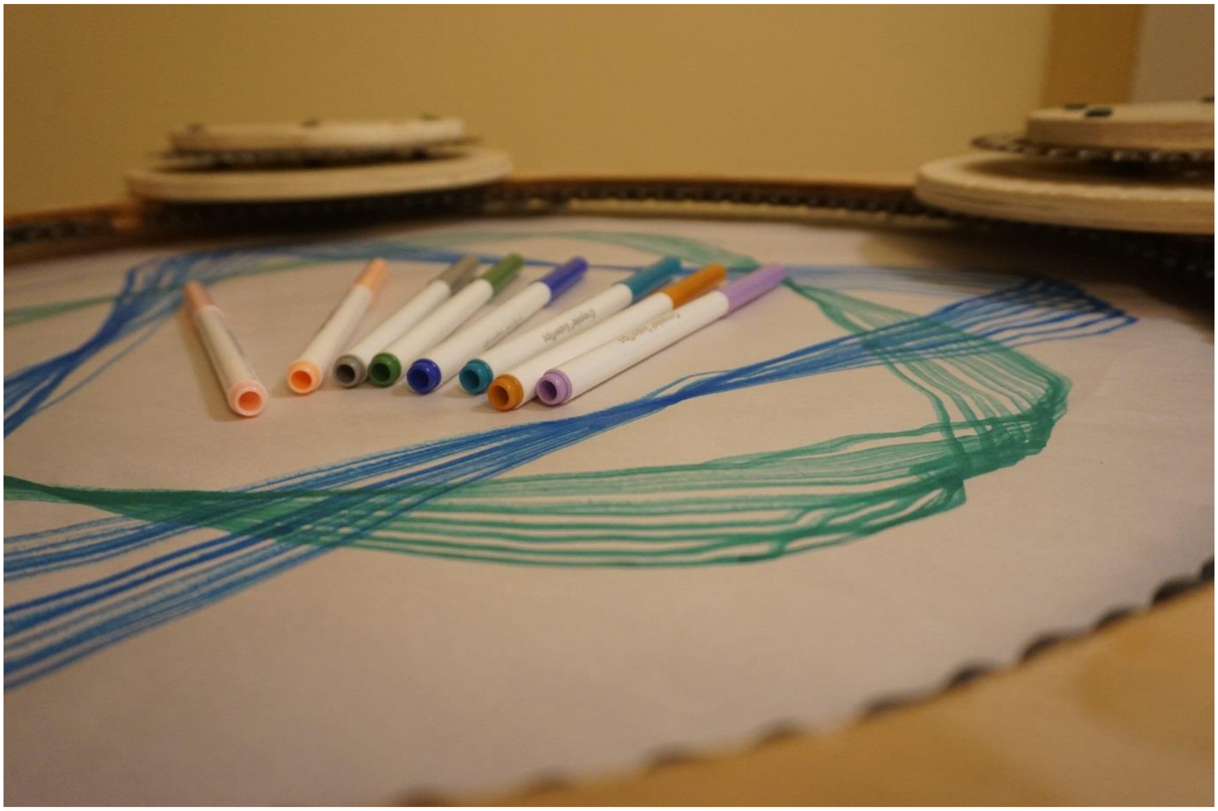


INSPIROGRAPH

Team BlackBox

Alex Cody-Prentice, Keann Kline, Aren Page, Ish Tripp

Humboldt State University
ENGR 215 – Fall 2017

Table of Contents

List of Figures

List of Tables

1 Problem Formulation

1.1 Introduction

In the first phase of the design process Team BlackBox provides background on the design project, formulates an objective statement and provides a black box diagram shown in Figure 1-1.

1.2 Background

The client that Team BlackBox will collaborate with is Redwood Discovery Museum, an educational, non-profit children's museum located in Eureka, California. The Redwood Discovery Museum educates young children in Humboldt County through fun exhibits intended for ages 3-8, incorporating the foundations of science, arts, and general health. Toy-maker and founder of the Redwood Discovery Museum, Ken Pinkerton, has hand-crafted many of the exhibits on display. Pinkerton has had a long-time passion for crafting toys with a philosophy of hands on education and to minimize further exposure to digital screens.

1.3 Objective

The primary objective of the project is to create an interactive exhibit for the Discovery Museum that provides an enjoyable experience for two types of children; those who are curious about learning something new and those with a desire to engage with science in a fun way. This objective comes with constraints from the client which will be upheld throughout the design of the project. Two constraints that will hold high value through every piece of the project design are 1) the requirement for a product which can withstand the destructive force which children embody and 2) a product which upholds the utmost safety and will not injure or harm the user in any way.

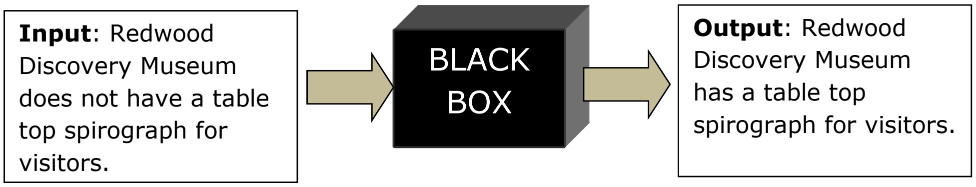


Figure 1-1: Black Box Model demonstrating what the design implementation will accomplish.

2 Problem Analysis and Literature Review

2.1 Introduction to Problem Analysis

The problem analysis classifies each of the client criterions and discusses the respective constraints to identify what will be required in the design of the project. This section also covers specifications, considerations, production volume and usage.

2.2 Problem Analysis

2.2.1 Specifications

The specifications for the projects are elements that must be implemented when designing the project. Specifications to be considered during the design phase are:

- Must not have choking hazards.
- Must be able to transport through a standard doorway with help of two individuals.
- Must be "table top" in design.

2.2.2 Considerations

Considerations are requirements for the project that are implied by both specifications and general knowledge of the project. Considerations for the project will be as follows:

- Primary user age range will be 3-8 years old.
- System will be used indoors.
- Children may be unattended when using the system.
- Spirograph drawings may be taken home by users.
- Signage will be at a 3rd and/or 4th grade reading level.

2.2.3 Criteria and Constraints

The criterion below are elements which are of importance to the client in the design of the project. The constraints are the way in which the design meets the criterion. Each is weighted in order of importance to the client.

Criteria	**Constraints**	**Weight (1-10)**
Appeal	Multiple Color Options	5
O&M	<$1.00/per day	8
Ease of Use	Fluidity	8
Durability	Lasting longer than 1 year	9
Education	Understood by users ages 3-8	9
Inspiration	Stoke factor	9
Safety	ASTM Toy Safety Standards	10
Cost	≥$500	7

2.2.4 Production Volume

There will be two prototypes exemplifying the ability to successfully trace spirograph designs using ballpoint pens. The final project will be a fully functioning spirograph tabletop which allows up to three users to draw simultaneously on their own separate sheets of paper.

2.2.5 Usage

The spirograph system will be built to last with minimal repairs and necessary replacement pieces. The life of the spirograph tabletop will be approximately 20 years or equal to the life of the Discovery Museum business.

2.3 Literature Review

The literature review section will provide background information that will set a foundation for the design process.

2.3.1 What is a Spirograph?

A Spirograph is a toy that incorporates math to create a variety of complex shapes and designs. A few of the most common shapes that a Spirograph are used to draw are Epicycloids, Hypocycloids and Cycloids which are defined and illustrated in the sections below. The most common design of the toy includes a small inner cog containing a series of holes through its diameter which is guided using manual movement by an outer gear ring. The connection between the outer ring and inner cog is maintained by a series of teeth which keeps the rotation on track and the drawing along the correct rotational path. The user chooses an inner cog hole and inserts a writing tool to create a pattern specific to that hole in the inner cog.

2.3.2 History of the Spirograph

The Spirograph was invented in the late 1800's by a Polish mathematician by the name of Bruno Abakonowicz. The Spirograph was originally intended to be a mathematical tool rather than a toy. A British Engineer named Denys Fisher was the first to market the device as a toy. He originally used the Spirograph as a tool for drafting. Denys Fisher was a father and noticed his children's interest in the Spirograph. He then decided to market it as a toy in 1965 where it gained success at the Nuremburg International Toy Fair.

2.3.3 Design 1 – The Hypotrochoid

The first design that can be created with a Spirograph system is called a Hypotrochoid. A Hypotrochoid is traced by setting a point with radius r that is fixed inside a circle. The point is not directly centered in the circle, but instead is offset. In the equation of the Hypotrochoid the variable d is used to express the distance the point is from the center. This circle then rotates along the interior of a larger circle, tracing the path of the inner point as shown in Figure 2-1.

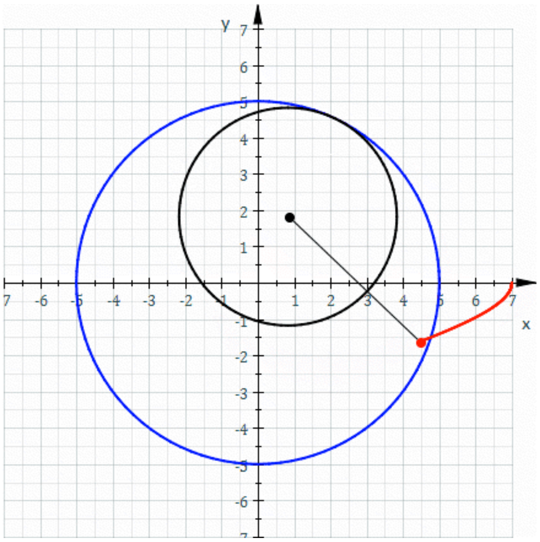


Figure 2-1: Hypotrochoid on (x,y) graph illustrating resultant path (Derbyshire,2006)

2.3.4 Design 2 – The Epitrochoid

In contrast to the Hypotrochoid, an Epitrochoid traces a path along the opposite side of an inner circle’s circumference. In the Epitrochoid, the point is attached to a smaller circle with a fixed radius that rotates along the outer rim of a larger fixed circle. The variable D is used to measure the distance from the exterior circle center to the traced point.

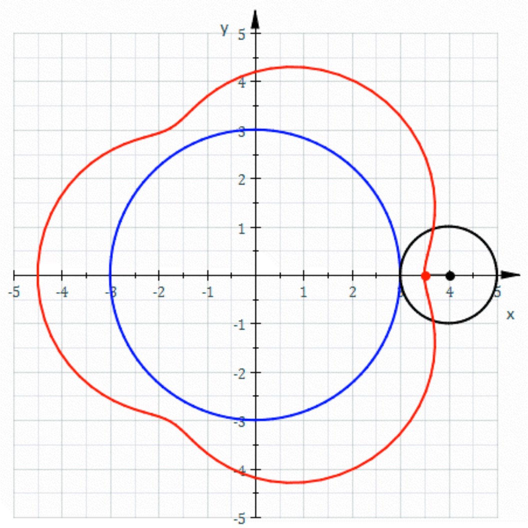


Figure 2-2: Epitrochoid on (x,y) graph illustrating resultant path (Derbyshire,2006)

2.3.5 Cycloids vs. Trochoids

The two designs mentioned previously are examples of Spirograph designs which can be implemented by adjusting the location of the interior and external circles. When referring to the actual tracing of the point, the definitions of Cycloids and Trochoids are used. When the traced point makes contact with the surface of the outer circle evenly, a cycloid is created. This is when the radius of the smaller circle is equal to the radius of the larger circle. When the traced point does not make contact with the surface of the outer surface at all, a Trochoid is formed. A trochoid is when the radius of the smaller circle is lesser than the radius of the outer circle. A trochoid is also formed when the radius of the inner circle is greater than the radius of the outer circle, this ratio causes the traced point to extend the rim of the outer surface. Both Cycloids and Trochoids are created in a Spirograph and are illustrated in Figure 2-3.

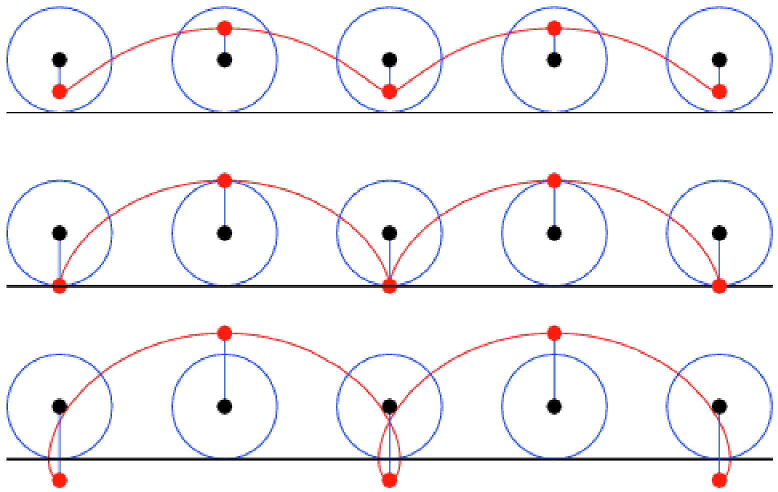


Figure 2-3: Relationship between trochoids (top and bottom) and Cycloids (center). (Weisstann, 2017)

2.4 Gears and Cogs

2.4.1 How do Gears Work?

The most common spirographs are created using gears. "Gears" is the termed used to identify a system that involves multiple parts which transfer energy among each other. To accomplish this at least one piece of the system must be moving.

The gear system most identifiable is a system that involves one or more circular shapes with teeth around the circumference. Each piece interlocks with each other by their teeth. In this manner, an applied force can drive the system and be directed along a path.

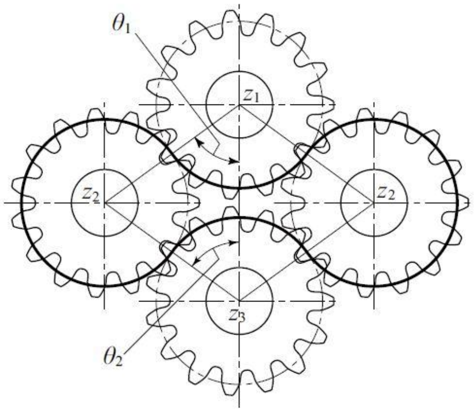


Figure 2-4: A Gear System (Kohara, 2002)

2.4.2 Spirograph Gears

In a Spirograph, the gear system is used in ether a Hypotrochoid design or a Epitrochoid design. This allows for the driver to create a geometric shape with a writing implement in place of the inner circle point. As the system is driven, a cycloid or trochoid shape is then created from the path of the point.

2.4.3 Organic Gears

Various styles of gear systems are being used in experimental systems. Among these new designs are those of the unconventional organic style gear systems. These gear systems use organic shapes in place of the traditionally used pointed interlocking teeth. The gears use the basic system style of a larger shape with interlocking pieces along the circumference. These larger shapes can also be changed too, instead of using circular shapes, multiple squares, rectangles or ellipsoids can be used.

Figure 2-5: Unconventional Gear System (Boyer, 2013)

2.5 Building Materials

2.5.1 Wood

Wood can be a cheap affordable material to work with. Wood excels in organic gear design due to the ability to create uneven shapes. However, wood expands and contracts depending on the amount of moisture it comes into contact with. This can be a serious problem when creating shapes that must fit and work together in uniform in order for the system to work properly.

2.5.2 Metal

Metal is a very durable material under a variety of conditions and remains correctly fit and working if maintained. However, metal will require constant lubrication on moving parts in order to work appropriately. Metal can also be more expensive depending on which type is used.

2.5.3 Plastics

Plastics do not need to be maintained like many other materials. Plastics are also very durable under a variety of conditions and will hold shape through an extended product life. However, plastics can be very difficult to work with if you do not possess the expensive tools needed to work with the material. Plastics are also very toxic in raw working form.

2.6 Geometric Patterns

2.6.1 Elementary Shapes

Spirographs tend to have very intricate Geometric patterns that contain a great wealth of mathematical knowledge, from basic math to difficult calculus problems. As mentioned previously, patterns traced by using the inside and outside of a circle results in basic geometric designs such as the hypotrochoid and epitrochoid. Although these patterns are very simple to create their equations shown in Figures 2-6 and 2-7 display the difficulty behind them.

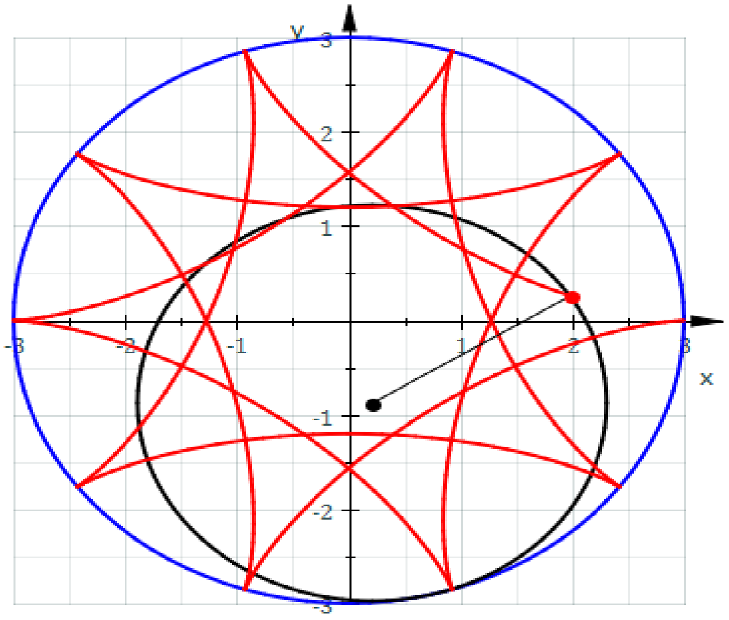


Figure 2-6: Hypotrochoid: $x=(a-b)\cos(t)+h\cos((a-b)t/b)$, $y=(a-b)\sin(t)-h\sin((a-b)t/b)$ **(Chapin, 2006)**

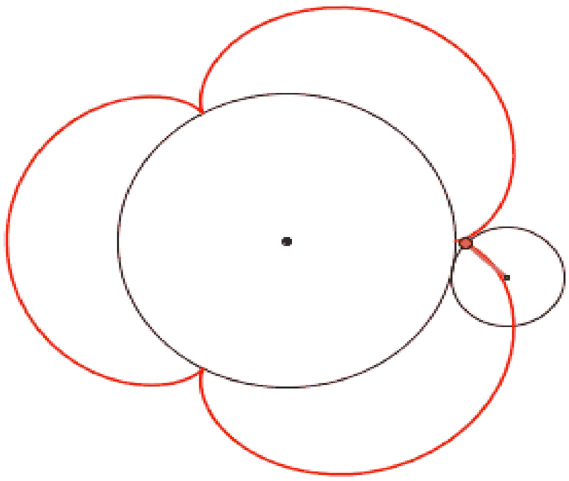


Figure 2-7: Epicycloid: $x=(a+b)\cos(t)-b\cos((a+b)t/b)$, $y=(a+b)\sin(t)-b\sin((a+b)t/b)$ **(Chapin, 2006)**

A typical child between the ages of 3 and 8 years old is unable to grasp the principles used in these geometric designs. The use of simpler patterns traced from simple shapes like circles, squares, and triangles will be much easier to demonstrate a mathematical foundation that they are able to understand. In addition, the overlapping of such can also provide a beautiful and intricate design.

2.7 Elementary Curriculum

Team Black Box has a targeted audience of children between the ages of 3 and 8. Less intricate patterns may be easier when correlating mathematical foundations that the target audience may have been exposed to in school. Considering the level of difficulty, utilizing the principles of simple polygons and circles or ovals they may have seen before. For example, the visualization of ‘r’ as a radius and its area formula r^2 or even the circumference 2r. The same idea holds for simple polygons like squares and triangles.

2.8 Upcycling

The term upcycling refers to the idea of using a discarded item and fashioning it into something that can be entirely new. This method has the potential to extend the life of that item for a longer period of time than if it were to be thrown away. This reduces the amount of waste going into the environment’s waste stream. Upcycling also reduces the amount of energy spent on producing the needed product since the product is made mostly, or entirely, from discarded items.

As Clarissa Morawski discusses in her article, Embodied Energy, the amount of energy required to manufacture a product is called embodied energy. This is energy that is embedded within the products that we buy and is lost when we throw these products away. Not only does the manufacturing of the product take energy but it also takes energy to create and harvest the virgin materials for the initial product (Morawski, 2006). When upcycling is used instead of buying a new product we take advantage of embodied energy in discarded materials and thus lower the demand for new products made by virgin materials.

Less energy is needed overall to produce goods if we produce goods made with recycled products and reuse and repurpose products to make new ones. For example, Morawski writes that 95% less energy is used from making sheet metal out of aluminum cans rather than virgin aluminum. She also states that one year in Canada about 3.4 billion glass bottle servings were produced in reusable glass containers which saved 5 million gigajoules of energy (Morawski, 2006).

The same concept of saving embodied energy can be applied to the spirograph design, it can be made from used and discarded parts, so as to save the embodied energy in the used parts.

2.9 Client Information

The client is the Redwood Discovery Museum, in Eureka CA. They have provided requirements and guidelines for the project as well as providing some materials. Fortunately, newsprint paper provided by the museum can be used as the drawing medium that the children will use.

One consideration that is necessary is to make the project easily taken apart with tools. Another is that for the whole system, including the sizing of the table, to fit through a standard doorway, which is no more than 2 x 4 ft. This design needs to be able to be moved, although wheels are not necessary. It was specified that the writing apparatus would need to be tied down somehow so that the children could not take them. No redwood is to be used in this design whatsoever. Redwood splinters and splintering wood is not to be used. All other materials are acceptable.

There are some things that are not necessary but are still desired. There is plexiglass available at the museum and, so it is encouraged to incorporate the plexiglass into the design to cover up things that might otherwise be covered by a non-translucent surface. Ball point pens have ink cartridges that are easily replaceable and so ball point pens are also wanted. Signage is desired, however, making a high-quality project is more important than signage.

Making the attraction accessible for children in wheelchairs is important also. According to ADA accessibility guidelines, 25 inches or less is used to reach over an object, such as a table. Another standard that is important is having 60 inches for a wheelchair to turn around in. Since we are using a table, only 36 inches are the minimum for the width of the path around the table (United States Access Board, 2002).

2.10 Product Appeal for Children

Product appeal is used in designing a product so that it attracts people and sometimes a certain group of people. According to a book written by Dan Acuff, children in different age groups are stimulated by different things. This means that advertisers can hone in on their age group and sell their product in large numbers if they advertise specifically to the interests of the targeted age group. For example, children ages 3 to 7 love things that transform. Because of this, products that transform tend to sell better than products that do not. An example given by Acuff was how Clark Kent changes into superman and how the Power Rangers each transform from ordinary human beings in their own unique Power Ranger. An instruction manual on how to create a product aimed at children is included and can be used to make our project appealing to children (Acuff, 1997).

Acuff states that there are four needs that a child ages 3-7 have. These needs can affect our marketing or signage of our design. These needs include 1) the need to be entertained, 2) the need for love, 3) the need for safety and 4) the need for autonomy (Acuff, 1997).

2.11 Marking Tools

A number of different marking tools can be used for the spirograph. Traditionally, a standard ballpoint pen was the main marking tool for the original spirograph children's toy that was manufactured in 1908, The Marvelous Wondergraph . The benefits of using a pen are that ink is very visible and tends to last an extended period with minimal replacements of ink. A pencil could also be used, although pencil lead is not as visible and would require either sharpening or mechanical clicks for continued use. One unconventional alternative marking tool for a spirograph may be chalk. While chalk is likely the most child-safe marking tool, it can be very messy and would likely produce a spirograph picture of the poorest quality. Another alternative marking tool is a marker which, similar a ballpoint pen, would be very visible but would create a fuller spirograph picture.

2.12 Cognitive Development in Children

The blending of art and math go hand in hand in a child's cognitive development. As children progressively gain their motor skills they show eagerness to mimic what they see around them. One of the first creative activities that a child engages in is art. Children are driven to express themselves by drawing pictures, which typically reflect images they have once seen or have pieced together in their imagination. By allowing children to experiment with writing tools, colors and shapes, they can define themselves and even communicate through art. By using their creativity to experiment with size and shapes, children become better equipped to understand mathematical concepts by making comparisons and utilizing spatial reasoning. (Rymanowicz 2015) The spirograph captures the beauty of both art and mathematics. A spirograph can boost a child's cognitive development by using it to their creative advantage.

2.13 Child Safety

Child safety is of the upmost importance in the design process of any toy. The Federal Toy Safety Standard, ASTM F963-16, provides compliance guidelines on how to manufacture a toy that is safe for children. However, many elements of safety in toys for children are common sense. A children's toy should be built durable and safe for that child's age range (Goodson, 1993). Many childhood injuries are the direct result of toys designed without the safety of the child in mind (Abrahams and Ehsani and Gruss and Winkler, 2016). The components of any toy should be those which a child is unable to lodge a body part into. Body parts typically at risk for a table-top toy include fingers, hands and arms. Likewise, the tools used to work a toy must not have sharp edges that can potentially cut into a child's delicate skin. A very common child safety concern with toys is choking hazards. It can be a problem for a toy to have removable parts that the child is able to fit in their bodily orifices. Lastly, a toy with removable parts that have a sharp point, such as a pencil, can pose the risk of accidental stabs to themselves or children around them. Awareness of these issues help to ensure that the design of a toy is safe for the child.

3 Search for Alternative Solutions

3.1 Introduction

Brainstorming sessions were held within the group in order to formulate alternative solutions for the design of the Spirograph. Each design adheres to criteria that was provided to Team Blackbox by the client. A total of seven alternative solution designs were developed, a select few of which will ultimately be presented to the client.

3.2 Brainstorming

Multiple brainstorming sessions were held among the team where ideas were documented on both paper and whiteboard. Various components, structures and client criteria for the Spirograph design were discussed during the sessions. Notes from these sessions can be found in Appendix A.

3.3 Alternative Solutions

3.3.1 The Double Carousel Spirograph

The Double Carousel Spirograph incorporates flat disk versions of a carousel rather than a tall and realistic version. This allows children to avoid having their fingers hit by any components other than the pens. The Double Carousel Spirograph operates by having two disks that rotate at the same time, similar to how the earth rotates as it orbits around the sun. Figure 3-1 illustrates that as both components **D** and **C** rotate, the pens (component **E**) will make a mark on the paper (component **B)**. With the addition of holes (components **F)** different combinations of disks (component **D)** can be placed inside the holes (component **F**) to create different combinations of geometric patterns. If it is deemed safe then animal-shaped components can be mounted around the pens to mimic a real carousel.

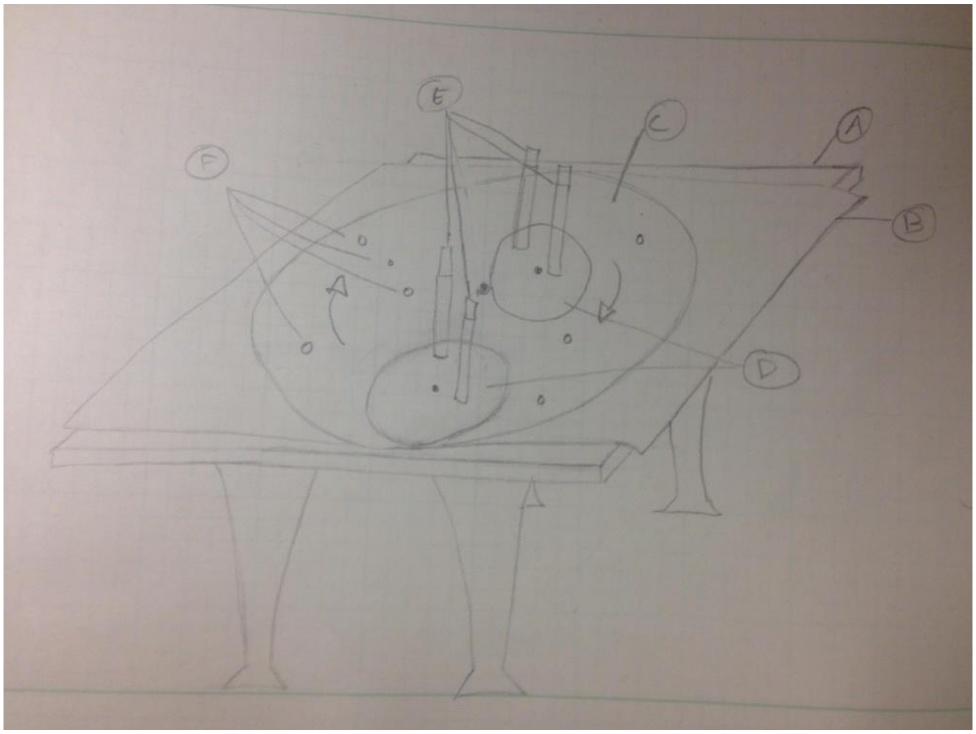


Figure 3-1: The Double Carousel Spirograph Design (Drawing by Alex Cody-Prentice)

3.3.2 The Magnetic Spirograph

The Magnetic Spirograph is a magnetic version of the original spirograph. The smaller cog (component **C**) is iron, while the rest of the materials are not. The attractive force of the magnet (component **A**) could be used to pull the smaller cog (component **C**) along the larger cog (component **B)**. The magnet can potentially be attached to the bottom of the table and grooves can be added to help guide the magnet along. This would eliminate the user needing to figure out how exactly to pull the cog along. While deterring the user from figuring out how to pull the cog along may be seen as a detriment to cognitive development the joy of creating a beautiful geometric design may be lost if it is too difficult to do.

The large cog (component **B**) and small cog (component **C**) come in various size and can be interchanged within the system. This makes it possible to create many combinations of designs. Multiple holes for the pens can be installed in the smaller cog (component **C**) to create the option for various geometric designs being drawn.

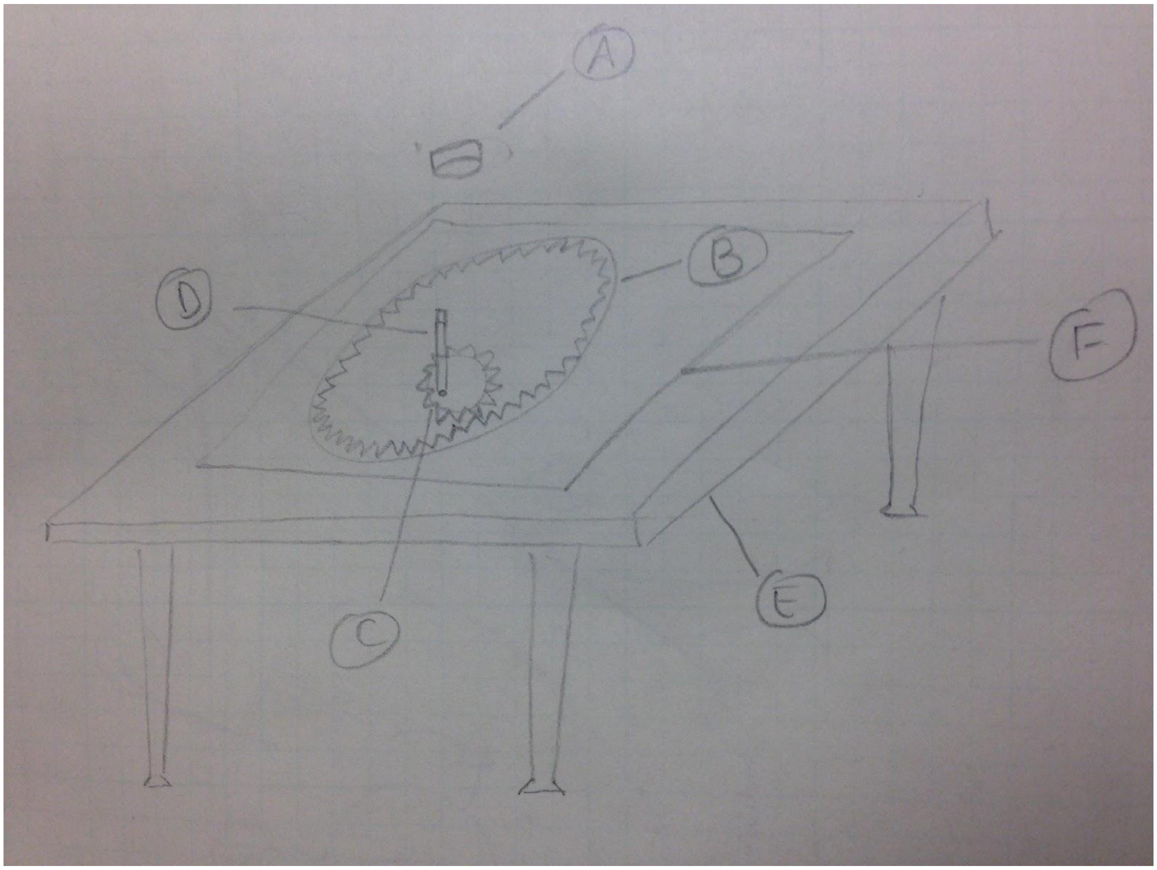


Figure 3-2: The Magnetic Spirograph Design (Drawing by Alex Cody-Prentice)

3.3.3 The Marching Spirograph

The Marching Spirograph allows children to create geometric images on paper with minimal help from an adult. The system is situated on a circular tabletop containing a paper roller device that sits atop the table and feeds paper across by simply turning the paper roller knob. Various outer cog shapes can be chosen to fasten to the paper and table using their attached cog pegs. A variety of removable inner cogs with rotating, vertically-extended handles in the cog center can be fixed with any one choice of colored ballpoint pens in any desired cog hole. Holding onto the cog handle, the user places the inner cog inside the outer cog to line up the “teeth”. The user can then walk around the circumference of the table while holding onto the cog handle. While the user and cog handle simply move in a perfect circle about the table, the inner cog and pen are working to create an elaborate spirograph image on the paper.

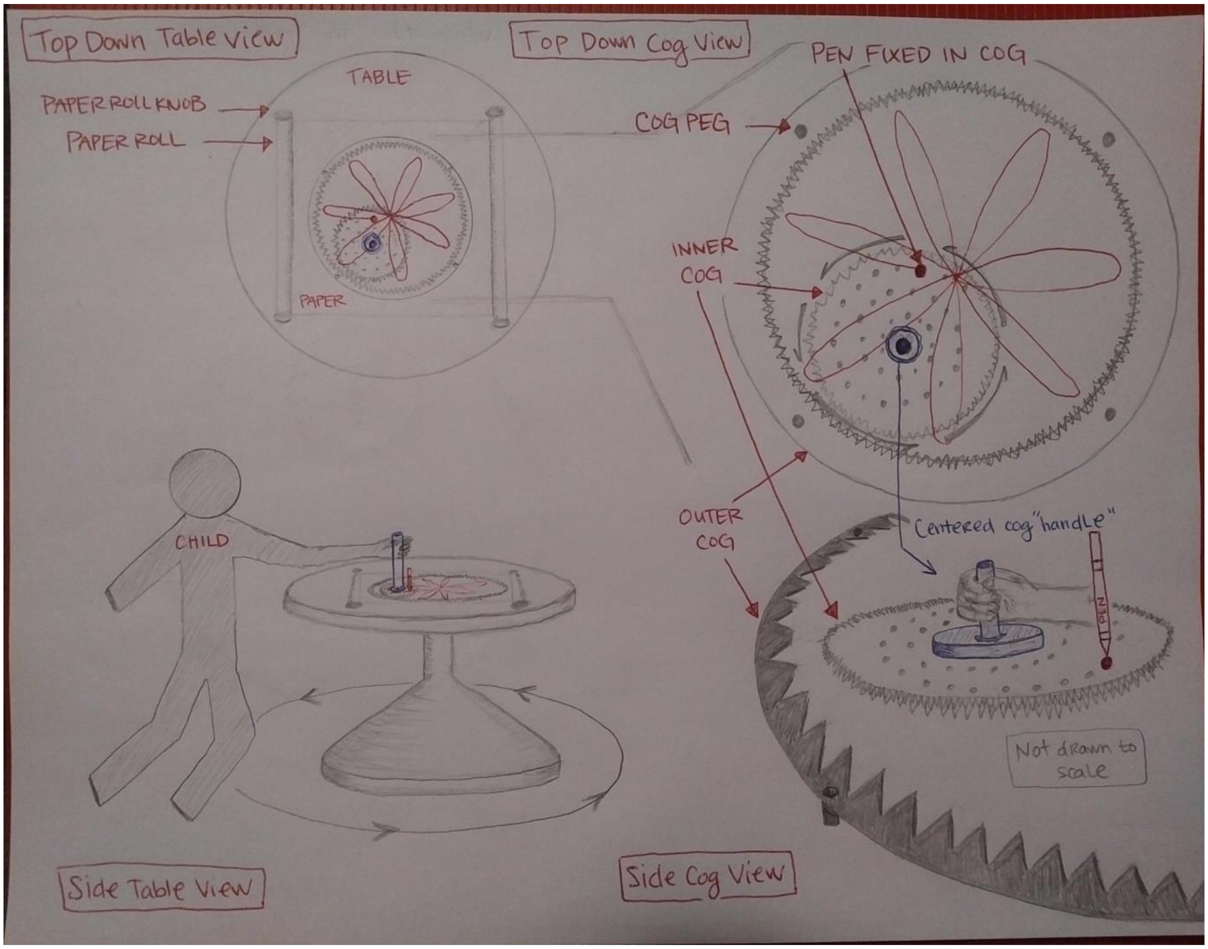


Figure 3-3: The Marching Spirograph Design (Drawing by Keann Kline)

3.3.4 Pivoting Arms Spirograph

The Pivoting Arms Spirograph offers the user the ability to be creative using kinetic energy. The system sits on a rectangular tabletop with rounded corners for safety. There is a paper roll situated at the upper portion of the table. At the bottom of the table is a wind up handle that manages a primary wire reel. The wire winds out of the primary reel and around two separate secondary reels that are situated 60° and ahead of the primary reel. A system of wooden pivoting arms is attached to each secondary reel by rotating arm pins. This pivoting arm system can be lifted off the arm pins of the secondary reel to allow the winding capability. The system of pivoting arms meets over the center of the paper where a ballpoint pen is fixed. The user raises the pivoting arm system from the secondary reels and winds the handle. The user then sets the pivoting arm system onto the pins of the secondary reel. This triggers the unwinding of the reels creating a spirograph image on the paper.

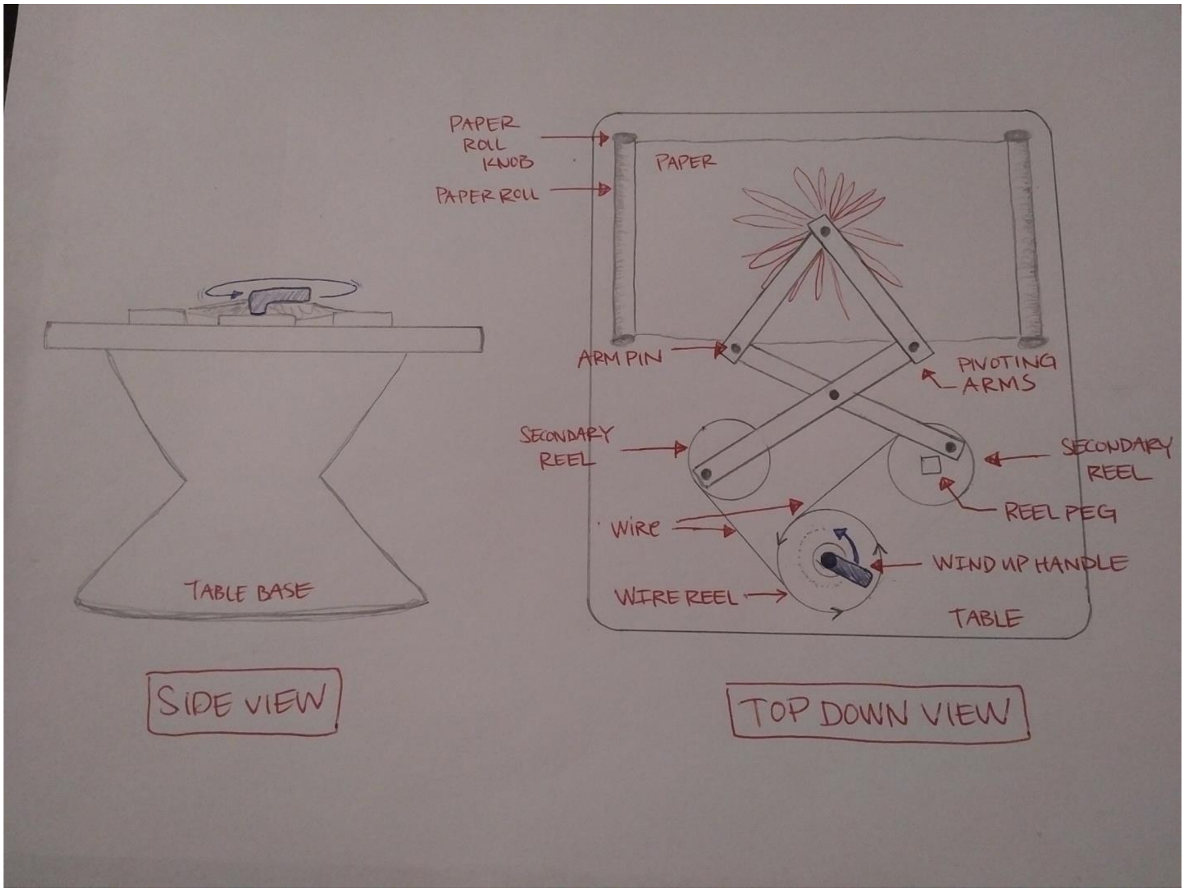


Figure 3-4: Pivoting Arms Spirograph Design (Drawing by Keann Kline)

3.3.5 The Circular Circumference

The Circular Circumference design involves a circular imprint inside a thick plank of wood. Around the circumference of this indentation is an imbedded bike chain. Along the inside of the bottom of this indentation a plastic circle is placed to reduce friction and prevent tearing of the paper that is being drawn upon. Along the circumference bike chain, the user guides along a center console. The center console consists of a bike cog attached to a wooden circle; this wooden circle hides the gears, preventing any potential hazards to the user's safety. Along the bottom of the bike cog, a circular plastic cut out is attached to allow for less friction between the metal and drawing surface. On the surface of the protective wooden circle, holes are drilled in the pattern of a Fibonacci sequence. The holes are large enough for a ballpoint pen to be inserted into each hole. In addition, a wooden knob is connected to the center of the console by a bearing, allowing the circle to spin around this focal point. The writing surface is a roll of paper attached by a rod to the bottom of the table. The paper is then threaded to the top of the table and through the system. This allows for the paper to be exchanged regularly. On the opposing side of the system, a method of tearing the paper off will be mounted.

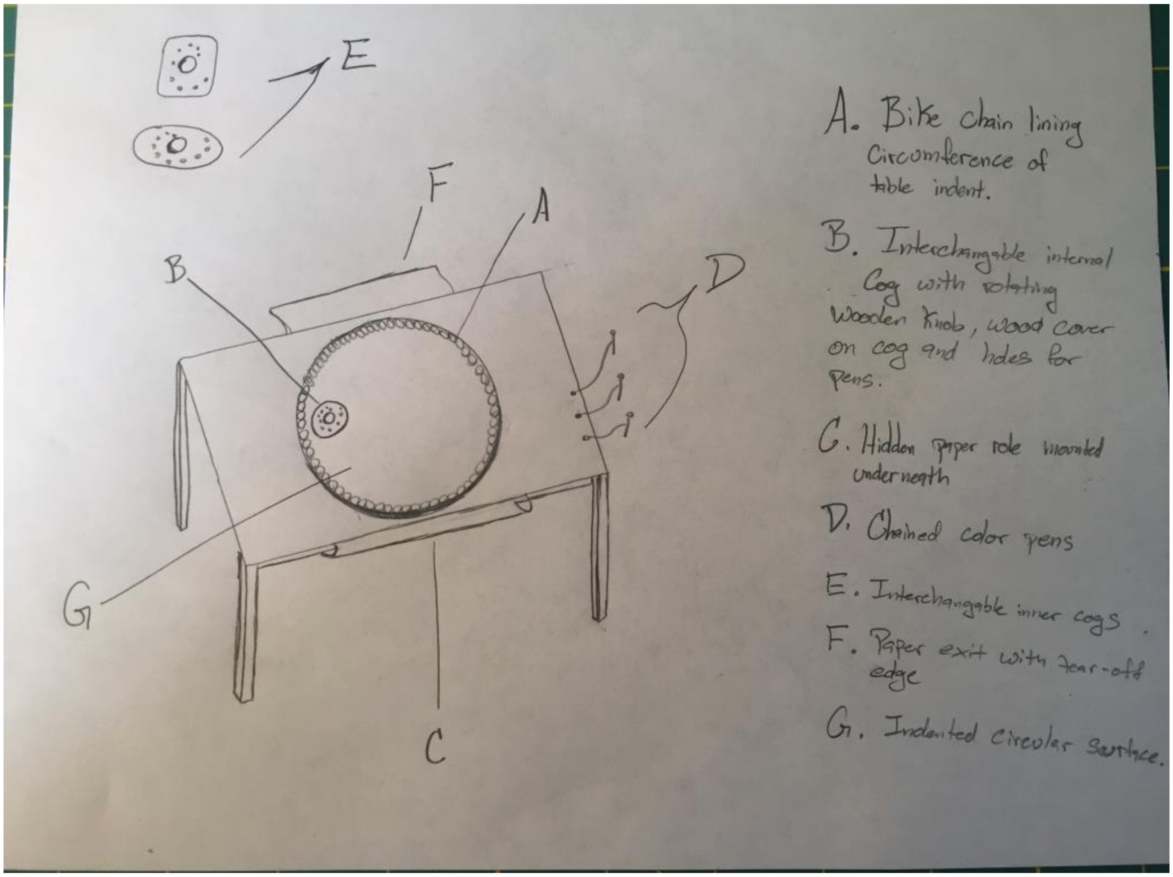


Figure 3-5: The Circular Circumference Design (Drawing by Aren Page)

3.3.6 The Square Dance

The Square Dance design consists of a wooden, square shape mounted to the center of an indented surface. The centerpiece will be shaped like a square with rounded corners to allow a circular gear to move along the outer circumference. The circumference of this piece will be lined with a bike chain that acts as a guide for a piece to rotate along the outer rim. The outer piece will be very similar to the previous design, consisting of a metal bike cog sandwiched between a circular wooden protective cover and a smaller plastic circular piece below to reduce friction. The outer piece will also have a mounted knob attached by bearing that allows it to spin. However, the internal structure that is shaped like a square will be removable and mounted easily with a metal rod attached to the underside. This will allow different shapes to be used in the center and thus allowing for a large array of designs to be created. There will be one centerpiece shaped like each shape; a square, a circle and an ellipsoid. These centerpieces will also be "misplacement-proof" by attached chain to each piece. This design is also a table top mounted system which is used with slide through paper attached to the underside of the table. On one side of the system, a roll of paper is threaded from a roll and on the opposing side; there is a mounted tear off ridge.

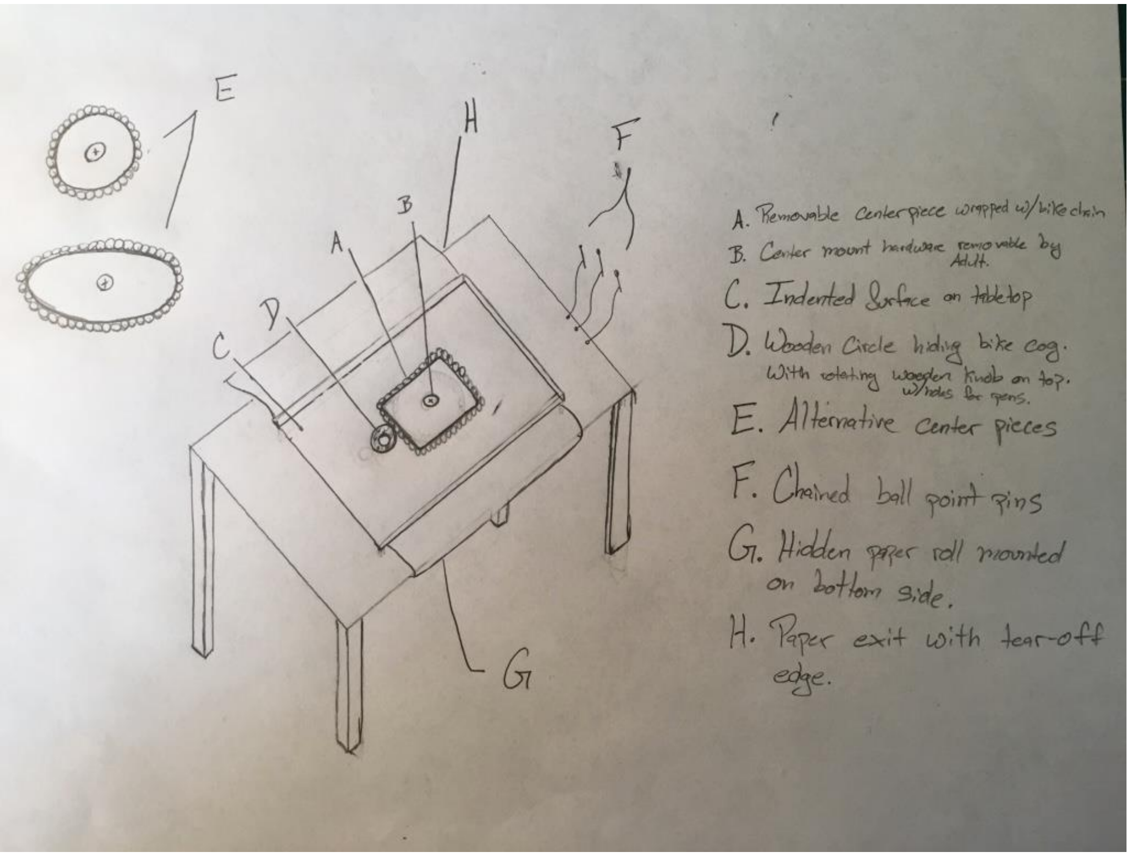


Figure 3-6: The Square Dance Spirograph Design (Drawing by Aren Page)

4 Decision Phase

4.1 Introduction

The Decision Phase outlines the deconstruction of the alternative solutions in Section 3. This section will evaluate each alternative solution using a Delphi Matrix. The figures produced in the Delphi Matrix are expected to identify a final solution that satisfies the most important criteria discussed in Section 2.

4.2 Criteria Definition

The definitions below are an explanation of criteria that will be implemented in the final solution.

Appeal – The system should be appealing to the users so that use of the system is more desirable. This includes additional pen color options and aesthetic attraction.

Maintenance Cost – The Cost to operate and replace broken pieces of the system must not exceed $1 dollar per day of use.

Safety – The level of safety of the system must minimize user injury to the fullest extent possible.

Education – Any possible ways of adding educational value to the use of the system should be implemented so that users will benefit from cognitive development.

Durability – The Spirograph must have a minimum of one-year life without major repair while withstanding continual daily use.

Usability – Users must be able to figure out how to use the system with minimum parental intervention.

Inspiration – Any possible ways of creating inspirational aspects within the system should be implemented in order to continue the desire to learn amongst the users.

4.3 Decision Process

The following list identifies the four alternative solutions from Section 3 which were evaluated using the Delphi Matrix.

- The Interchangeable Bicycle Cog Spirograph
- The Marching Spirograph
- The Square Dance Spirograph
- The Carousel Spirograph

4.4 Final Decision Justification

The method employed to decide on a decision was the Delphi Matrix. To create a Delphi Matrix there must be criteria to weigh the solutions against. A number from 1-10 was given to each criterion; zero being not important and 10 being very important to the project. Each solution was then given a number from 0-50 for each criterion, which represented how well the solution did in respect to each criterion. The weights of each criterion are added up for each solution and the solution with the highest number was chosen. The Delphi Matrix used is shown in Table 4-1.

Table 4-1: The Delphi Matrix

Solution Ratings

		INTERCHANGEABLE		MARCHING		SQUARE		CAROUSEL	
Criteria	**Weight**	**Vote (0-50)**	**Weight x Vote**	**Vote 0-50)**	**Weight x Vote**	**Vote (0-50)**	**Weight x Vote**	**Vote (0-50)**	**Weight x Vote**
Appeal	5	40	200	33	167	37	183	35	175
Repair	8	37	293	33	267	35	280	35	280
Ease of Use	8	42	333	42	333	37	293	38	307
Durability	9	42	375	38	345	38	345	38	345
Education	9	37	330	37	330	37	330	37	330
Inspiration	9	42	375	33	300	32	285	38	345
Safety	10	33	333	33	333	33	333	37	367
Cost	7	40	280	33	233	33	233	38	268
TOTALS		**2520**		**2308**		**2283**		**2417**	

4.5 Final Decision

By utilizing the Delphi Method, it was concluded that the Interchangeable Bike Cog is the leading solution. This design most satisfies the client and the constraints of our criteria. The Interchangeable Bike Cog design allows for a simple reconstruction, considering the inner portion of the outer cog will be lined with a bicycle chain fitted by multiple inner bicycle cogs. Another characteristic that gives the Interchangeable Bike Cog design an advantage over the other solutions is the fluid movement of bicycle gears, whereas the other designs would require the tedious construction of gear teeth.

5 Specification of Solution

5.1 Introduction

The details of Section 5 include a thorough description of the final solution chosen in the previous section. The major components of the design will be displayed with specific details and functions.

5.2 Solution Description

The Inspirograph is a larger upcycled tabletop version of a traditional spirograph design. The table stands at 28 inches high, which adheres to the Americans with Disabilities Act making it accessible for children of all backgrounds. The Inspirograph design implements a variety of upcycled materials. Upcycled materials are reinvented parts from previous use in order to prolong the life of these resources and reduce the amount of material from being thrown away. The Inspirograph uses repurposed bicycle components to create the gears of the system while implementing a salvaged table for the system and salvaged plywood as seen in Figure 5-1.

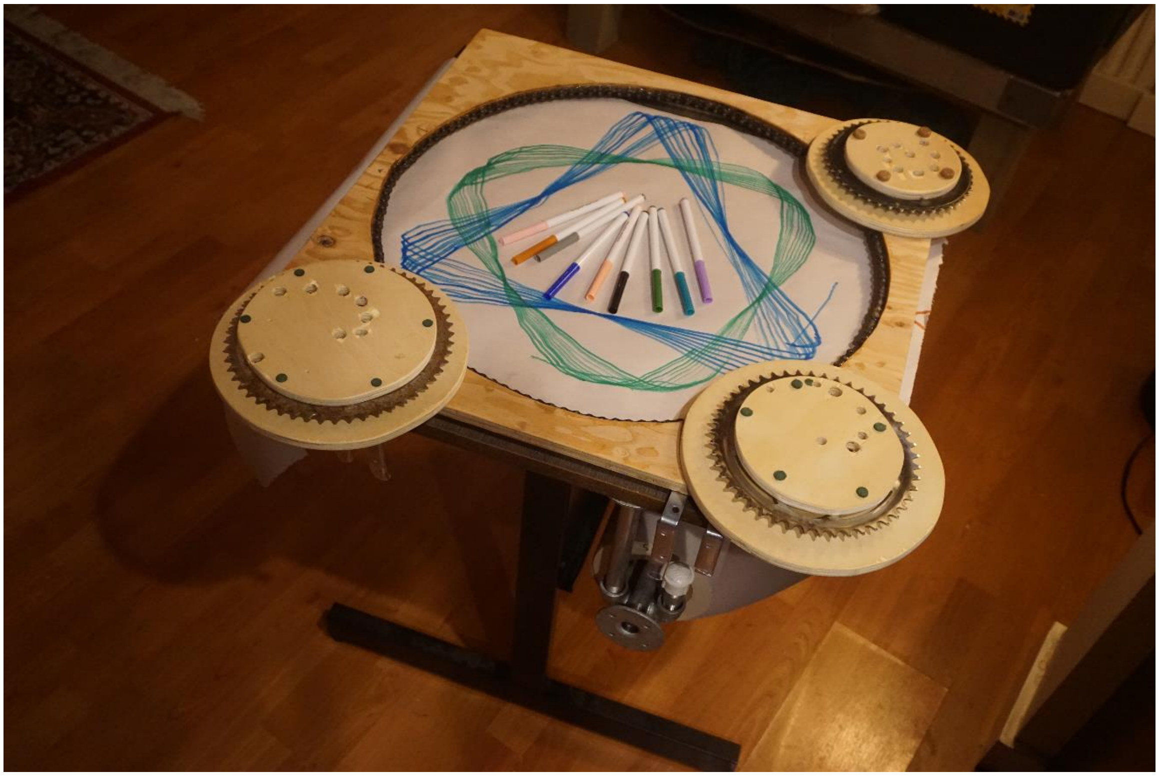


Figure 5-1: The Completed "Inspirograph" Table Top (Photo by Aren Page)

5.2.1 Cogs

The cogs of the Inspirograph are created from reused bicycle cogs as illustrated in Figure 5-2. These bike cogs are sandwiched in between two circular cuts of plywood that act as protective coverings for the sharp parts of the gears. The plywood pieces and bike cog are spaced apart with rubber grommets to allow some flexibility in the movement of the inner cog on the track. This creates the appropriate spacing giving the cog an easy rotation along the bike chain. Along the top plywood piece holes are drilled in the shape of a Fibonacci spiral; this provides a place to put a writing implement. Using a Fibonacci spiral in pen placement allows the user to create different designs depending on which hole they use to draw with.

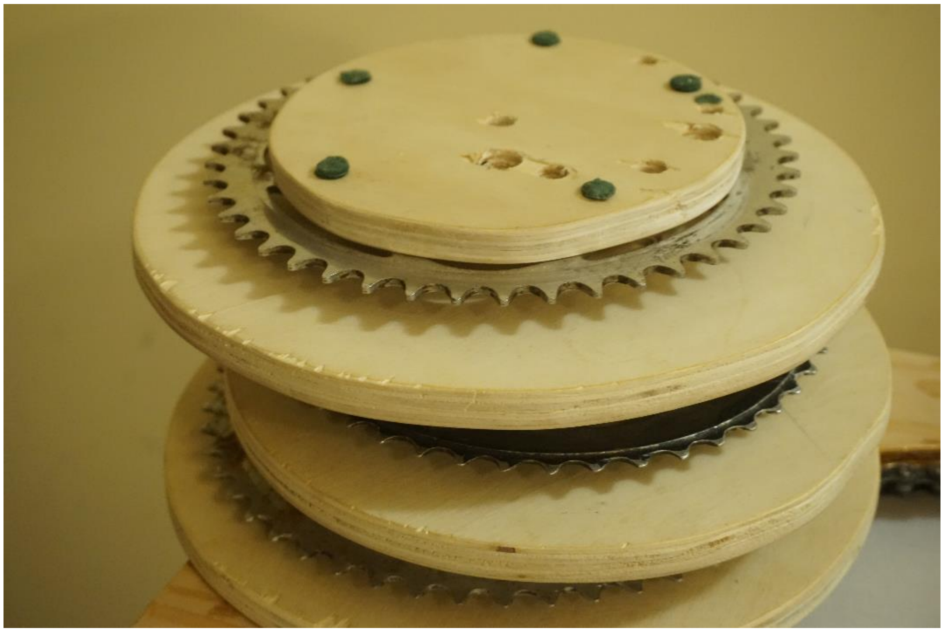


Figure 5-2: Bicycle cogs sandwiched between plywood guards (Photo by Aren Page)

5.2.2 Hinged Gear Surface

The surface of the Inspirograph is made from a sheet of plywood that has been attached to the table surface with two hinges. In the center of the plywood sheet a circular hole was cut to mount the bicycle chain and create the space for the user to draw the spirograph design. The hinges are utilized to allow the user to easily lift up the surface of the spirograph and replace the writing paper as seen in Figure 5-3. Simultaneously this provides a piece which holds the paper taught when drawing.

Figure 5-3: Hinged plywood surface with mounted bike chain (Picture by Aren Page)

5.2.3 Hook & Paper Roll Holder

A galvanized steel hook was used to create a durable and easily maintained paper roll holder. The hook holds a steel pipe which threads through a roll of paper. This allows the paper roll to be lifted out and replaced easily while reducing friction from rolling out the paper. As seen in Figure 5-3, the roll is held in place by two galvanized steel flanges screwed to either side of the metal pipe and once unscrewed, the paper roll can be easily replaced.

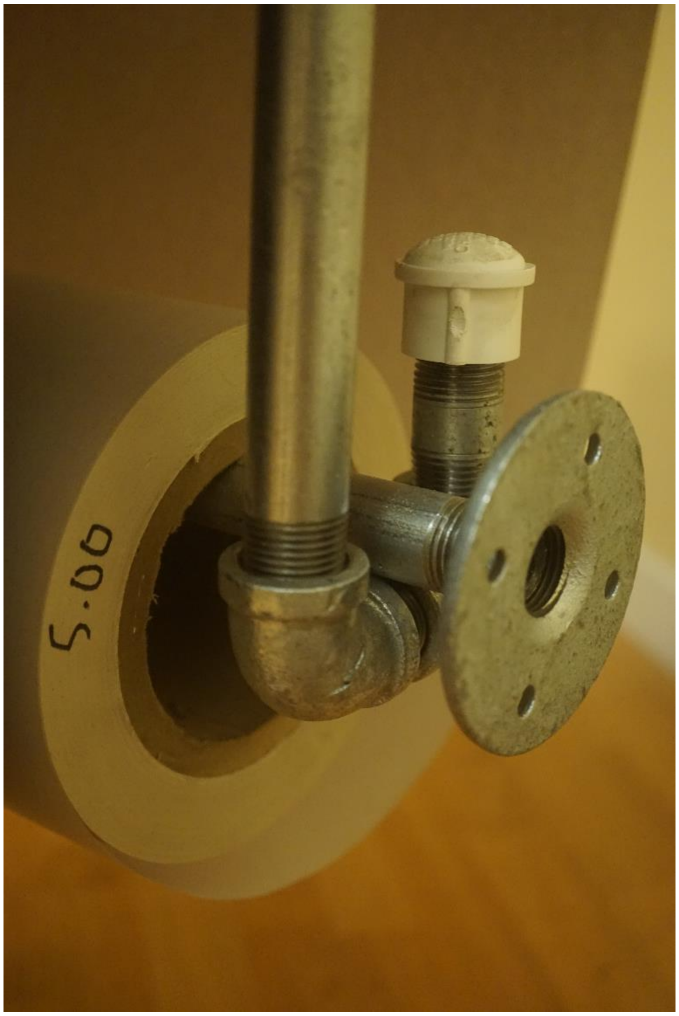


Figure 5-4: Galvanized Steel Hook System (Photo by Aren Page)

5.2.4 L-Bracket Supports

Durability was a very important component in the Inspirograph, therefore to prevent possible breakage from over extension, L- Brackets were implemented. Illustrated in Figure 5-5, L-Brackets prevent the top surface of the spirograph from going beyond ninety degrees. This will prevent the hinges from experiencing too much downward force and breaking. It will also prevent an observer from being injured while the user is replacing the spirograph paper.

Figure 5-5: L-Bracket System implemented on backside of the Inspirograph (Photo by Aren Page)

5.2.5 Marker Storage Box

The concern that the Inspirograph markers would go missing resulted in the creation of a storage box. The box was placed on the underside of the tabletop for easy access and can hold up to 40 different colors.

Figure 5-6: Marker box fastened to underside of table top (Photo by Aren Page)

5.3 Cost Analysis

5.3.1 Design Costs

The design costs indicate the total number of hours that Team BlackBox put into the design project. A total of 241 hours went into the design project. The majority of design hours went into construction and finalizing the design. Figure 5-1 represents the distribution of hours that went into the project.

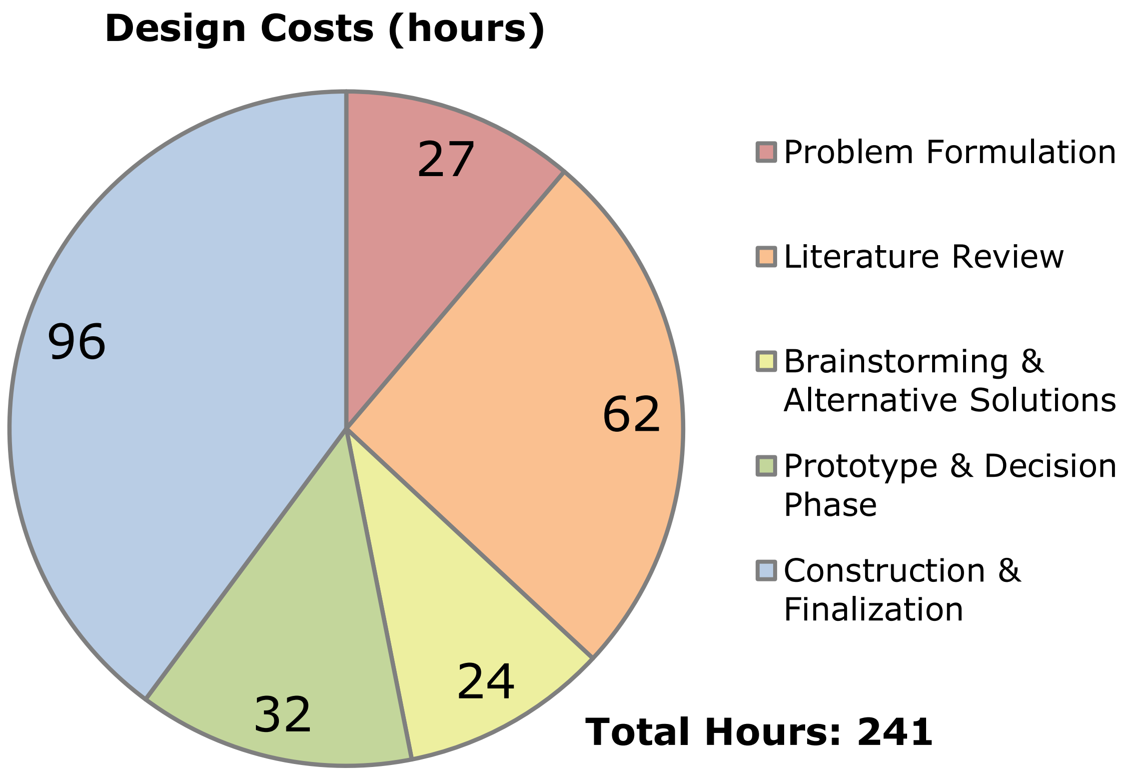


Figure 5-7: Total Team Design Hours

5.3.2 Materials Cost

Table 5-1 indicates the cost of materials that were used in the construction phase of the Inspirograph. The budget for the project was $500.00 and the total amount spent to construct the project was $238.99. A number of the project components allowed for either donated or upcycled materials to be used. These included the table, bicycle gears and bicycle chains. Other components required that new materials be purchased.

Table 5-1: Cost of Materials for Inspirograph

Date	Vendor	Supply Type	Cost
10/20/2017	AMPT Skate Shop	Bearings	$10.88
10/20/2017	Arcata Scrap & Salvage	Bike chains/sprockets and cog handle pieces	$10.85
10/26/2017	Ace Hardware	Screws, drill bit, felt pads, pens	$24.21
11/3/2017	Pierson Building Center	Plywood	$11.83
11/5/2017	Ace Hardware	Brackets, hinges, epoxy, screws	$33.39
11/6/2017	Walmart	Dowel, hooks	$4.17
11/7/2017	Ace Hardware	Steel pieces for paper roll component	$66.46
11/10/2017	Ace Hardware	Corner Braces, hinge covers, PVC caps	$8.20
11/11/2017	Ace Hardware	Epoxy, wood plugs	$18.41
11/12/2017	Ace Hardware	Sand Paper	$6.34
11/12/2017	Ace Hardware	Felt pads, rubber grommets	$24.98
11/12/2017	CVS	Felt tip markers	$7.37
11/13/2017	Ace Hardware	Hacksaw blades	$6.49
11/16/2017	Ace Hardware	Cable ties	$5.41
		TOTAL	**$238.99**

5.4 Maintenance

Maintenance

The Inspirograph was designed and constructed to be durable. The life of the system is estimated to be 20 years. It was determined that the Inspirograph will undergo approximately 10 uses per business day. Given that markers and paper will be the primary components for upkeep, the estimated operation and maintenance cost will be roughly $200.00 per year. Figure 5-2 provides a breakdown of the operation and maintenance costs.

Table 5-2: Operation and Maintenance Costs

Material	**Cost**
Marker	$28.08
Paper	$156.60
General Hardware	$10.00
Total Annual O&M	**$194.68**

5.5 Implementation Instructions

In order to use the Spirograph, a user must firstly select a colored marker from the marker box mounted to the bottom of the spirograph. The marker must then be placed in the holes on top of the inner cog. The user then rotates the marker in accordance to the outer bike chain. After several full rotations around the outer chain, a complex geometric design will begin to take shape.

5.6 Results

The results of building the design concluded that the Inspirograph will serve as a fun and inspirational exhibit for children to expand their creative learning. The system is safe, sturdy and able to withstand the ravages of time. It has been deemed simple to use and likely to expand a child's cognitive learning by offering the ability to make artistic geometric patterns with ease.

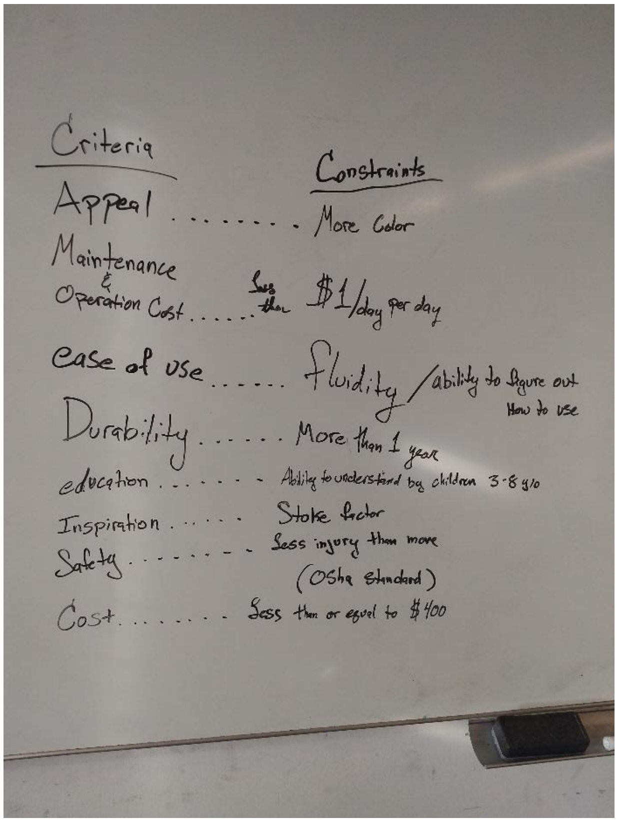
6 Appendices

6.1 References

1. Acuff, Dan. (1997). What kids buy and why: the psychology of marketing to kids, New York: Free Press.
2. Bronson, M., Goodson, B., & U.S. Consumer Product Safety Commission. (1993). Which toy for which child: A consumer's guide for selecting suitable toys for children : Ages birth through five. Washington, D.C.: U.S. Consumer Product Safety Commission.
3. Chapin, Suzanne; Johnson, Art. (2006). “Math Matters : Understanding the Math You Teach, Grades K-8”. Math Solutions Publications. Retrieved September 27th, 2017.
4. Deck, Karin.(1999, March 1st).“Spirograph Math” . Humanistic Mathematics Network Journal. Issue 19. Article 7. Retrieved September 27th, 2017.
5. Gears, K. (2015). Gear Systems | KHK Gears. Retrieved from http://khkgears.net/gear-knowledge/gear-technical-reference/gear-systems/
6. Matt Winkler, Alan S. Abrahams, Richard Gruss, Johnathan P. Ehsani (2016) “Toy safety surveillance from online reviews” Decision Support Systems, Vol. 90, 23-32.
7. Morawski, Clarissa. (2006). "Embodied Energy". Alternatives Journal, 19.
8. Nakaya, R. (2017). Gears of all shapes: Square, oval, pentagonal, organic & more | The Kid Should See This. Retrieved from http://thekidshouldseethis.com/post/72557353864
9. Oderinde, T. (2016, July 01). What is a Spirograph? Retrieved September 28, 2017, from https://prezi.com/cc6qsem-shwg/what-is-a-spirograph/
10. Plastics, T. (2017). Plastics have changed our world almost as much as semi ... Retrieved from https://www.tapplastics.com/uploads/pdf/robotarticle.pdf
11. Radzevich, S. P. (2016). Dudley's Handbook of Practical Gear Design and Manufacture, Third Edition. CRC Press.
12. Robert, F. (2017). Hypotrochoid. Retrieved from http://www.mathcurve.com/courbes2d.gb/hypotrochoid/hypotrochoid.shtml
13. Rymanowicz, Kylie. (2015). “The art of creating: Why art is important for early childhood development.” <http://msue.anr.msu.edu/news/the_art_of_creating_why_art_is_important_for_early_childhood_development> (Sept. 27, 2017).
14. United States Access Board. (2002). "ADA Accessability Guidelines (ADAAG)". https://www.access-board.gov/guidelines-and-standards/buildings-and-sites/about-the-ada-standards/background/adaag#4.2 (Accessed Sep, 27,2017).
15. Volunteer Amy Shell-Gellasch, March 14, 2014. (2017, March 17). The Spirograph and kinematic models: Making math touchable (and pretty). Retrieved

September 28, 2017, http://americanhistory.si.edu/blog/2014/03/the-spirograph-and-kinematic-models-making-math-touchable-and-pretty.html
16. Weisstein, E. (n.d.). Trochoid. Retrieved September 28, 2017, from http://mathworld.wolfram.com/Trochoid.html
17. Weisstein, E. (n.d.). Trochoid. Retrieved September 28, 2017, from http://mathworld.wolfram.com/Cycloid.html
18. Wiesstien, E. (n.d.). Epitrochoid. Retrieved September 28, 2017, from http://mathworld.wolfram.com/Epitrochoid.html
19. Wiesstien, E. (n.d.). Hypotrochoid. Retrieved September 28, 2017, from http://mathworld.wolfram.com/Hypotrochoid.html

6.2 Brainstorming Notes



Criteria	Constraints
Appeal	More Color
Maintenance & Operation Cost	less than $1/day per day
ease of use	fluidity / ability to figure out How to use
Durability	More than 1 year
education	Ability to understand by children 3-8 y/o
Inspiration	Stoke factor
Safety	less injury than move (OSha Standard)
Cost	less than or equal to $400