will be an electroluminescent wire in the shape of a volcano. The top layer of this board is painted with lines that outline the current flow from a battery through each Circuitblock and then into the load.

Specifications and Dimensions

In order to meet the design requirements, a number of critical decisions about the boards' specifications were made. All three boards have the same external shape and height for uniformity. The Display Case is essentially a board with plexi-glass walls and internal components that will be visible to the user. Unlike the Display case, the Resistor Board and the Complete the Circuit Board have multiple layers underneath the top layer. This is because these two boards require electronic wiring. Figure 11 and Figure 12, below, show the multiple layers of the two boards.

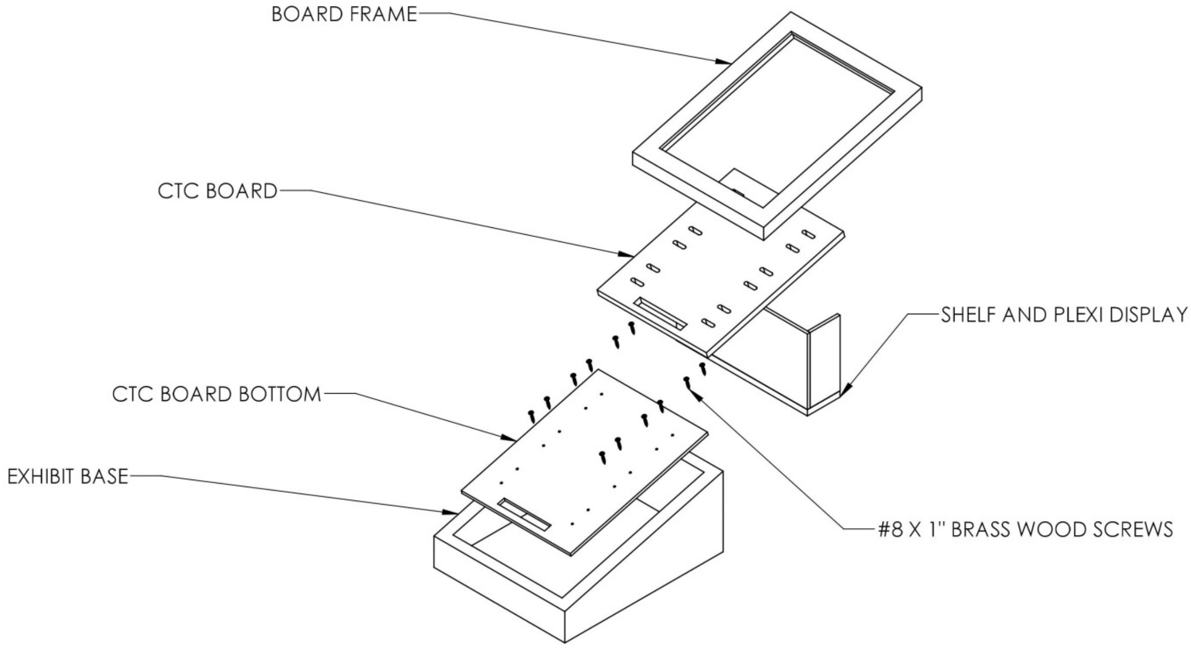


Figure 27: Exploded view of the Complete the Circuit Board

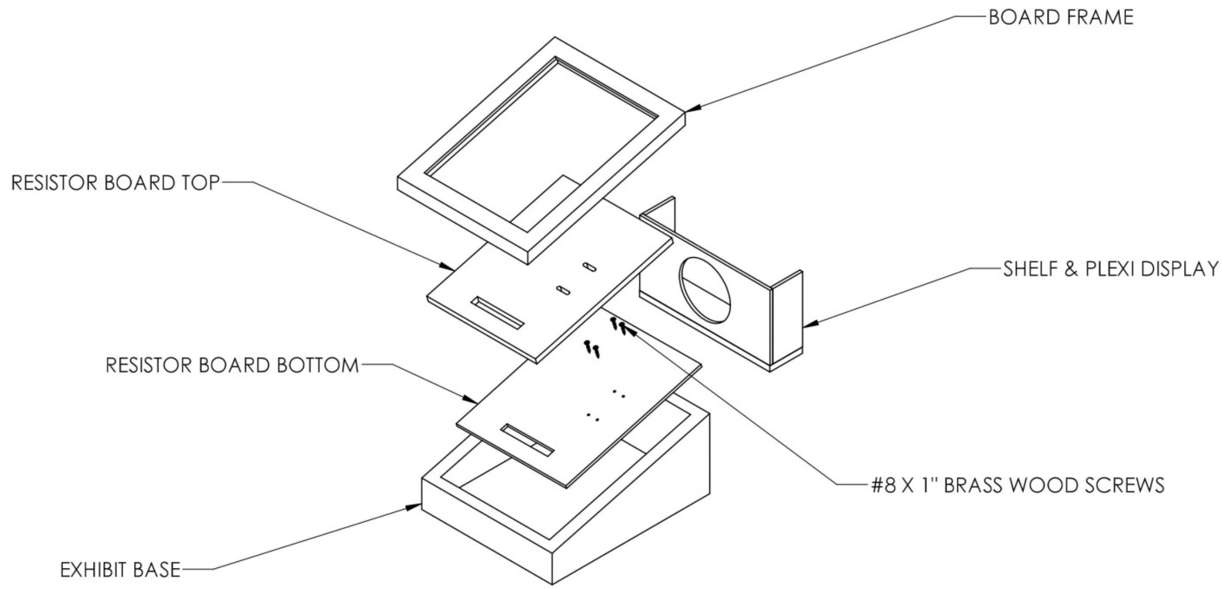


Figure 28: Exploded view of Resistor Board

The topmost layer is the layer that the user sees and interacts with. This layer consists of holes that go through the layers. These holes serve as peg holes for the pegs of the component parts that insert into the board. The shape of these holes is the same of the oval shape of the pegs of the component pieces. The Resistor Board and Complete the Circuit Board have different number, spacing, and placement of peg holes due to the difference in functionality. The second layer is where the electrical connection between the component pieces and the internal wiring occurs. This layer consists of a thin wooden board with brass nails going through the board. The placement of these nails is located directly underneath the peg holes on the first layer. These nails are wired from underneath the second layer to the electrical wiring housed in the layer below. In an earlier section, it was explained that the component pieces have a rivet implanted at the bottom of each peg. When the component pieces are inserted into the board, the rivets at the

bottom of the pegs will make contact with these brass nails. Once contact is made, current will then run through the rivet which will in turn run through the wire that is soldered to the rivet to create a working circuit. The bottommost layer is the area that houses the wires and electronic components. The circuit that the user interacts with is prewired in this area and is connected to the load unique to the board. Once the user correctly connects the component pieces into the board, the prewired circuitry underneath will be complete and power will flow to the specific load for each board.

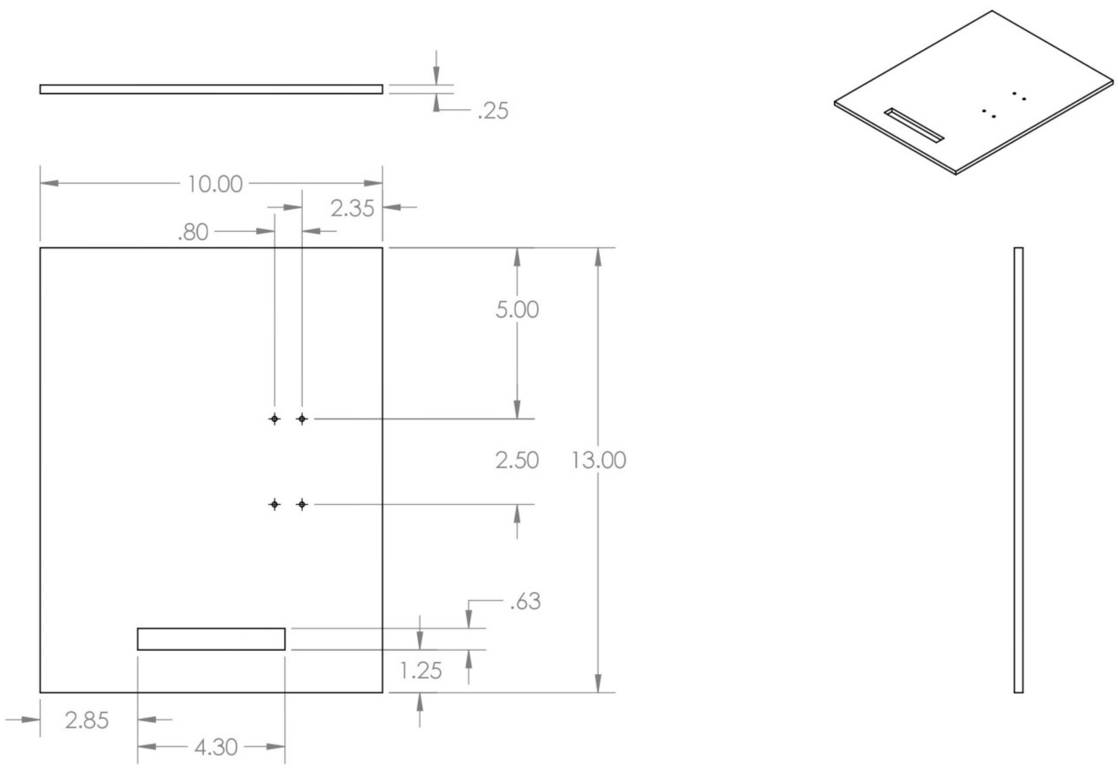


Figure 29: Top layer view of Resistor Board with dimensions

For the Resistor Board, the top layer consists of two peg holes (see Figure 13). Both the large and small resistor pieces are inserted into the same peg holes. It is important to note, that

depending on whether it is a large or small resistor piece, the rivets of the piece will make contact with different brass nails on the second layer. The rivets on the resistor pieces are positioned strategically so that the specific resistor piece will only make contact with its corresponding nails. This is because the large and small resistor components create different connections to different circuits pre-wired underneath on the next layer. As a result, by inputting a small resistor component into the Resistor Board, the wiring for the small resistor will activate the fan attached to this board and cause it to spin at a faster rate than the larger resistor component would cause; thereby teaching the concept of resistance change.

For the Complete the Circuit board, the top layer is a wooden board consisting of multiple peg holes which will allow six Circuitblock parts to be inserted into the board at one time (see Figure 14). The spacing of one set of peg holes for a Circuitblock is 2.5^{in} away from another set of peg holes, as shown in the figure below. This spacing eliminates the Circuitblock pieces to overlap or clash with another piece when being inserted.

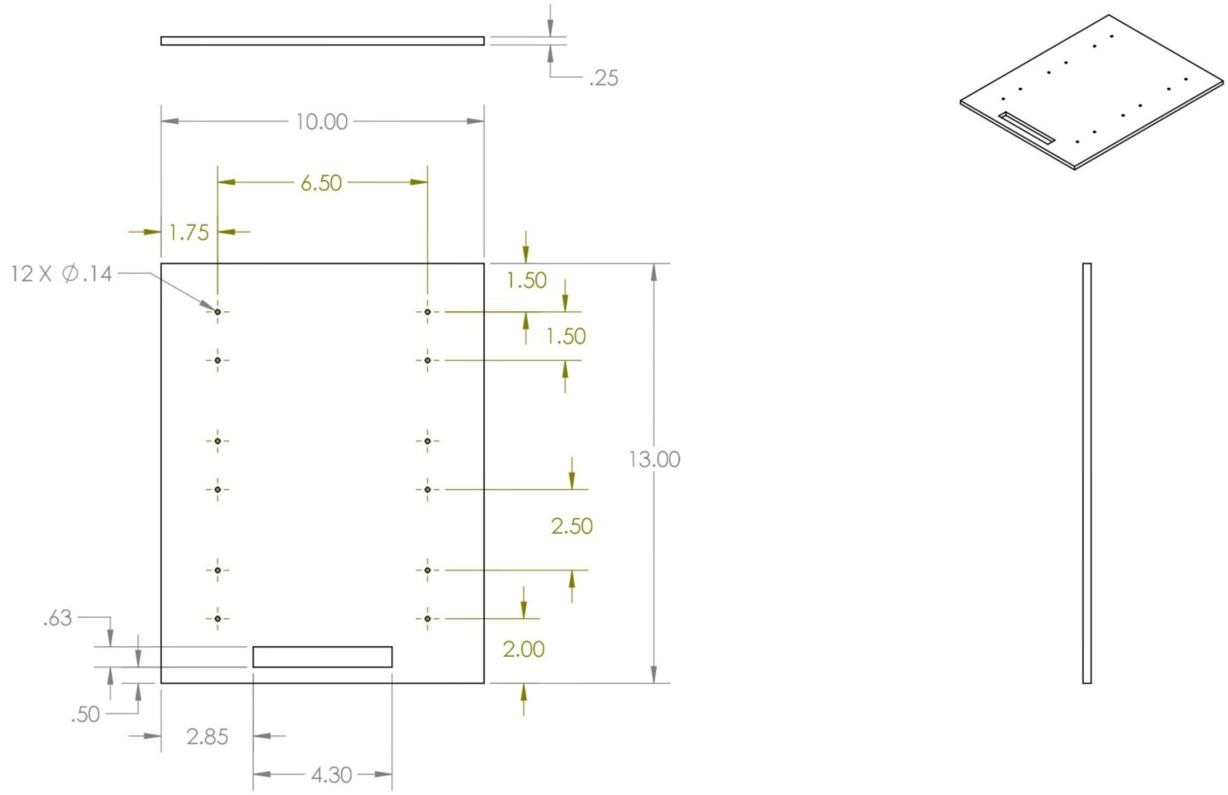


Figure 30: Top Layer View of Complete the Circuit Board with dimensions

Similar to the Resistor board, the second layer consists of a brass nail located directly underneath each of the peg holes on the layer above it. The rivets of the Circuitblock pieces will make contact to these brass nails and conduct current through the wire inside the piece.

Manufacturing of Boards

As requested by the museum, the construction of the boards and table was a contract job done by a custom designer contractor, Stephen Gonzales. Stephen has worked on various table and exhibit designs for the museum in the past. Desiring uniformity of their exhibits, the museum wanted a familiar contractor to build the boards and table.

Methodology and Results

This section will discuss how the team met customer requirements and also go through the cost breakdown of the project.

Meeting Requirements

To measure success for this project, it was important to keep constant communication with the client to ensure that customer requirements were met. Discussed in an earlier section, customer requirements for the exhibit included safety design, minimal supervision, interactive and educational features, economic costs, and low maintenance. These customer requirements can be grouped into two categories; effective design and economic costs. In order to have an effective design that meet customer requirements, the exhibit must be safe, interactive, educational, involve minimal supervision and low maintenance by the staff. This was achieved through a thorough iterative design process. Safety was the issue of most concern and was addressed by child proofing all aspects of the exhibit. This includes removing all sharp edges/points, using parts that only pass a choke tube test, restricting access of the internal electrical components from the user, and securing all heavy objects to the table. Child proofing the exhibit also addresses the issue of requiring only minimal supervision by the museum staff. The exhibit meets the requirements of being interactive and educational by having the user read instructions and figure out the learning concepts imbedded in each of the three stations. The exhibit has instructional signage with simplified text and animated graphics, as well as plug-in style parts to make the user experience intuitive and reduce the need for additional guidance by staff.

Cost Analysis

Furthermore, in order to ensure the project did not surpass the given budget of $3,000, educated material choices were made to provide an economic final product without affecting functionality. Below is a summary of the major costs made by the team.

Table 5: Summary of Cost Table

Cost Type	Sum of Costs
Cast Material	$312.37
Electornic Components	$76.25
Total Cost:	$388.62

As seen in Table 5, the two major categories for costs originate from the material used for casting and the material for the electrical components. A bill of materials, which show each item bought and its cost, is located in Figure 33 of the Appendix. Overall, the total cost spent by the team for this project is $388.62, which is significantly under the initial budget given by the museum. An important fact to note is that the cost to construct the exhibits and signage is not included here. Construction was done by a third party contractor preapproved by the museum. Most exhibits in the museum are done by the same contractor to create uniformity within the museum floor. As a result, there costs are not included within the team's original budget.

Conclusion

This report will conclude with a brief project summary, an exhibit maintenance plan and an update of the project's current status.

Project Summary

This report demonstrated all the research, decisions, designs and prototypes that took place in order to create an interactive and educational engineering exhibit. This project satisfied the museum's need by designing a function three-part exhibit that can now be manufactured and implemented.

Maintenance

In order to sustain the exhibit over the years, an additional three sets of board components were casted as replacement parts for the museum. Furthermore, a manual is the process of being written that explains the board making, electronic wiring, and part making processes. The museum will also be given a flash drive containing all of the solid works models used for this project. Finally, the museum will be presented with a supply box consisting of the original part molds, as well as surplus mold mix, part mix, and part dye.

Current Status of Project

As of today, May 26th, 2015, the current status of the project is described in the following section.

The prototyping and testing of the boards, component parts, and electronics have all been completed. The project team is in the process of making component pieces and will be completed within the next week. The boards and table specifications were given to a third party contractor and are currently being built. Final signage text will be finalized during a meeting held with

Michelle Jenkins this Thursday and then will be sent to the museum’s printing company. Once the museum receives the materials from the contractors, the team will wire the boards. The exhibit will then be ready to be installed into the museum. The team will perform final testing and the Circuit Labs Exhibit will be expected to open in July of this year.

Appendix

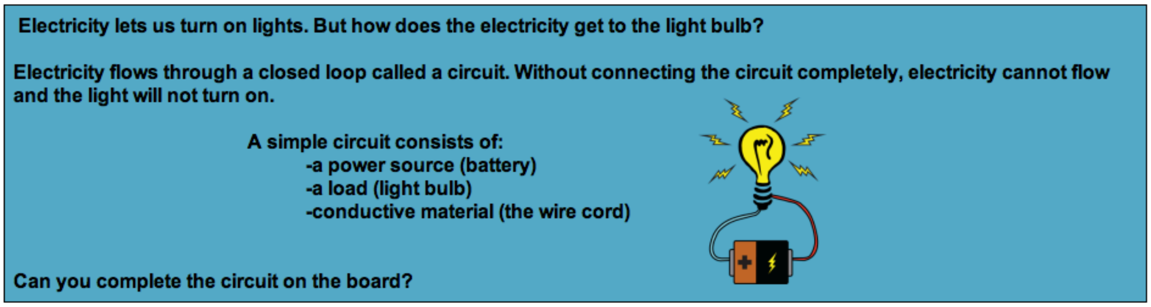


Figure 31: Signage- Complete the Circuit

Why do circuits matter?

Circuits are used to make the products you love work!

Circuits can be found in:

Cellphones
Laptops
X box/ Play Station/ Nintendo Wii
Televisions
Radios

Want to learn more about circuits?

Check out the college major of Electrical Engineering!

Figure 32: Signage- Display Case

	Item Name	Description	Quantity	Price
	OOMOO 30	SILICONE MOLD RESIN	5.08 KILOGRAMS	$101.88
	SMOOTH-CAST 300	URETHANE PLASTIC RESIN	6.99 KILOGRAMS	$88.85
	EASE RELEASE 200 12-OZ AEROSOL	CASTING LUBRICANT	.34 KILOGRAMS	$13.20
	SUPER SEAL & EASE-RELEASE 205 4-OZ KIT	CASTING LUBRICANT	.11 KILOGRAMS	$7.64
Cast Material	SO-STRONG BLUE 2-OZ	BLUE PLASTIC DYE	56.00 GRAMS	$13.60
	SO-STRONG FLESH TONE 4-OZ	FLESH PLASTIC DYE	113 GRAMS	$13.60
	SO-STRONG YELLOW 2-OZ	YELLOW PLASTIC DYE	56 GRAMS	$13.60
	SHIPPING + TAX	REYNOLDS SHIPPING FEE	N/A	$50.00
	MICELLANEOUS	Wires, solder, Cups, stir sticks	N/A	$10.00
			Total Cost of Cast Material:	**$312.37**
	RELAY	ELECTRONIC COMPONENT	1	$0.50
	SHRINK TUBING	ELECTRONIC COMPONENT	2	$7.00
	SOLDERING STAND	ELECTRONIC COMPONENT	1	$17.00
Electronic Components	BATTERY HOLDER	ELECTRONIC COMPONENT	1	$0.75
	12 V POWER SOURCE	ELECTRONIC COMPONENT	1	$10.00
	CONNECTIONS	ELECTRONIC COMPONENT	3	$1.00
	AEROCOOL SILENT MASTER 200MM BLUE LED COOLING FAN	DC FAN	1	$20.00
	EL Wire	EL WIRE	1	$20.00
			Total Cost of Electronic Components:	**$76.25**
			Overall Total Cost:	**$388.62**

Figure 33: Bill of Materials

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