Fall 2018

Educational Color Mixer

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Executive Summary

This document is a record of how the engineering design process was used to create an educational color mixing device. The customer was the St. Louis Science Center and the intended user was children ranging from ages five to fifteen. The design problem proposed was as follows: create an educational color mixing device that (1) lasted less than a total time of 60 seconds and (2) visually displayed the ratio of primary colors need to make a desired color. The functionality of the proposed final design was evaluated with three engineering models. A power consumption model was used to account for all electrical components in the device, a pump flow model was used to ensure the flow of viscous paint, and a tipping force model was used to lower the risks of user injury due to the model falling over. A preliminary budget of $250 was given for the design, and the working prototype satisfied the cost limitations. The result was a self-contained paint mixing system called Splash. Splash works in the following way: users select a color from the built-in color wheel, and the selected color is deposited into a receptacle that the user can remove from the device and use to their desires.

MEMS 411: MECHANICAL ENGINEERING DESIGN PROJECT
FALL 2018

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

After defining specific customer needs, design metrics were created to ensure measurability. Each metric was assigned a unique ID number, a unit of measurement, an acceptable goal, and an ideal goal. It is important to note that multiple needs can be measured with one metric and that a singular need can be measured by two metrics. Metric 1 is an example of the first situation and metrics 8 and 9 show an example of the second situation. Table 3 shows the metrics created for each need.

Table 3: Target Specification........ 12

1 INTRODUCTION

The intent of this project is to create an interactive exhibit for the St. Louis Science Center that demonstrates the mixing of primary colors into a user-specified color in a visually stimulating way. The goal is to create the color dispensing device so the inner workings are visible to the users. The device must have an interface that allows users to designate a final color, prompting the device to dispense appropriate amounts of the three primary colors that can be mixed and result in the specified color. While the primary function is educational, it is also imperative that the device be safe for children to use. The intended target audience for the device ranges from young children to high school age teenagers, so aspects of the device and its operation must appeal to various interests. This project began with investigation into similar existing products including a search for relevant patents. An interview was carried out with the customer to determine the specific needs of the user. Preliminary designs were created before a mock-up prototype was developed. This launched the development of a working prototype with set goals of operation that were desired by the user. Aspects of this design cycle included computer aided design, assessment of engineering models, testing and analysis of components before a final working prototype was developed and presented.

2 PROBLEM UNDERSTANDING

2.1 BACKGROUND INFORMATION STUDY

2.1.1 Existing designs

Crayola Spin Art [1]

Parts included in this design:

- Hand pump
- Primary color paints
- White Crayola crayons
- Circular pattern papers
- Housing where mixing takes place

Figure 1 Crayola Spin Art Product

This product uses the primary colors to create artwork. The paints mix while the device is in motion, creating secondary colors. The product is operated via a hand pump that is pressed down a few times. This causes the inside component to spin at a high speed. The housing is raised a few inches above the spinning component to contain the paint. Some of the down sides of this product according to customer reviews are that the pump is too hard for young kids to press, and the paint still creates a relatively large mess. The white, circular insert paper is hard to find and handmaking them is hard and time consuming.

Learning Resources Primary Color Mixer [2]

Parts included in this design

- Divided flask
- Swirled nozzle

Figure 2 Learning Resources Primary Color Mixer

This product uses water and food coloring dye to mix two colors together. The user provides the water and dye and chooses which colors to pour in each side of the flask. The colors are mixed when the device is turned upside down, combining the two colors in the swirled nozzle and pouring the final color into a receptacle. The clear, divided flask shows which two colors are being combined, and the user has full control over which two colors to combine to, allowing the user to make many different color combinations. Some reviewers on Amazon claim that this product can be difficult to clean, especially the connector between the flask and the nozzle. The product is visually stimulating, but the result is dyed water that doesn't have any future uses besides the option of using it again in this color mixer.

Learning Resources Color Mixing Lenses [3]

Parts included in this design:

- Red, blue, and yellow lenses
- Lens frame holder with 3 slots.

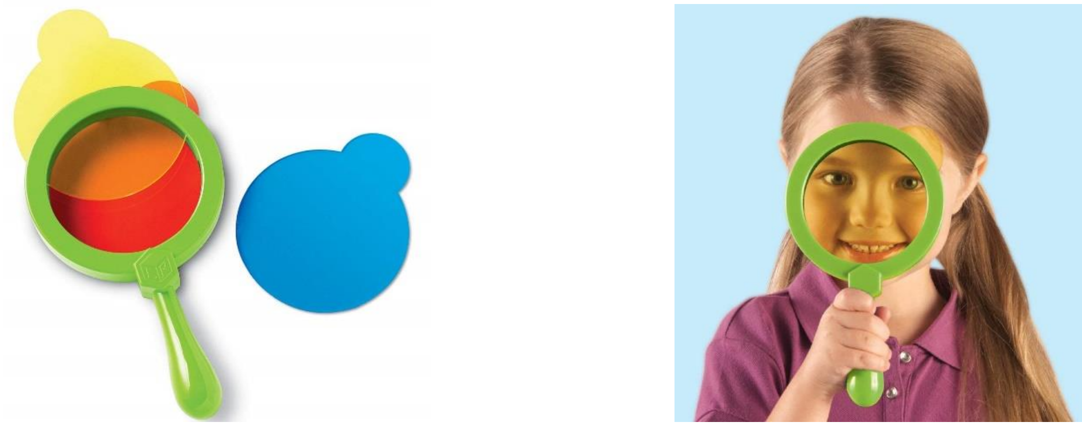


Figure 3 Learning Resources Color Mixing Lenses

This product combines primary-colored lenses together to look through, allowing the user to see in primary, secondary, and tertiary colors. The frame has three slots that can hold each lens, allowing the user to choose whether to combine one, two, or three lenses. Each lens has a large tab for small hands and those developing fine motor skills to easily grasp and change them out of the frame. The lenses rest inside the slots but do not lock, so young users can change the lenses, but the lenses may fall out when the frame is tipped. The lenses are designed to be thick enough that they will not bend if handled roughly. Some customer reviews on Amazon state that the colors mix well but that the lenses can easily fall out or get misplaced since they are not attached to the frame.

2.1.2 Related Patents

Patent No.: US4967938A [4]

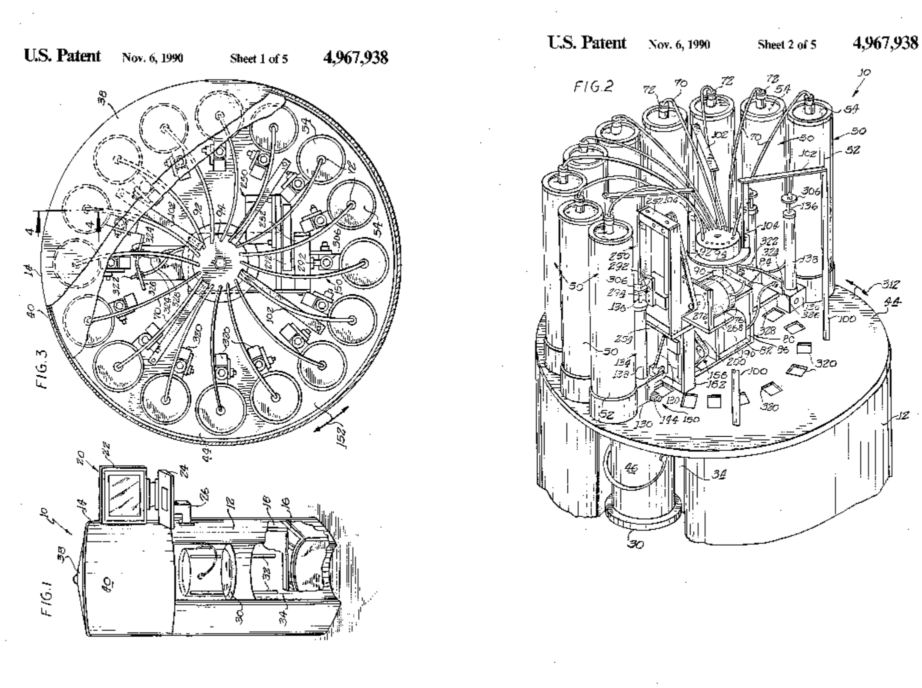


Figure 4 Patent No.: US4967938A

Patent No.: US4967938A applies to a "Paint Dispensing Apparatus" that dispenses paint colorants into a paint base before a mixing process generates the desired color. To achieve this a plurality of colorant containers are attached to hoses to a dispenser and a metering station that ensures exact dispensing of colorant.

Patent No.: US3140666A [5]

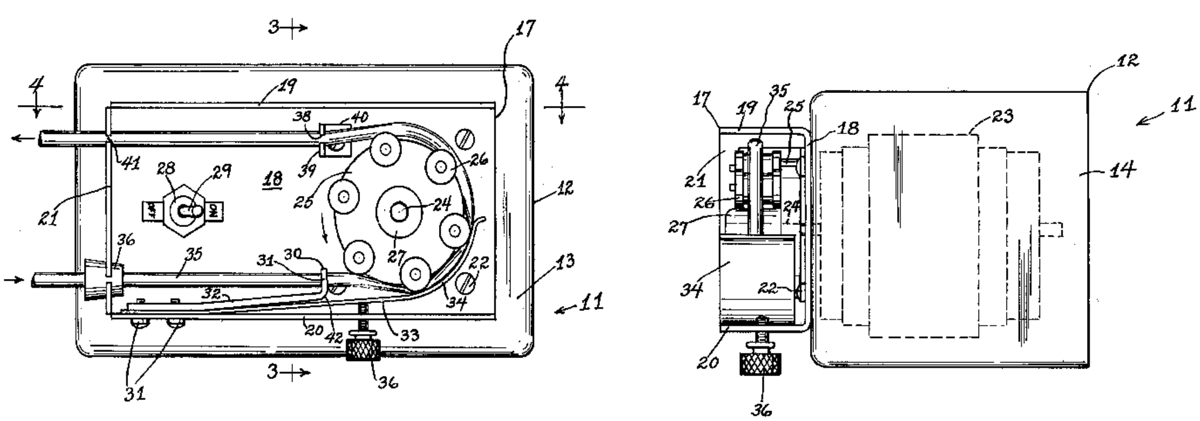


Figure 5 Patent No.: US3140666A

Patent No. US3140666A is a peristaltic pump that pushes fluid through the tube using several cam elements that are evenly spaced around the perimeter of a rotating piece. The cam elements compress the tubing as the rotating piece moves them across the tubing, causing a pressure differential that moves the fluid through the tube.

2.1.3 Relevant Codes and Standards

16 CFR 1505 Requirements for electrically operated toys or other electrically operated articles intended for use by children [6]**.**
This standard describes the requirements an electrically operated toy must meet if it is intended for use by children. It covers the labeling, manufacturing requirements, electrical design and construction, performance, maximum acceptable surface temperatures, and maximum acceptable material temperatures of the device. Since the color mixer will have electrical components and is intended for use by children, our design will have to meet these specifications.

ASTM D4236-94 Standard Practice for Labeling Art Materials for Chronic Health Hazards [7]**.**
This Standard is put forth by ASTM International to ensure the safety of materials in art products. It assesses the levels of components known to scientific and medical literature to cause chronic adverse health effects in volume, physical form, or concentration. This standard applies exclusively to products packaged in small volumes for use by any age. This would ensure paint selected for use in this project is safe for child use, and the standard qualifies materials for the Art and Creative Materials Institute's Approved Product Seal. Note: we are awaiting purchase of this standard's physical copy or pdf to view the full content.

2.2 USER NEEDS

For customer satisfaction, a table of user needs was constructed. The contents of the table were determined via an in-person interview with a representative from the St. Louis Science Center, Chiamaka Asinugo. The desired needs of the customer and an interpreted need for the device can be found in table 1.

Table 1: Customer Needs Interview Table

Product: Color Mixer
Customer: Chiamaka Asinugo

Address: Jolley Hall 110
Date: September 7, 2018

Question	Customer Statement	Interpreted Need	Imp.
Age group?	Safe and interactive enough for 5-15-year-olds. Anyone should be able to use it	The CM is fun for both children and teenagers.	3
What colors should be included?	As many as possible, but at least 10. Can specify input colors or output color.	The CM can mix a large range of colors.	5
What setting will it be used in?	A display in the science center. A new one, not added into an existing one.	The CM is engaging.	4
Who will be operating?	The kids. Should be very user-friendly.	The CM is safe for children.	5
How many runs should you get before cleaning/ restocking?	Ideally 30 times before cleaning. Paint should last the entire day.	The CM reservoir lasts for many use cycles.	4
What do you see yourself using it for?	Interactive activity for science center. Fun for kids and adults, interactive. Get WashU affiliation out.	The CM specifies that it is a WashU project.	2
What is done with the color after its mixed?	Ideally, they can take it with them. Doesn't have to be a large amount of paint.	The CM dispenses the paint into a disposable receptacle.	3
Who does the cleaning?	There's a person in charge of maintenance but should be easy to clean.	The CM is easy to clean.	4
Who does the mixing?	The user or the machine is fine, as long as the color is accurate.	The CM dispenses the correct mix of colors.	5
Should it be portable?	Can be, but…. Not necessary	The CM is portable.	1
How big should it be?	Not larger than a door but fitting on a table would be good.	The CM sets on a table.	2
How long should the activity last?	About a minute, but the more they can see the better.	The CM works quickly.	3

Aesthetic?	The kids don't care if it's pretty. Make it bright, but safety is more important	The CM is brightly colored.	1
Longevity of device?	About 10 years. Easily cleaned and durable.	The CM is durable.	4

The interpreted customer needs were extracted from table 1 and assigned an ID number and an importance rating. Table 2 displays this information.

Table 2: Interpreted Customer Needs

Need Number	*Need*	*Importance*
1	The CM is fun for both children and teenagers.	3
2	The CM can mix a large range of colors.	5
3	The CM is engaging.	4
4	The CM is safe for children.	5
5	The CM reservoir lasts for many use cycles.	4
6	The CM specifies that it is a WashU project.	2
7	The CM dispenses the paint into a disposable receptacle.	3
8	The CM is easy to clean.	4
9	The CM dispenses the correct mix of colors.	5
10	The CM is portable.	1
11	The CM sets on a table.	2
12	The CM works quickly.	3
13	The CM is brightly colored.	1
14	The CM is durable.	4

2.3 DESIGN METRICS

After defining specific customer needs, design metrics were created to ensure measurability. Each metric was assigned a unique ID number, a unit of measurement, an acceptable goal, and an ideal goal. It is important to note that multiple needs can be measured with one metric and that a singular need can be measured by two metrics. Metric 1 is an example of the first situation and metrics 8 and 9 show an example of the second situation. Table 3 shows the metrics created for each need. Table 3: Target Specification

Table 4: Target Specification

Metric Number	*Associated Needs*	*Metric*	*Units*	*Acceptable*	*Ideal*
1	1, 2, 3	Possible output colors	Integer	> 10	> 30
2	4	Meets child safety codes	Binary	Yes	Yes
3	5	Number of runs before running out of paint	Integer	75	150
4	6	Has identifying WashU logo	Binary	Yes	Yes
5	7	The receptacle is disposable	Binary	Yes	Yes
6	8	Time to clean	min	< 10	< 5
7	9	Percent of times color can be identified as color chosen	Percent	90	100
8	10, 11	Total weight	kg	< 8	< 5
9	11	Device footprint	m^2	< 0.25	< 0.15
10	12	Time to dispense (and mix, if applicable)	s	20-45	30

11	14	Lifetime of device	Years	> 7	> 10

2.4 PROJECT MANAGEMENT

In order to complete this project on time a Gantt chart was created with the project milestones and deadlines. The Gantt chart can be seen in table 4 below

Table 5: Project Management Gantt Chart

WEEK	9/24	10/1	10/8	10/15	10/22	10/29	11/5	11/12	11/19	11/26	12/3
Report											7
Concept Selection	24										
Concept Embodiment			12								
Prototype								12			
Proof of Concept				15							
Design Refinement						29					
POC Presentation						2					
Manufacturing								12			
Presentation											3
ERB Summary								16			

3 CONCEPT GENERATION

3.1 MOCKUP PROTOTYPE

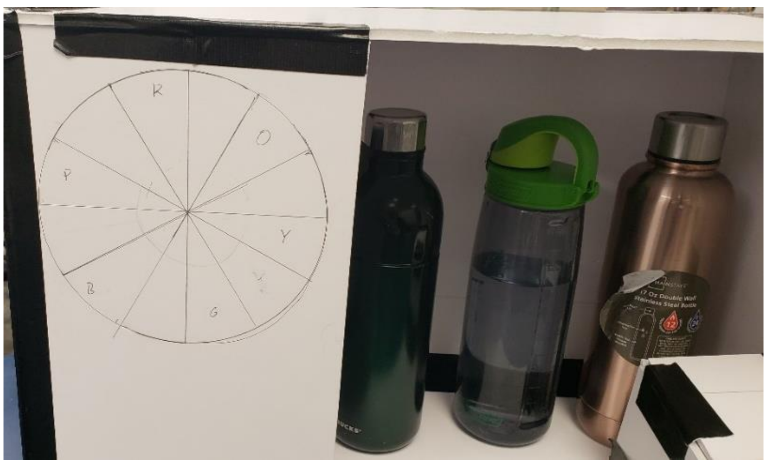
After building the mockup, it became evident that a few parameters needed further consideration:

(1) The material used to construct the body
(2) The necessity of separate compartments to house various internal objects
(3) A door to inhibit access to paint while the machine is running
(4) The arrangements of parts.

One material consideration for the body of the box was wood because it would provide an easier assembly. However, a transparent material like plexiglass or acrylic sheet was also considered because it adds visual interest to the design and aids in the learning process. Additionally, it was determined that separate compartments are necessary to house electrical components. This would prevent these components from being damaged or becoming hazardous if a paint leak occurred. A partition panel could be used perpendicularly to the front panel to separate the electrical components from the paint and a smaller receptacle compartment. Figure 7 shows the area behind the front panel that would house the electrical components. The color wheel would be comprised of electrical buttons and sit on the front panel. Figure 9 shows a close-up view of the positioning of the color wheel. Further, a compartment for the receptacle to be removed would be needed to keep the user from contacting potentially dangerous components. The proposed location of this compartment can be seen in the lower right corner of figure 6. Similarly, a door with a sensor would be used to automatically stop the device if opened during operation. The sensor would also hinder the device from starting until the door was properly closed. Figure 8 shows a side view of one possible door orientation. Finally, the dimensions of the body were also influenced by the mockup process. The volume enclosed by the body should not be so large or small that the exhibit appears empty or cramped.

Figure 6: (Left) Front view of in lab mockup

Figure 7: (Right) Three quarters side view into body. Additional housing compartment for electrical components and wiring would be located in empty space behind the front panel



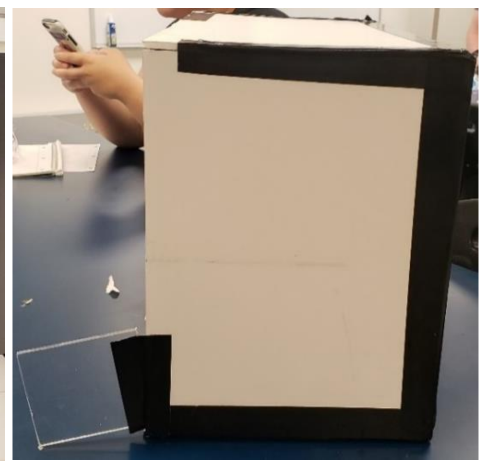


Figure 8: (Left) Front view, close-up of anticipated color selection button

Figure 9: (Right) Right side view of body with hinged glass door opened

3.2 FUNCTIONAL DECOMPOSITION

After completing a mockup prototype and re-examining the customer needs, shown in table 2, a function tree was generated. The function tree serves to define the basic functions of the device and subsequent sub functions. Each function on the tree must be met in order to have a fully function device. For the Splash design, six base functions were defined: supply power to the parts, process the electrical signals, have surface to surface interfacing, have human interfacing, dispense colors, and be visually appealing. There were two sub functions defined for the basic function of interactively dispensing color. Figure 10 shows the function tree generated for the Splash design.

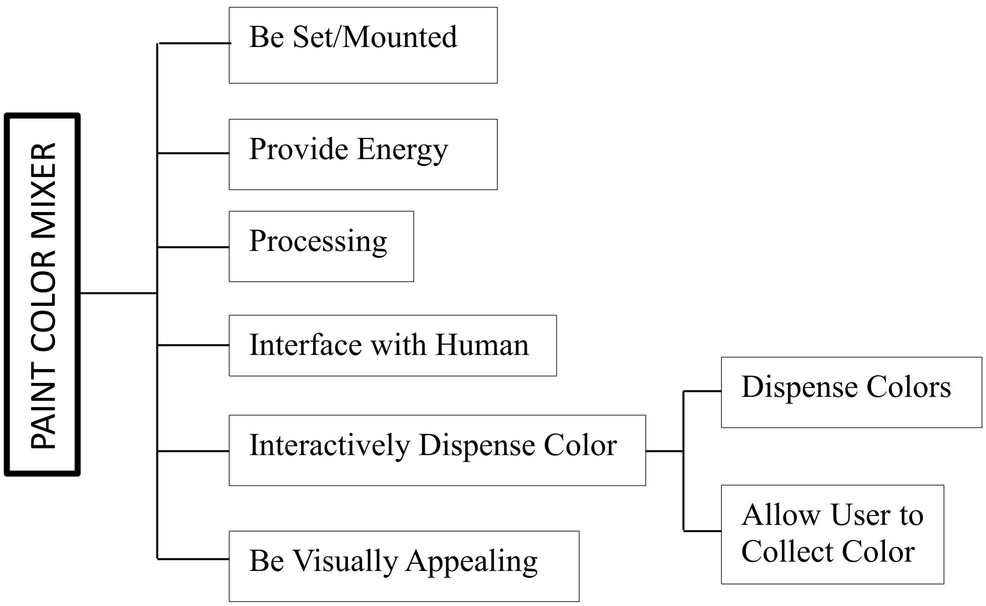


Figure 10: Function Tree

A morphological chart was created to find a minimum of three solutions for each basic function and subfunction defined in the function tree. The potential solutions for each function can be seen in figure 11.

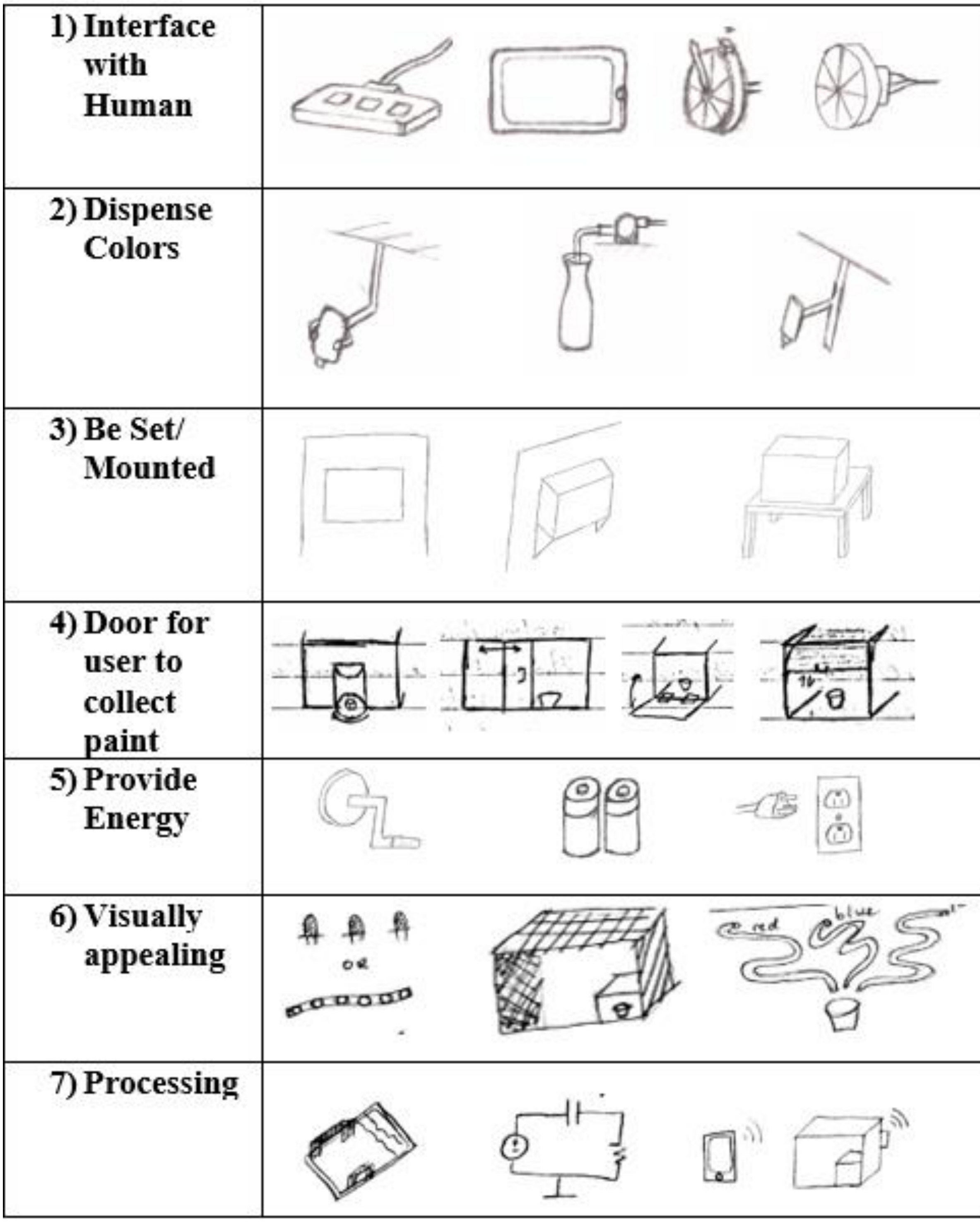


Figure 11: Morphological Chart for Paint Color Mixer

3.3 ALTERNATIVE DESIGN CONCEPTS

From the morphological chart one solution for each function was selected and combined to make an alternative design. Three alternative designs are depicted in this section, each designed by a different engineer on the team. The specific solutions from the morphological chart selected are numerical listed and followed by a brief description of the alternative design functionality. Finally, preliminary and final design sketches are provided.

3.3.1 Built- in, cylindrical paint color mixer by Briana Wynn

Solutions:

1. Unit is built into the wall
2. Microprocessor
3. Plug into wall
4. LEDs
5. Random color selector
6. Sliding door
7. Motorized arm to squeeze paint bottle

Description: Three motorized arms clamp together to squeeze a paint bottle. This dispenses paint into a tube that travels down to a receptacle. The paint tubes are wound around a cylindrical pole mounted from the ceiling. The paint receptacle is a small cup enclosed in the center of the hourglass shaped body. The body of the design is made from three pieces. The center piece is made entirely of a clear material. A sliding door is used to retrieve the receptacle. A color wheel with a proximity sensor will be built into the lower level of the body. The final position of the spinner can be determined relative to the sensor. This will allow us to figure out which color to dispense. Strip LEDs are used to decorate the body of the device. Storage for additional paint supplies can be found in the lowest compartment of the body. A microprocessor will be used to convert the input signal to a useable voltage for the motors. Figures 12 and 13 show preliminary and final sketches of this design.

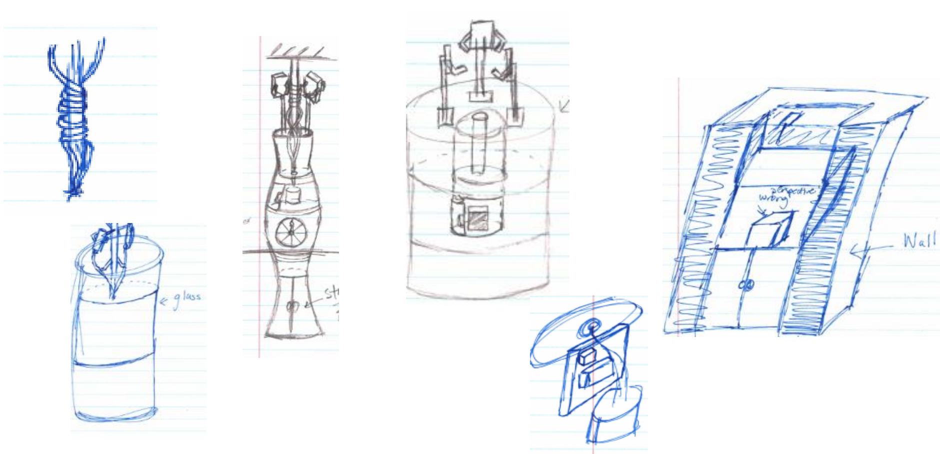


Figure 12: Preliminary sketches of Built-in Cylindrical Color Mixer

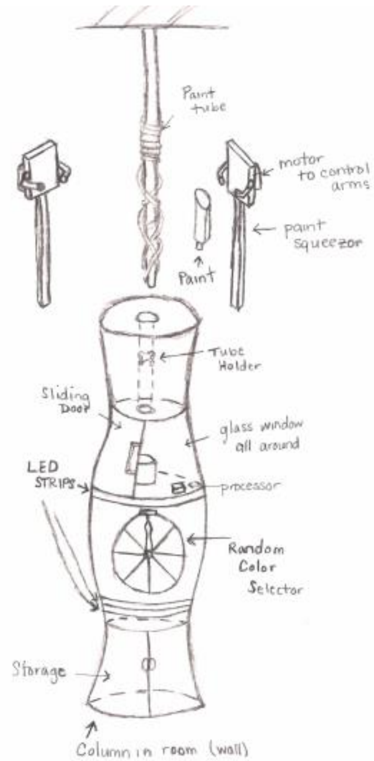


Figure 13: Final sketch of Built-in Cylindrical Color Mixer

3.3.2 Battery Powered, Pump-Driven Color Mixer by Michele Anderson

Solutions:

1. Unit is battery powered
2. Entire system rests on table and is portable
3. User receives paint through garage door styled opening
4. The unit is input-driven from the three primary color buttons
5. The unit uses a microprocessor for the signals
6. Peristaltic pumps move the paint from container to receptacle
7. Clear tubes are visually stimulating

Description: Three peristaltic pumps are used in this design to pump the paint from their respective containers through clear tubing that is visually stimulating to the receptacle that the user can take with them. The user specifies the color by pressing the red, blue, and yellow buttons, each for the desired amount of time (which has an upper limit) to dispense the color into the cup. This input-driven design allows for more possible color combinations. A microprocessor converts the input from the buttons to action by the pumps. The user collects the paint by opening the garage door style container, effectively blocking the paint from being distributed while the door is open. An additional sensor would be placed to ensure that the door is closed before the pumps would operate. Figures 14 and 15 show preliminary sketches for this alternative design.

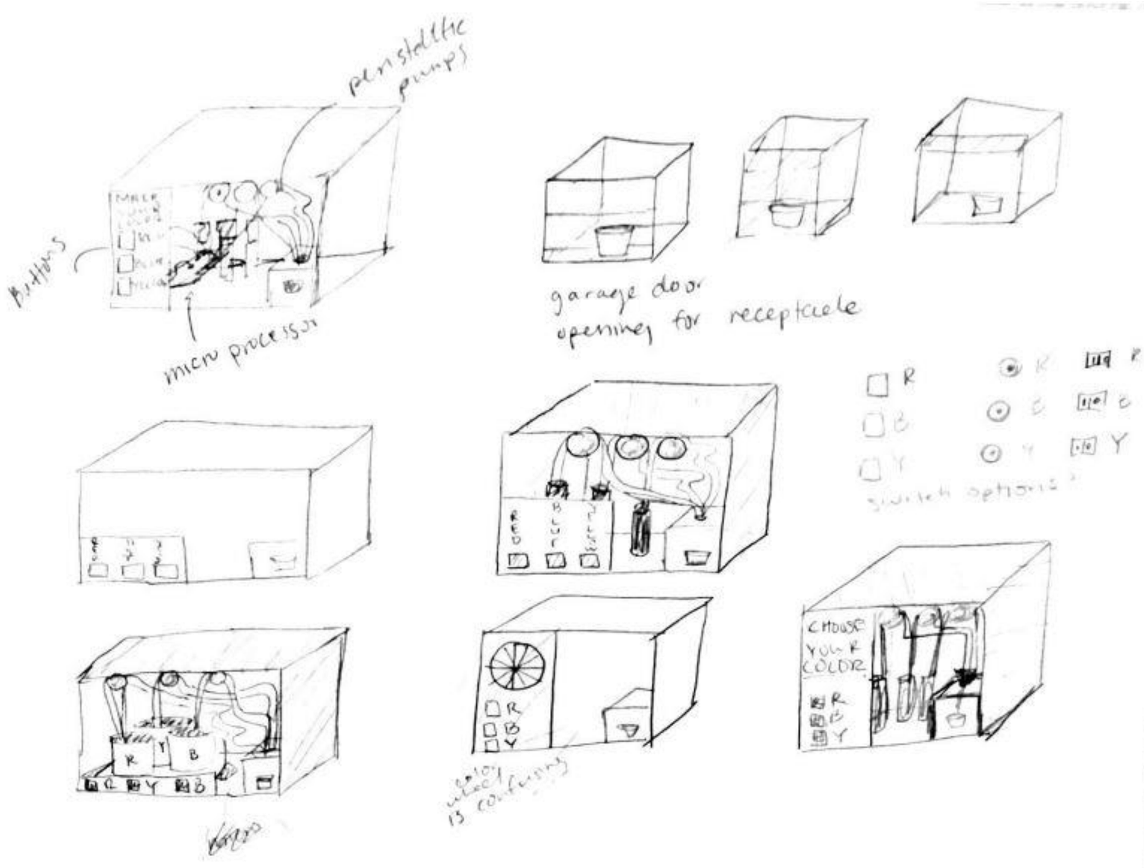


Figure 14: Preliminary sketches of Battery-Powered, Pump-Driven Color Mixer

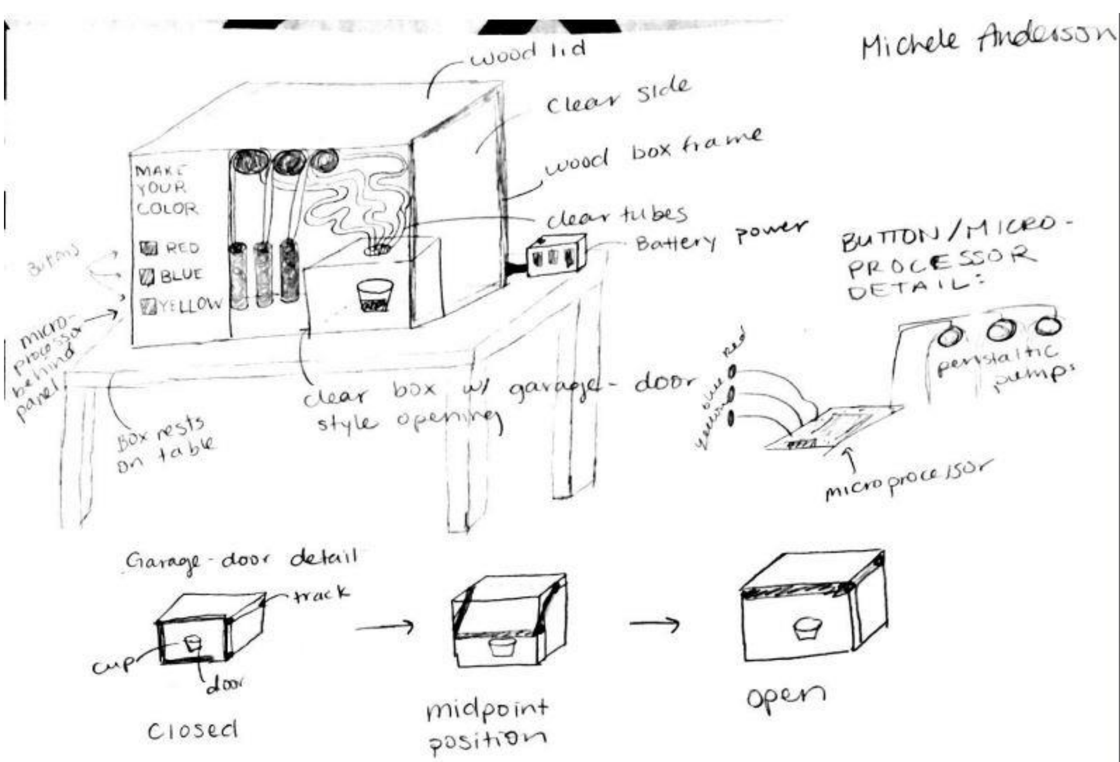


Figure 15: Final sketch of Battery Powered, Pump-Driven Color Mixer

3.3.3 “Color Mixer Alpha” Design By: Kellogg Atkinson

Solutions:

1. Mounted on table
2. Visible pumps and inner workings
3. User interface on top of unit
4. External removable nozzle for easy cleaning
5. Uses microprocessor
6. Open access to collection cup

Description: This design features three distinct sides to the color mixer. One has the glass panel that allows the tubing and paint to be seen. The front has the three peristaltic pumps line across the top, so the motion can be seen while pumping. A removable nozzle sits below allowing easy cleaning and would dispense into a cup awaiting below. The interface is on the top and features a twelve-segment color wheel with buttons for each option giving maximum choice to the user. Figures 16 and 17 show the intended implementation of this alternative design.

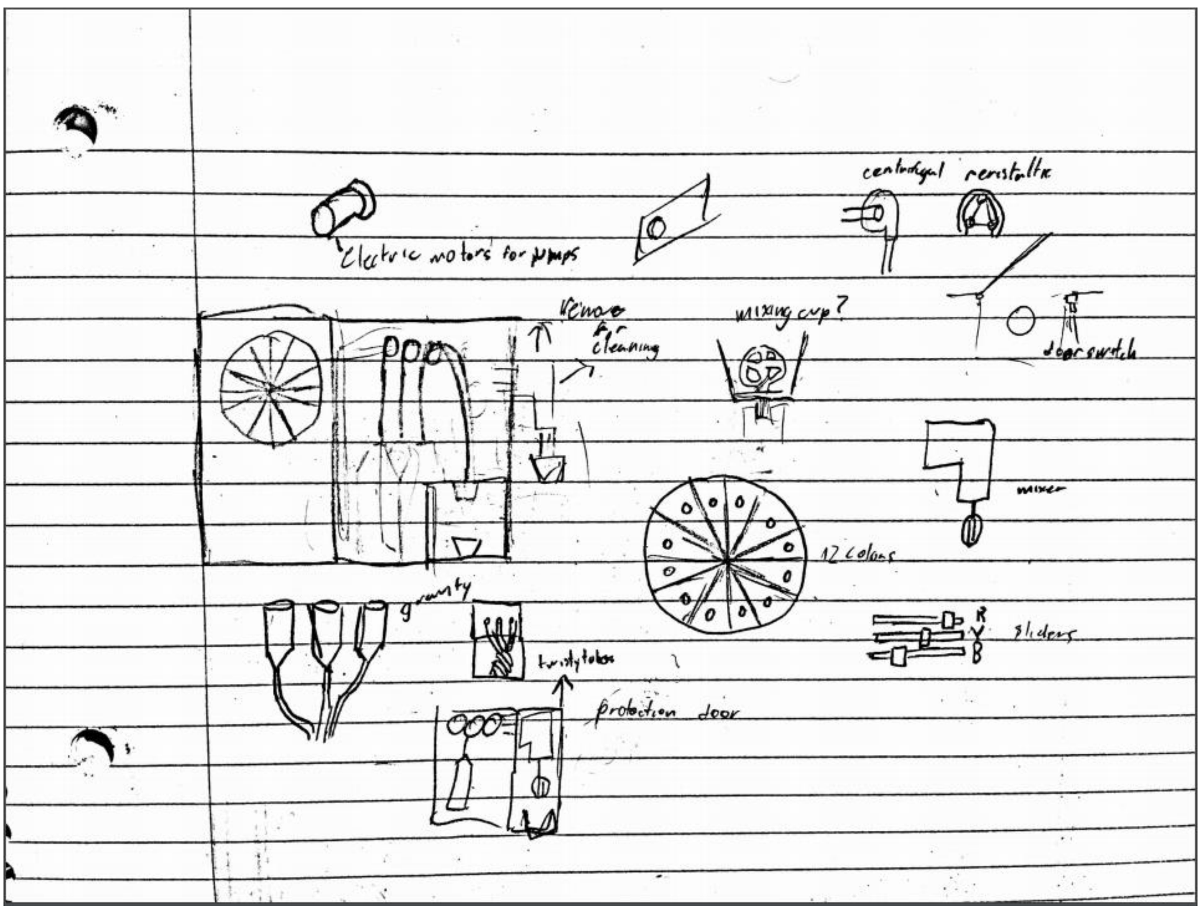


Figure 16: Preliminary sketches of Color Mixer Alpha

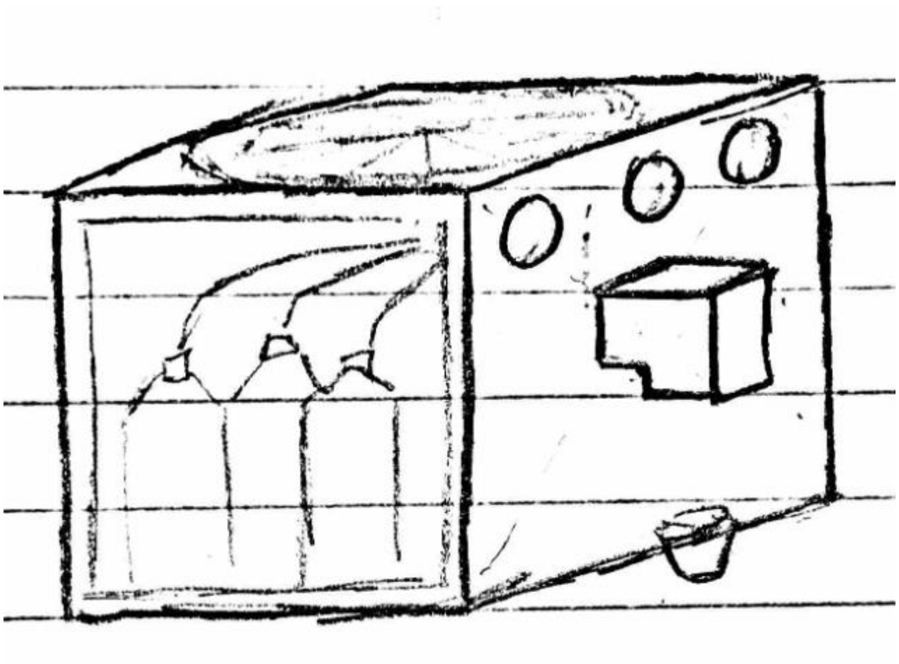


Figure 17: Final Sketch of Color Mixer Alpha

3.3.4 "IPad-Powered Food Dye Dispenser" Design By: Emily Stava

Solutions:

1. Unit is powered with a wall outlet
2. System is mounted on a wall
3. User receives paint through a hinged door
4. The unit is input-driven using an app on the IPad
5. The unit uses the IPad to interpret the user input
6. Gravity moves the food dye from the bottles to the receptacle
7. Clear tubes are visually stimulating

Description: In this design, the food dye bottles are mounted upside down at the top of the device and rely on gravity to move the dye to the receptacle. Using a less viscous liquid like dye, as opposed to pain, makes this possible. The user specifies the color by means of the app that runs on the IPad. This allows for an intuitive and more visually interesting interface. The user collects the paint by opening the hinged door, which would include a sensor to prevent the machine from running again before the door is closed. An additional sensor would be placed to ensure there is a cup under the nozzles before it is run. Figures 18 and 19 show this alternative design concept.

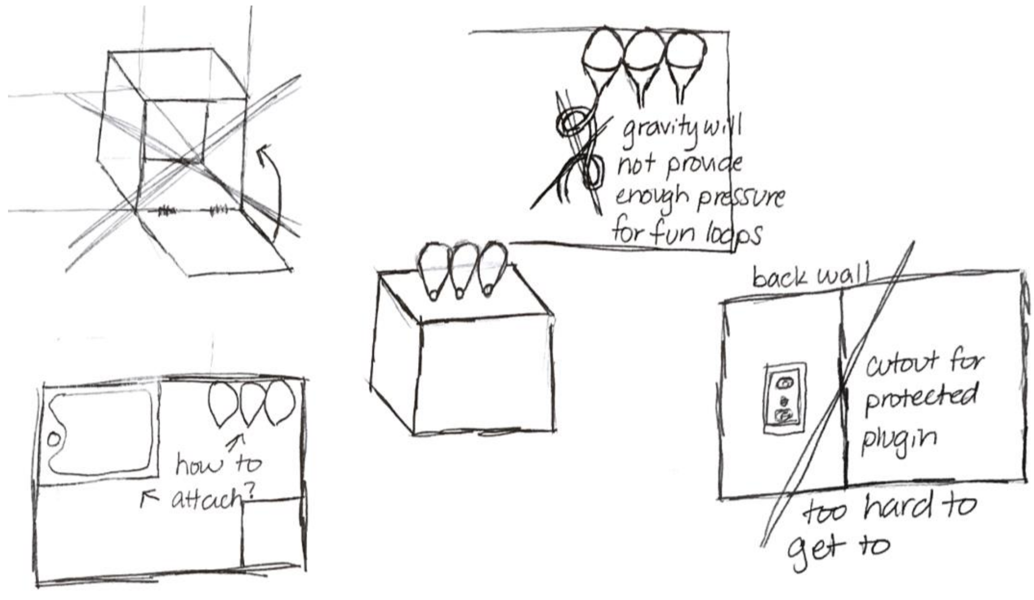


Figure 18 Preliminary sketches of IPad-Powered Dye Dispenser

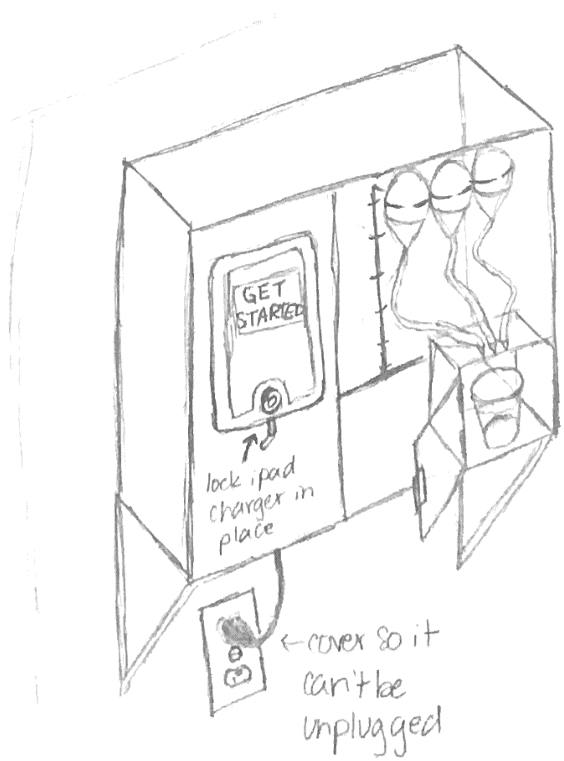


Figure 19 Final sketch of IPad-Powered Dye Dispenser

4 CONCEPT SELECTION

4.1 SELECTION CRITERIA

To determine the concept that will move forward in the design process, we developed 6 criteria based on our interview for the customer needs, and what we expect will be the most important aspects of functionality during the lifetime of the design's use:

1) Is safe
2) Is durable
3) Is easy to make
4) Is easy to use
5) Is easy to clean
6) Works quickly

The importance of each criteria was weighted against all other criteria. The result is an accurate importance weight used to later determine the best alternative design concept. Table 5 shows the criteria importance rating matrix used to calculate the final importance weights.

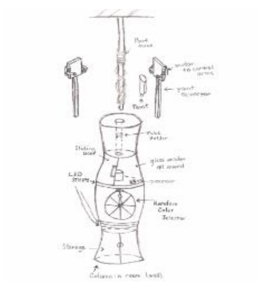
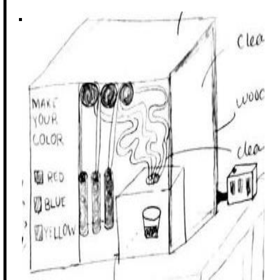
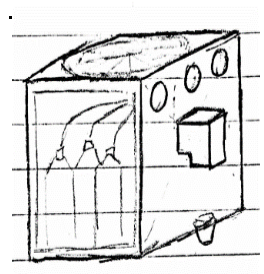
Table 6: Selection criteria

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Row Total	Weight Value	Weight (%)
Criterion 1	**1.00**	5.00	5.00	4.00	7.00	9.00	31.00	0.42	42.42%
Criterion 2	0.20	**1.00**	2.00	1.00	0.50	5.00	9.70	0.13	13.27%
Criterion 3	0.20	0.50	**1.00**	0.33	2.00	4.00	8.03	0.11	10.99%
Criterion 4	0.25	1.00	3.00	**1.00**	2.00	7.00	14.25	0.19	19.50%
Criterion 5	0.14	2.00	0.50	0.50	**1.00**	4.00	8.14	0.11	11.14%
Criterion 6	0.11	0.20	0.25	0.14	0.25	**1.00**	1.95	0.03	2.67%
						Column Total:	**73.08**	**1.00**	**100%**

4.2 CONCEPT EVALUATION

Each alternative design concept received an effectiveness rating from 1 to 5 for each of the six criteria. If the device effectively completed a criterion it received a rating of 5 and if the device ineffectively completed a criterion it received a rating of 1. The effectiveness ratings were multiplied by the corresponding importance weights to calculate a weighted rate. The sum of the weighted rates was calculated for each of the four designs and the highest rating design was deemed the best. Table 6 below shows the alternative design concepts, the effectiveness ratings, the weighted rankings, and the final ranks. It is clear from this table that the, "Battery Powered, Pump Driven Color Mixer" received the highest ranking and was used for the next phases of the design process.

Table 7: Alternative Design Concept Evaluation

		Alternative Design Concepts							
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
1: Is safe	42.42	5	2.12	4	1.70	2	0.85	3	1.27
2: Is durable	13.27	3	0.40	3	0.40	4	0.53	2	0.27
3: Is easy to make	10.99	1	0.11	4	0.44	5	0.55	2	0.22
4: Is easy to use	19.50	4	0.78	3	0.58	4	0.78	3	0.58
5: Is easy to clean	11.14	1	0.11	3	0.33	5	0.56	3	0.33
6: Works quickly	2.67	2	0.05	5	0.13	5	0.13	3	0.08
	Total score	**3.574**		**3.588**		**3.400**		**2.757**	
	Rank	**2**		**1**		**3**		**4**	

4.3 EVALUATION RESULTS

The winning concept is the Battery-Powered, Pump-Driven Color Mixer. The largest single contribution to it winning is its safety. Since the rest of the device is completely sealed in the box, the door is the only point of access to the inside. When opened, the garage-style door completely closes off the nozzles where the paint is dispensed, removing possible hazards. Its durability is on par with the other options, as it has nothing substantially more durable or more fragile than the others. It scored high on ease of making it, since it is a simple box shape and does not require making an app or other complicated digital interface. It is relatively easy to use with its three primary color buttons, but it is not necessarily easy to get a specific color, since the user must specify the colors to be mixed, not the output color. It is moderately easy to clean if the nozzles are detachable, since the tubes dispensing the paint will not be exposed to air, and thus will not have to be cleaned often. Because it uses the pumps to dispense the paint, it also works quickly.

4.4 ENGINEERING MODELS/RELATIONSHIPS

4.4.1 Power consumption model

Since the final design uses electrical components, power consumption is an important consideration. The pumps, sensors, motors, and microprocessor will all need an energy supply. The power consumption model would be useful in determining the size of the battery required to operate the device. Depending on battery availability, an optimal combination of power consuming components can be selected to ensure the device functions and to reduce the total cost of the project.

The total power required should be equal to the power consumed by the components, however, since there will be power losses, the total power of the battery should be greater than the power consumed.

$$P_{battery} = P_{gen} - P_{consumed} - P_{loss}$$

$$P_{consumed} = P_m + P_b + P_s + P_{mp},$$

where P_m, P_b, P_s, and P_{mp} are the powers consumed by the motors, buttons, sensors, and microprocessor respectively. These values can be determined directly from the specification sheets of the components and confirmed through experimentation. The power capacity of the battery is defined by the energy per time. The equation below shows this relationship.

$$P = \frac{\text{Energy}}{\Delta T}$$

Determining the power consumption is crucial for determining the maximum required current draw from the battery and selecting an appropriate battery.

4.4.2 Tipping Force Model

The final concept is designed to rest on a table and needs to be safe for children to use. As it is not currently modeled to be bolted down, it is important to know how much force can be applied to the box before the color mixer is overturned and potentially becomes dangerous. To do this, the center of mass of the different components in the color mixer needs to be found and an applied tipping force should all be shown on a free-body diagram. To find the maximum applied force before tipping, use moment balance. This can be done in the two directions that the box would tip in. If the force is determined to be too small, such that it presents a safety risk, the design should be reconfigured to either balance the loads better with respect to the moment origins, or additional weight should be added to offset the existing loads. The free-body diagrams and moment balance equations are shown in Fig. 20.

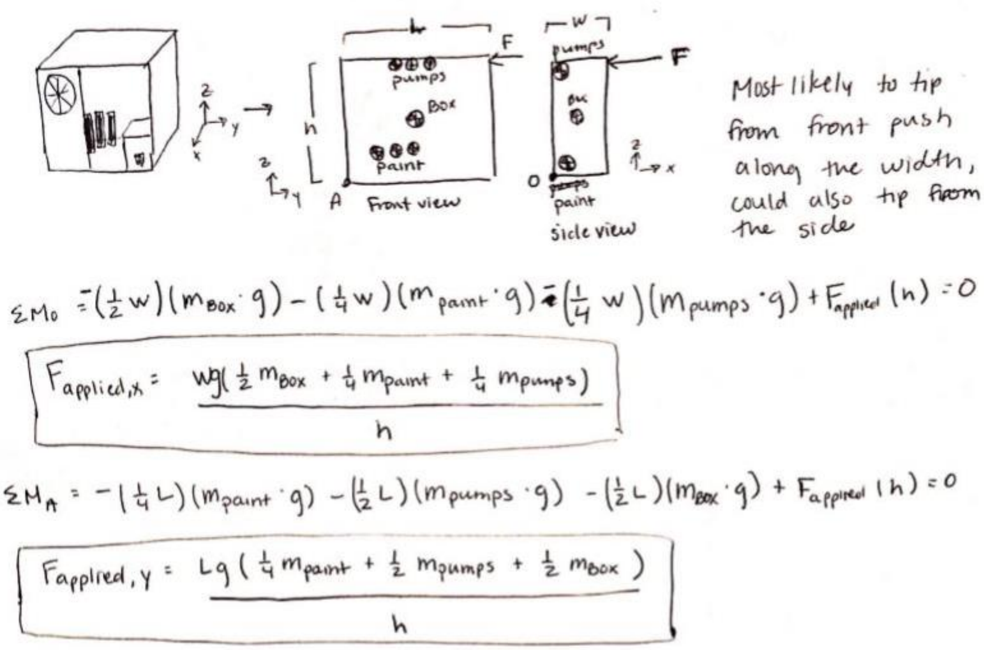


Figure 20: Tipping Force Model

4.4.3 Pump Flow model

The selection of the pump to supply the dispensing of the paint is important to ensure that the device functions as it is supposed to. The chosen category of pumps is the peristaltic pump as the internal working of the pump do not contact the fluid. This is important as paint could easily clog or damage the function of many pumps. The characteristics we need to rely on are the flow rate of the pump that is required as the viscosity of the fluid affects flow rate. These two factors are connected by Poisueille's Law and compared as most pump characteristics are given in terms of water. Other factors include the dimensions of the of the tubing in measuring the necessary pressure loss in Poisueille's Law.

$$Q_{paint} = \frac{V}{t}$$

$$Q = \frac{\Delta P \pi r^4}{8\eta L} \; Poiseuille's\ Law$$

$$\frac{Q_{paint}}{Q_{pump}} = \frac{\Delta P \pi r^4}{8\eta_{pump} L} \div \frac{\Delta P \pi r^4}{8\eta_{water} L} = \frac{\eta_{water}}{\eta_{pump}}$$

Q: Volumetric Flow Rate

ΔP: Change in Pressure along tubing

r: Radius of tubing

L: Length of tubing

η: Viscosity

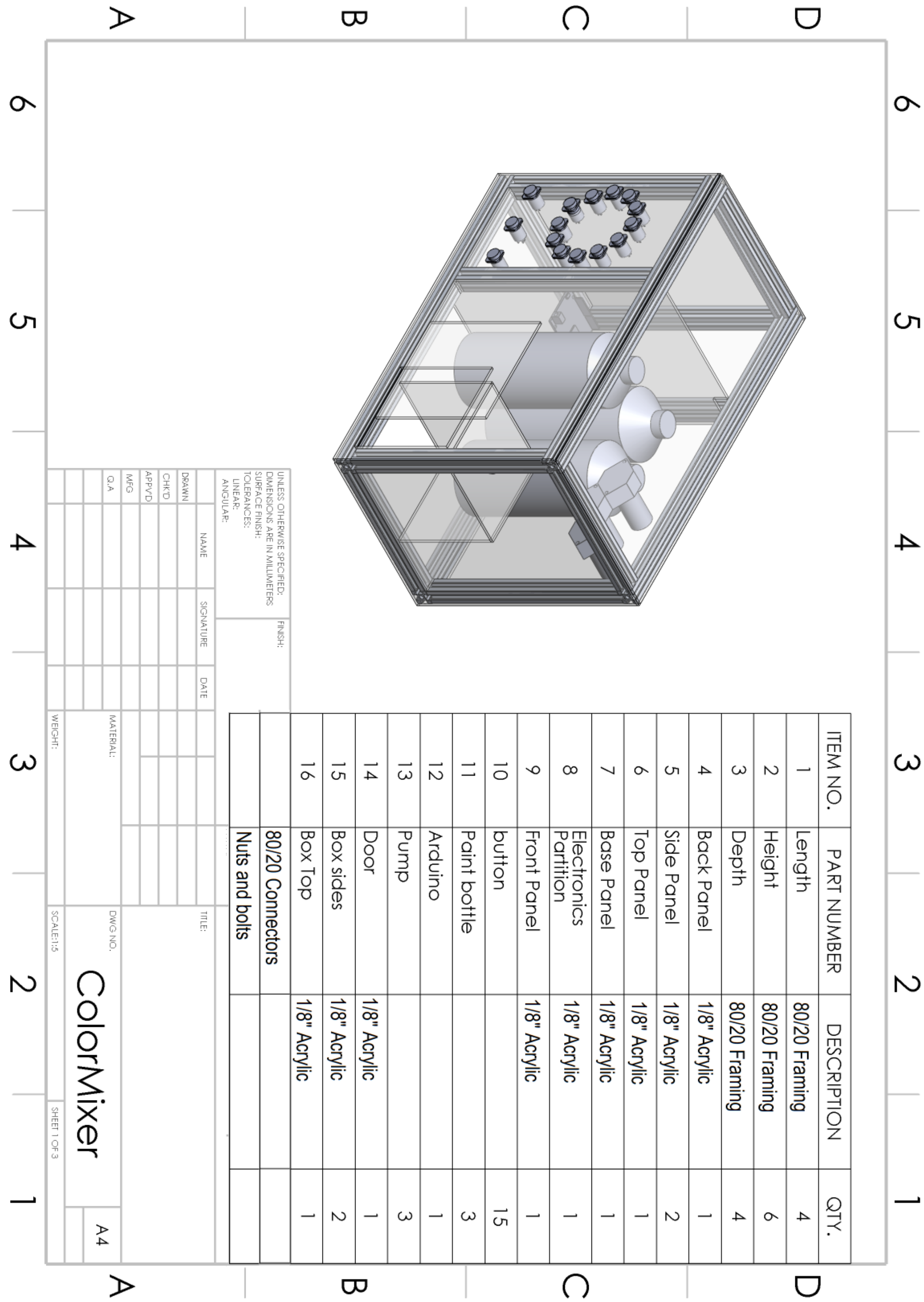
V: necessary volume

t: Allowable time to dispense

5 CONCEPT EMBODIMENT

5.1 INITIAL EMBODIMENT

Figures 21 through 23 show the state of our design going into the Proof of Concept (POC) prototype. Figure 21 shows the assembly view with a Bill of Materials (BOM), with numbers that correspond to the callout bubbles in Fig. 22. Figure 23 shows a front, side, and top view and includes basic dimensions.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Length	80/20 Framing	4
2	Height	80/20 Framing	6
3	Depth	80/20 Framing	4
4	Back Panel	1/8" Acrylic	1
5	Side Panel	1/8" Acrylic	2
6	Top Panel	1/8" Acrylic	1
7	Base Panel	1/8" Acrylic	1
8	Electronics Partition	1/8" Acrylic	1
9	Front Panel	1/8" Acrylic	1
10	button		15
11	Paint bottle		3
12	Arduino		1
13	Pump		3
14	Door	1/8" Acrylic	1
15	Box sides	1/8" Acrylic	2
16	Box Top	1/8" Acrylic	1
	80/20 Connectors		
	Nuts and bolts		

Figure 21: Color Mixer assembly view with BOM

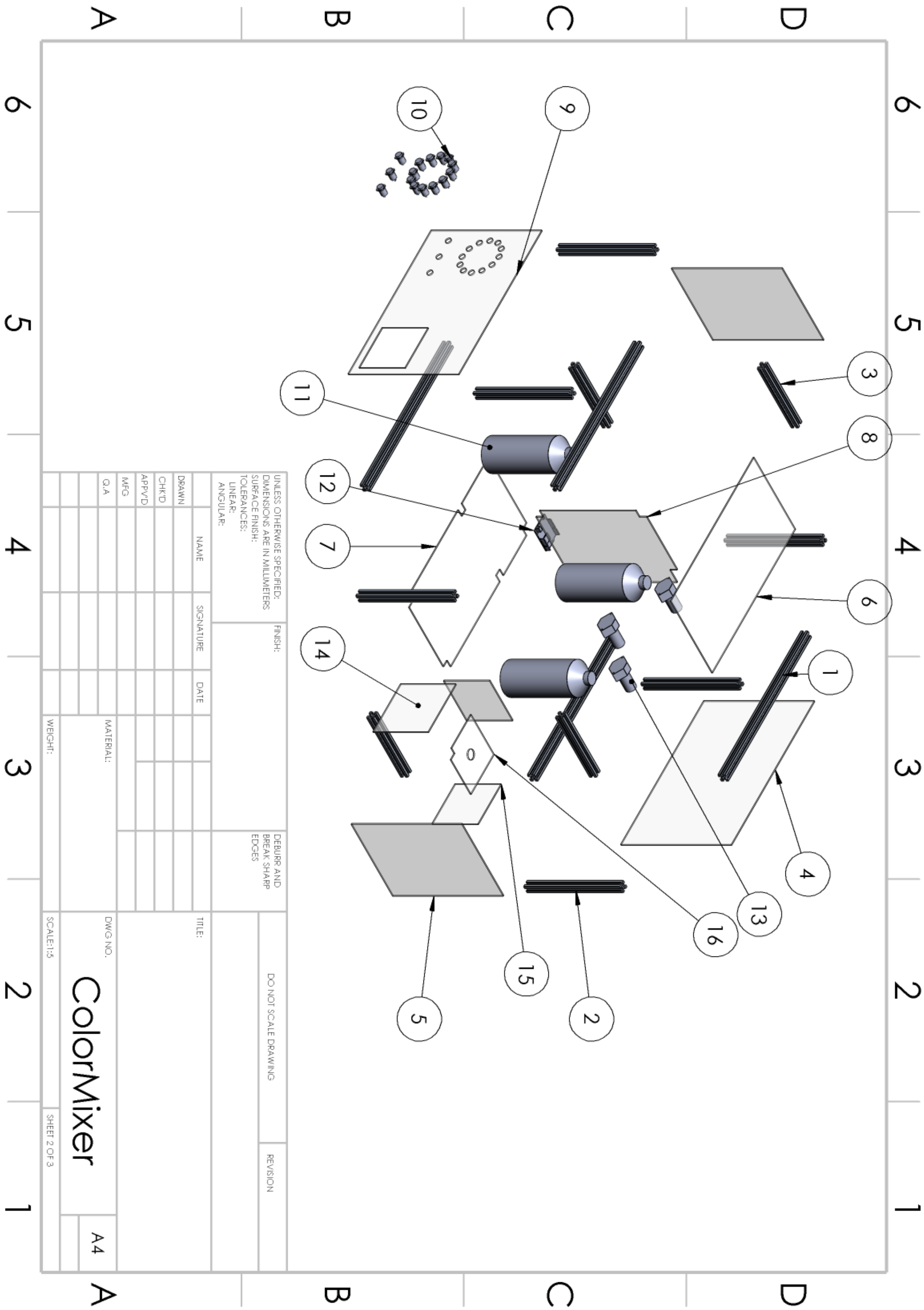


Figure 22: Color Mixer exploded view with bubble callouts

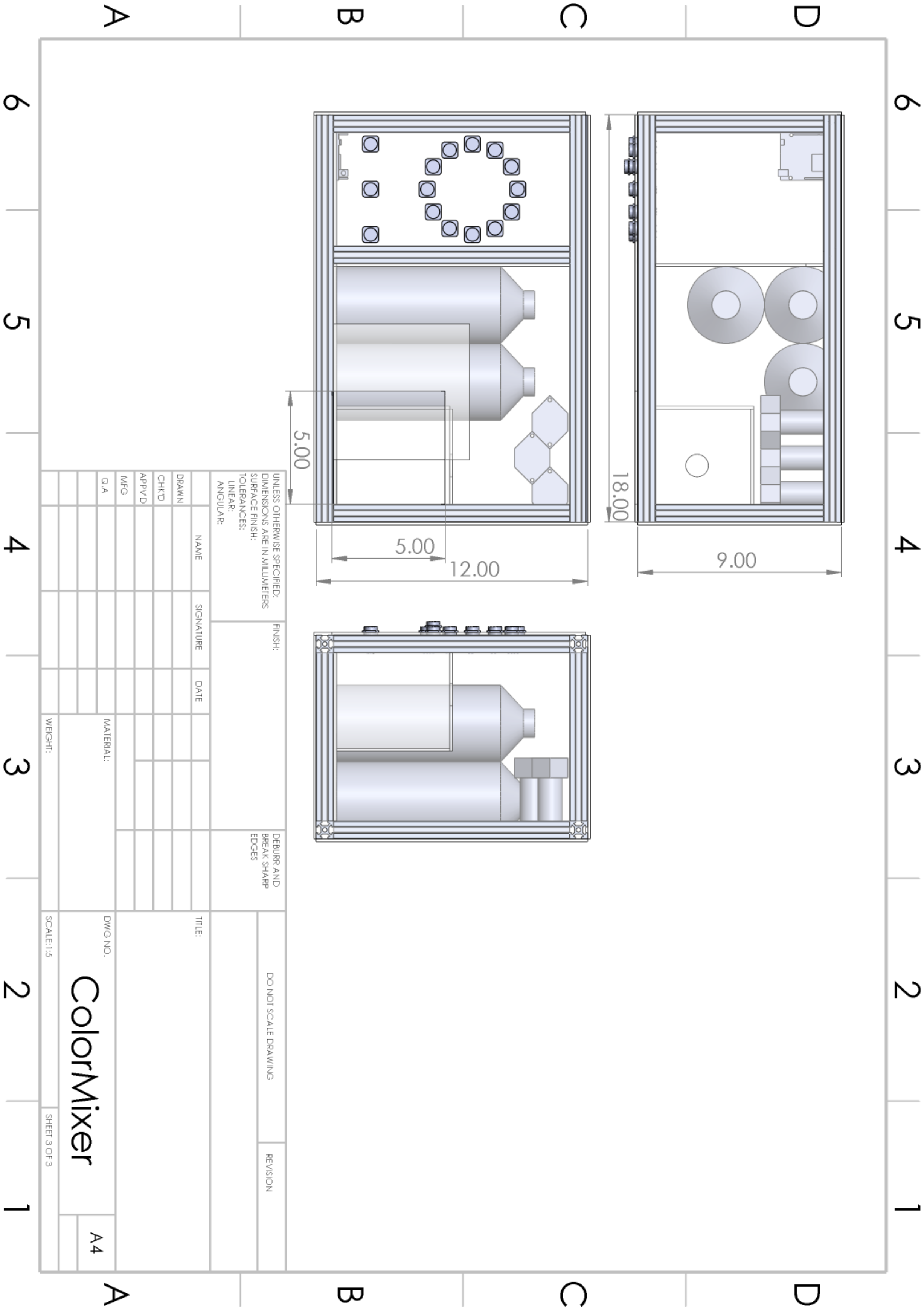


Figure 23: Color Mixer front, side, and top view with basic dimensions

Table 8: Parts list

Parts List			
Part	Material	Quantity	Price
Lengthwise support	80/20 Aluminum framing	4	Recycled
Vertical support	80/20 Aluminum framing	6	Recycled
Depth support	80/20 Aluminum framing	4	Recycled
Back panel	1/8" Acrylic	1	
Side panel	1/8" Acrylic	2	
Top Panel	1/8" Acrylic	1	
Base Panel	1/8" Acrylic	1	
Electronics partition	1/8" Acrylic	1	
Front panel	1/8" Acrylic	1	
Box sides	1/8" Acrylic	2	
Box top	1/8" Acrylic	1	
Door	1/8" Acrylic	1	
Sliding door runner		2	
Color selection button		15	26.40
Bottle of paint	Tempura	3	17.97
Arduino		1	Recycled
12V Peristaltic pump		3	74.85
80/20 Fasteners			
Nuts and bolts			

5.2 PROOF-OF-CONCEPT

5.2.1 Prototype performance goals

To be considered successful, the Color Mixer should meet three performance goals. It should be able to achieve the following for 6 color selections:

1) Dispense paint within a ±10% margin by weight
2) Finish dispensing paint within 60s of color selection
3) Be able to match the color dispensed to the chosen color on the color wheel

The first goal ensures the fairness of the device. The weight of the final paint amount dispensed will be measured. If the amount dispensed for at least six colors is within 10 % of each other, the color mixer will pass this test. The second goal is to ensure the user will not get bored while waiting for the paint. A stopwatch will be started when the button is first pressed to select the color, and the pain should be ready for the user to collect within 60s. The final goal is for reliability and accuracy. Six colors will be chosen and dispensed, then given to someone who is not a member of the design team. If that person can match the colors to the color that was selected, the color mixer will pass the test.

5.2.2 Design Rationale

The design is modeled off the Battery-powered, Pump-driven Color Mixer as detailed in Section 3.3.2, since the design selection analysis showed it to be the best option. The two primary options for a microprocessor were an Arduino and a Raspberry Pi, since both are common and have high quality documentation. An Arduino was the best option for this project, since it is the simpler processor and the processes it needs to regulate for this project are simple. The peristaltic pumps chosen are 12V pumps (although there were lower-voltage options available) to ensure there is enough power to pump relatively high viscosity paint. The flowrate can be modeled by

$$Q = \frac{\Delta P \pi r^4}{8\eta L} \text{ [8]}$$

Q: Volumetric Flow Rate

ΔP: Change in Pressure along tubing

r: Radius of tubing

L: Length of tubing

η: Viscosity

Since the flow rate is inversely proportional to viscosity and directly proportional to the change in pressure along the tubing, so with a higher viscosity fluid, the pump must be able to supply a higher pressure differential to maintain the flow rate. Goal 2 introduces a time component to the evaluation of the prototype, so it is important to keep the flowrate up. The Arduino can also run off 12V, so the same power source can power both. The paint bottles chosen are relatively large, giving them a high mass, which serves two purposes. It allows the paint to last longer before being replaced, as well as making it harder to tip the box, since the force required to tip the box is defined by

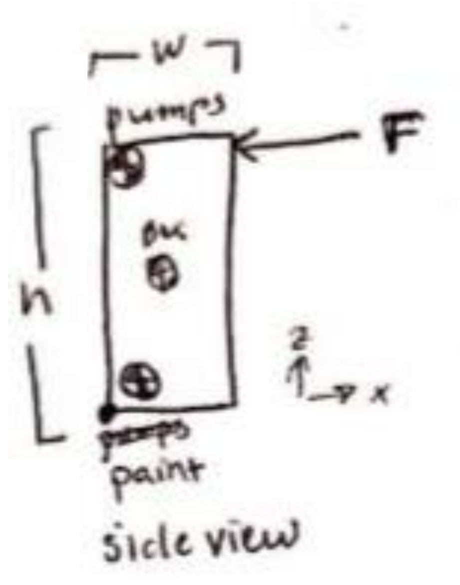
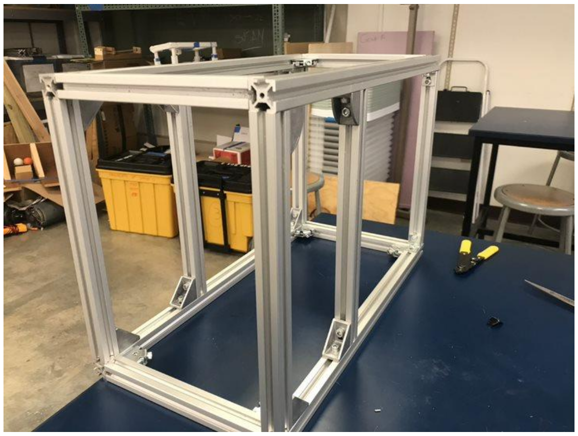


Figure 24 Definition of variables for the box tipping model

$$F = \frac{wg}{h}\left(\frac{1}{2}m_{box} + \frac{1}{4}m_{paint} + \frac{1}{4}m_{pumps}\right).$$

The two aspects that were tweaked are the method for selecting color, and the way the color is collected by the user. The three primary color buttons will still be included, but the main method of selecting color is to choose a preprogrammed color from the color wheel. Then the color can be 'topped off' with more red, yellow, or blue. This will allow the user to more easily receive the color they want. The door was also changed from a garage-style door to a sliding door. Both door designs are safe, since neither result in sharp edges hanging open like a hinged door would, but a sliding door is easier to build than a garage door.

Photographs of the concept embodiment are shown in Figs. 25-28.



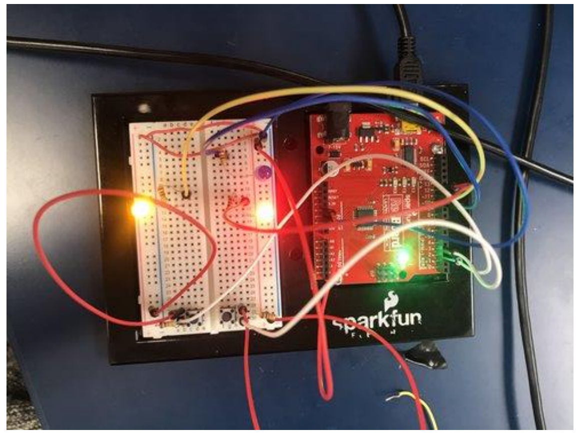


Figure 25: (Left) 8020 Aluminum Color Mixer frame

Figure 26: (Right) Arduino with lights programmed to model paint dispensing

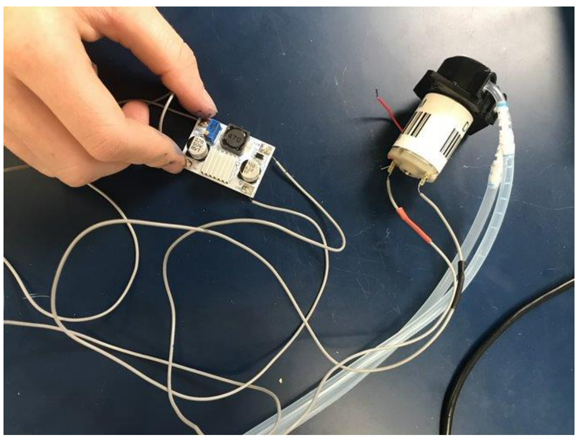


Figure 27: (Left) Peristaltic pump with voltage stepper

Figure 28: (Right) Paint and soapy water that has been pumped

6 WORKING PROTOTYPE

6.1 OVERVIEW

The Proof of Concept demonstration successfully demonstrated the code's ability to take input in the form of a button press and output a color by lighting up a combination of LED's; however, there was only one button and the color was randomly chosen by the code. The peristaltic pumps were demonstrated to be able to pump the paint by using a voltage stepper to step up the voltage provided by the Arduino. For the working prototype, the 12 color buttons were implemented so the user could specify the color. The LED's were also replaced with the peristaltic pumps, which were powered by a 9V battery instead of the voltage stepper, since the battery provided more power than the Arduino. This also required the implementation of transistors, so the Arduino could still function as an on/off switch for the pumps.

6.2 DEMONSTRATION DOCUMENTATION

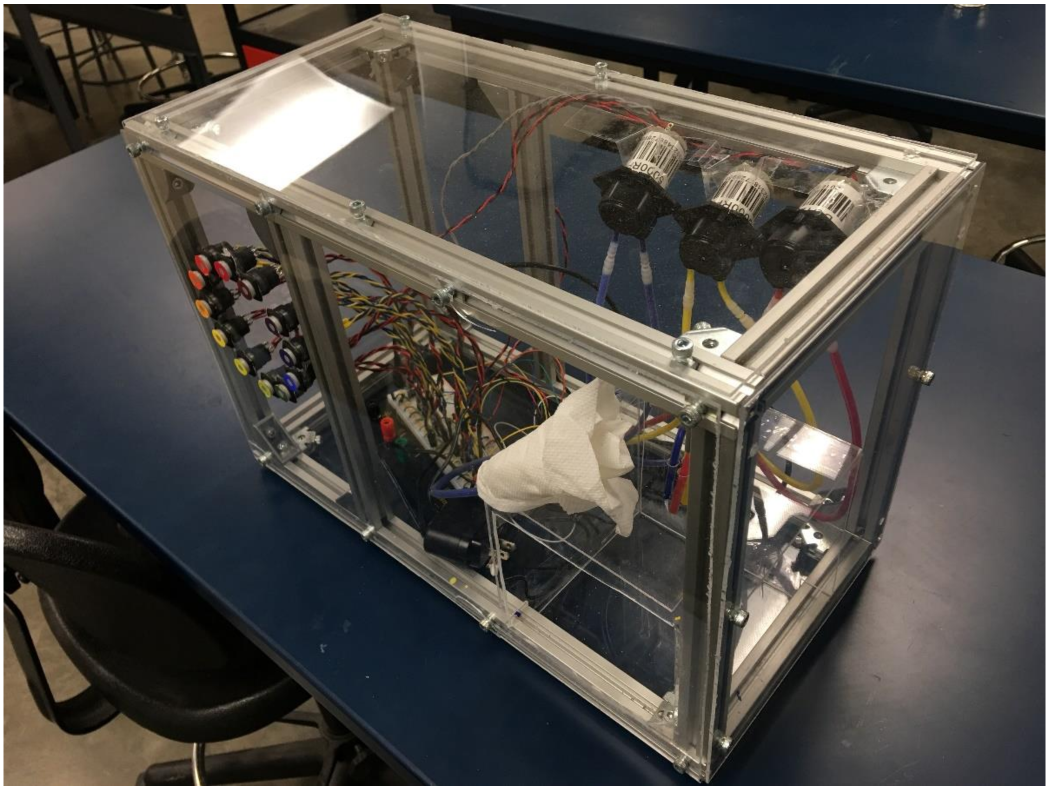


Figure 29: Working Prototype Isotropic View

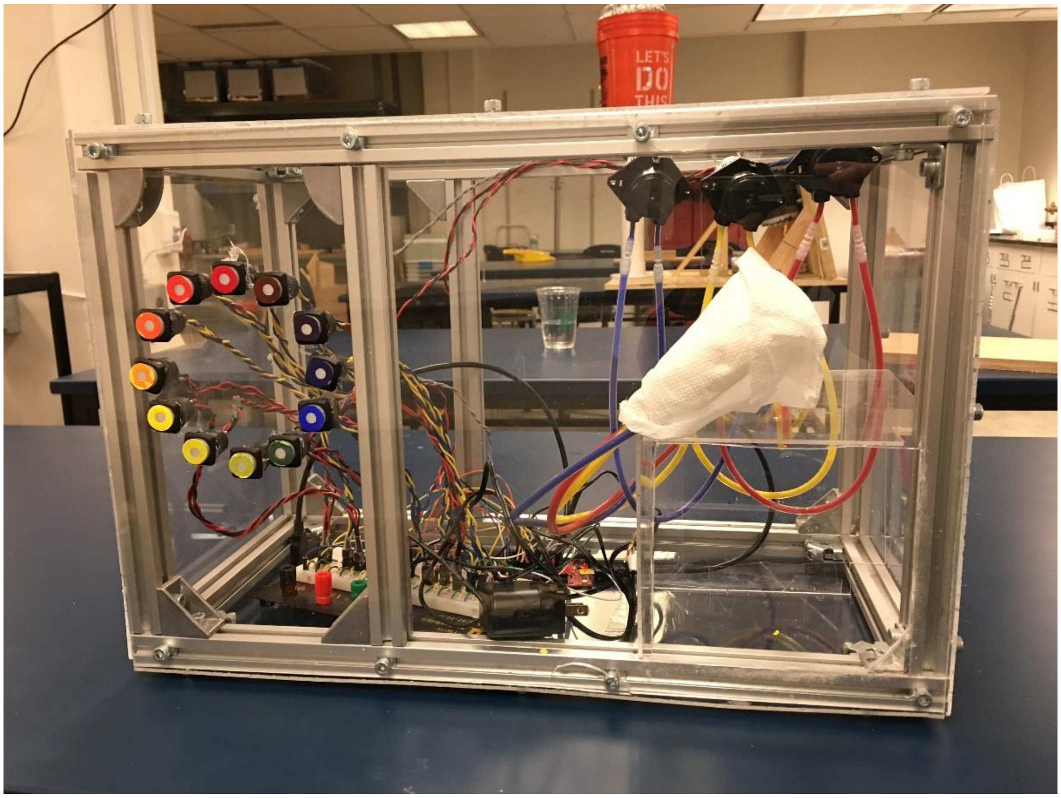


Figure 30: Working Prototype Front View

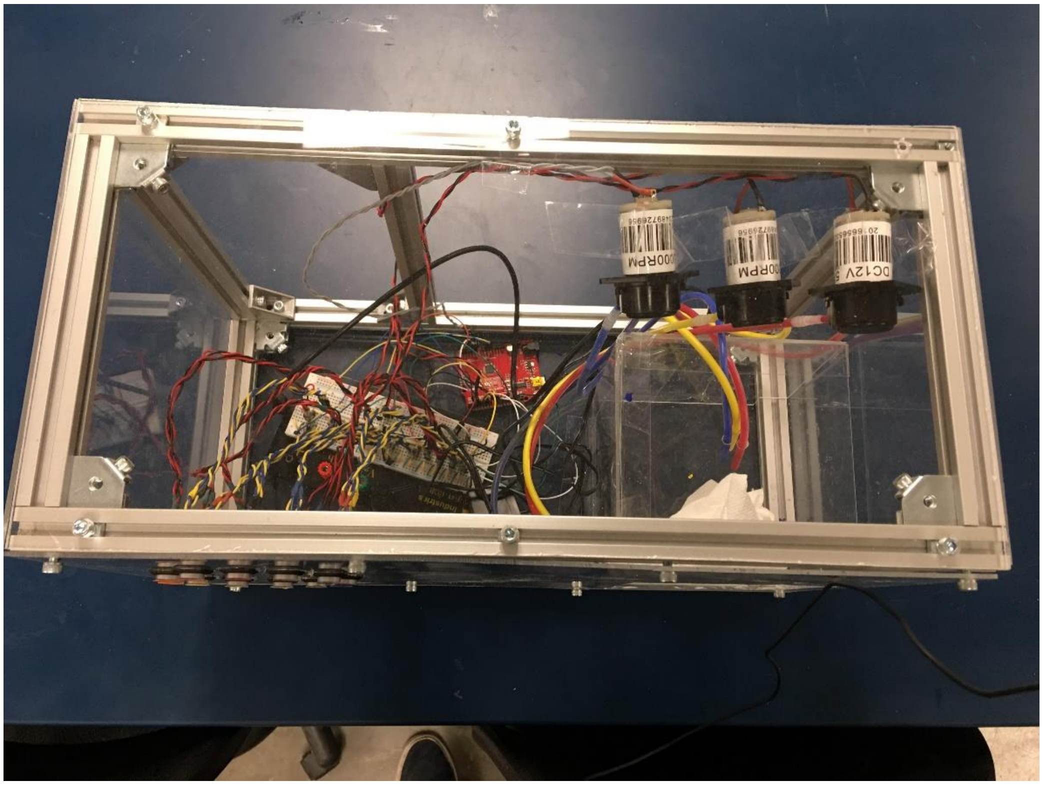


Figure 31: Working Prototype Top View

6.3 EXPERIMENTAL RESULTS

The three performance goals defined for the device were: a total elapsed time less than one-minute, consistent final product weights within 10%, and a color reliability eight out of ten times. The total time includes the time from when the button is pressed to the time the last drop of paint is dispensed. Each color was programed into the Arduino based on the amount of time the two primary colors need to run. The ratios where then normalized such that the maximum dispensing time is 20 seconds. Further, the Arduino process the information within a few milliseconds, thus processing time does not significantly affect the total elapsed time. Finally, since the pumps are primed with paint prior to the devices initial used, the time for the paint to travel from the bottle to the cup can also be neglected. The total elapsed time is effectively the 20 second run time of the pumps. The final mass of the dispensed paints was found to range from 10 g to 15 g across all colors. However, within the same colors the weight discrepancies were more consistent. The percent difference was 40 %. This error can be contributed to the different paint densities, which was not accounted for when the performance goals were drafted. Further, the paints dispensed across the colors seemed to be consisted volumetrically by eye. This is perhaps an even more important factor since the children will most likely evaluate the fairness of the device based on visual amount of paint and not weight. The final performance goal was to achieve color reliability. This means that the color dispensed could be accurately selected from a color wheel at least eight out of ten times. By visual comparison the colors produced accurately reflected the chosen color that was expected in all trial cases Table 8 shows the results from our working prototype.

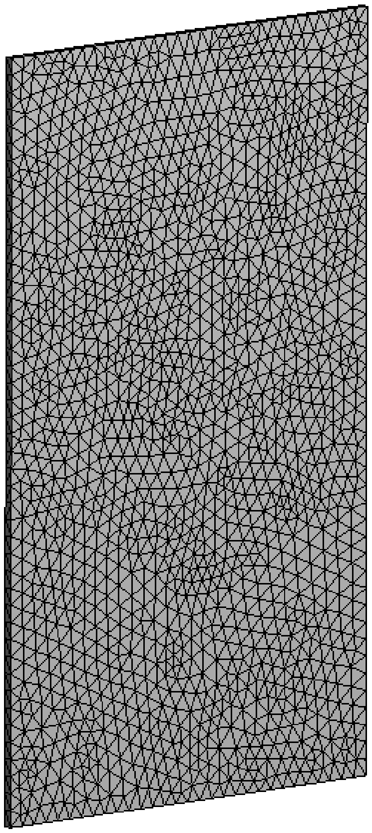
Table 9: Results from working prototype performance goals testing.

Performance Goal ID	Performance Goal	Experimental Result
Total time elapsed	< 60 seconds	~ 20 seconds
Final product weight	within 10% by mass	40%
Color reliability	> 80%	>95%

7 DESIGN REFINEMENT

7.1 FEM STRESS/DEFLECTION ANALYSIS

The part analyzed in ANSYS Mechanical is the sheet of acrylic that the buttons will be mounted in, with dimensions 9” x 6” x 0.093”. For simplification purposes, each of the 12 buttons on the color wheel are represented as ½” diameter circles sketched onto the acrylic sheet instead of as individual components that are incorporated into the acrylic via holes and bolted into place. There is a fine mesh with almost 18,000 nodes, which is fine enough for this geometry. There are four load steps, with 10lbs scoped to a button circle at the most extreme locations on the color wheel. The boundary conditions are that each outer side of the acrylic sheet are fixed, as they will be mounted into the frame and will not be able to move. The 10lbs load is an estimation of a harder-than-average press of a button. Assuming the load is an accurate estimate, the results of the finite element analysis is an accurate representation of the acrylic sheet’s performance.



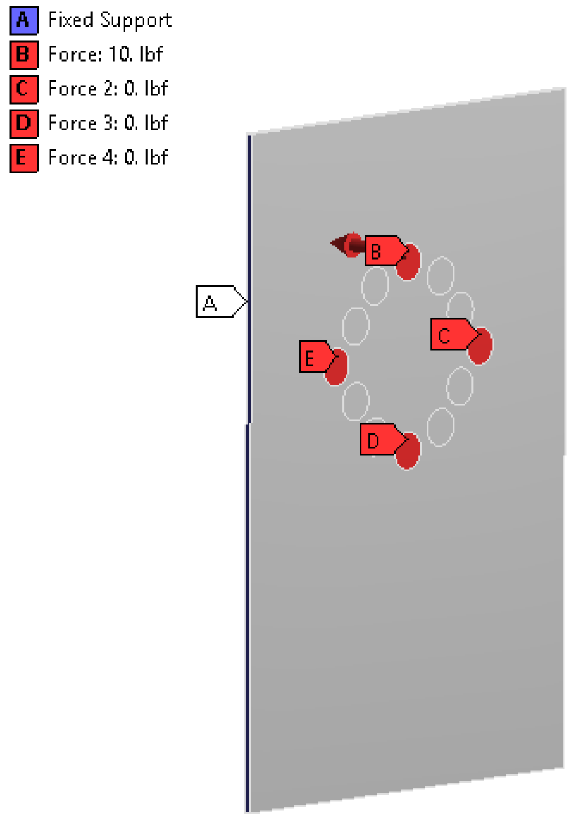
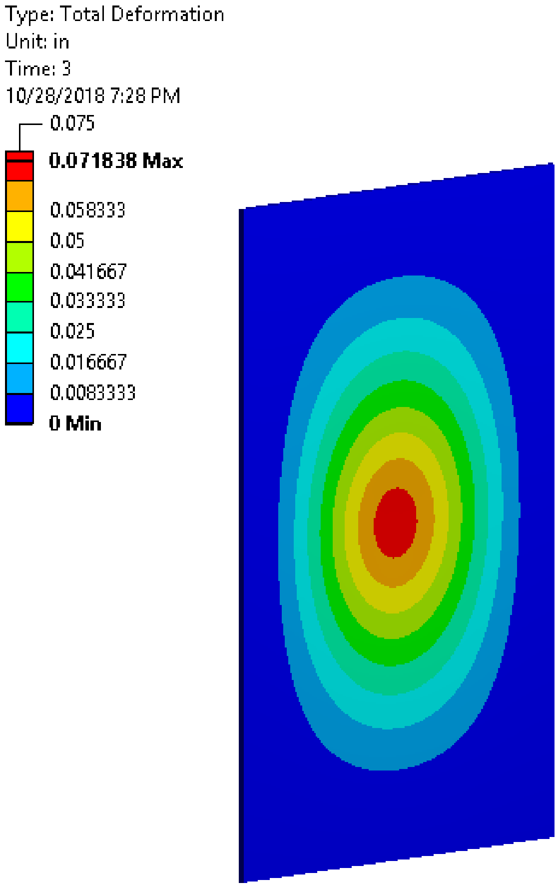


Figure 32: Acrylic sheet with mesh shown

Figure 33: Acrylic sheet with boundary conditions and load step 1 shown

In Fig. 29, only the first load step is shown; for each additional load step, the 10lbs force will be scoped to a different point to represent each button being pressed. The worst-case scenario for stress and deflection results occurs when the 10lbs force is scoped to point D on Fig. 29.



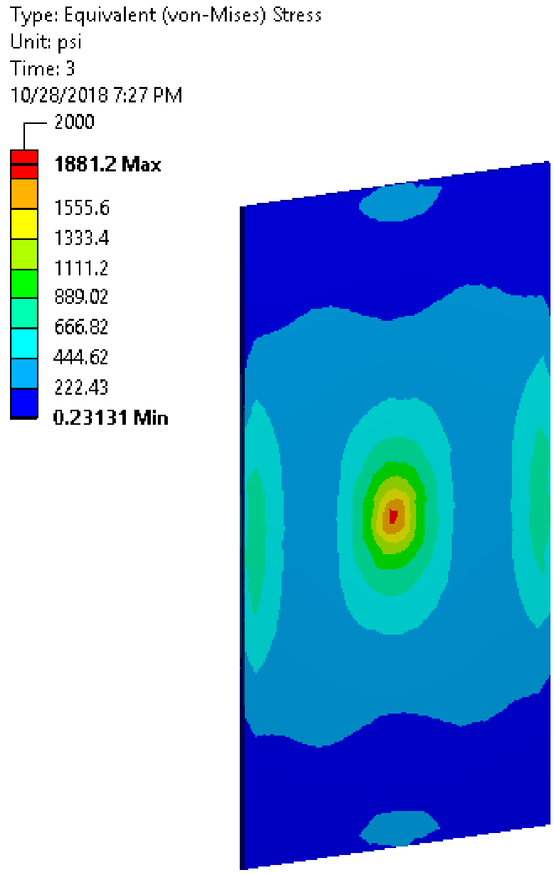


Figure 34: Deformation results for 10lbs at point D

Figure 35: von-Mises stress results for 10lbs at point D

The von-Mises stress results predict a maximum stress of 1.88 ksi, well below the ultimate stress of 10.2 ksi for acrylic Plexiglas [8]. This means that the acrylic has a safety factor of 5.4. Given the high safety factor, even if the load used in the analysis is a low estimate, the acrylic should still perform as expected and refrain from breaking. Additionally, the deflection is negligible.

7.2 DESIGN FOR SAFETY

This section outlines five risks that have been identified and prioritizes them based on likelihood and magnitude of the impact.

Risk Name: Paint consumed by a child

Description: A child could eat the dispensed paint if they are not supervised closely enough and suffer adverse consequences.

Impact: 4; Depending on the type of paint, the child could become ill.

Likelihood: 4; Children commonly put non-food items in their mouths.

Risk Name: External paint spill

Description: If the paint were dispensed without a cup under the nozzles, or if a user had their hand under the nozzles while the color mixer was dispensing paint, it would make a mess.

Impact: 2; The paint would either get on the inside of the cube where the cup sets, or it would get on the hand of the user. It would be an annoyance, but easily cleaned up, especially if it were noticed promptly.

Likelihood: 3; The color mixer should be intuitive, and there will be image-based instructions, but mistakes do happen.

Risk Name: Internal paint spill

Description: The paint could spill out of the bottle or leak out of the pump and interfere with the electrical components.

Impact: 4; If paint got on any electrical components, the color mixer would likely stop working completely.

Likelihood: 1; The electrical components will be far from the paint bottles and separated by acrylic.

Risk Name: Door pinches fingers

Description: The design includes a sliding door, which could be slid closed while a user's fingers are in the way and pinch them.

Impact: 2; The door will not require much force to close, so it would not cause much damage or pain if it hit someone's fingers.

Likelihood: 2; Even if the door were closed while a user's hands were still in the way, it likely would not pinch them unless they were positioned specifically so a small amount of skin were between the box and the edge of the door.

Risk Name: Tip over

Description: A user could grab the top of the box and pull it down, tipping the color mixer.

Impact: 4; The color mixer would likely stop working and the paint could spill all over the inside of the box. It could also fall on the user that tipped it over, injuring them.

Likelihood: 1; The center of gravity will be low, and the box is relatively short and squat, so a notable amount of force would be required to tip it.

Based on Fig. 32, the two risks that should be the highest priorities are the device being tipped over and a child consuming the paint. Those two are the most important because they cause the most harm to the user, as opposed to just the device. The damage caused is also more long-term. The finger pinch is the lowest priority because, although it would harm the user, it would be very minor, and it is not very likely to happen. The internal and external paint spills are of moderate importance because they would be a nuisance at the least, and the external paint spill is fairly likely to happen.

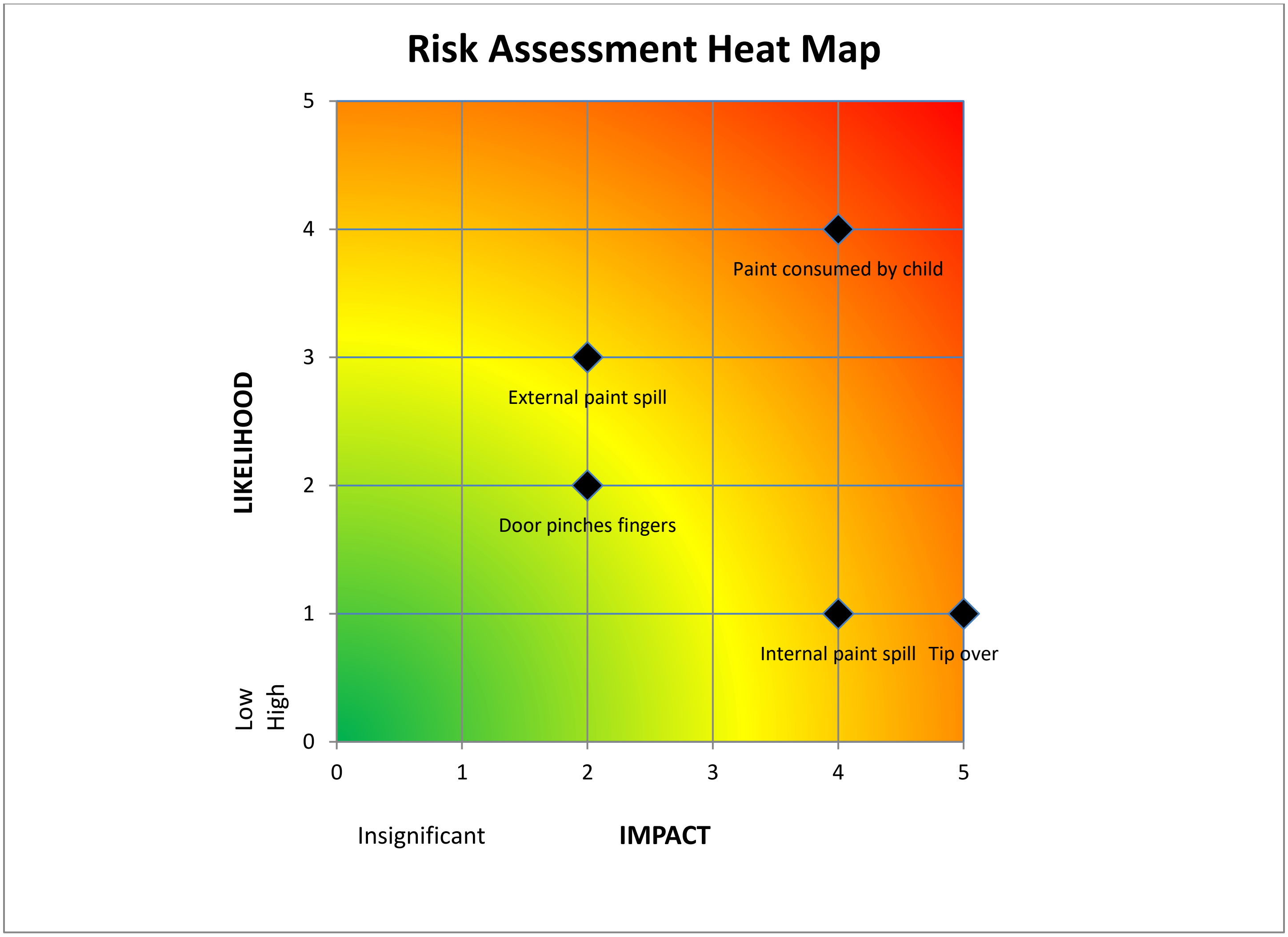


Figure 36 Risk assessment heat map

7.3 DESIGN FOR MANUFACTURING

7.3.1 Draft Analysis

Due to the simplicity of the part, there were few modicifcations needed to make it appropriate for injection molding. To aid in ejection of the part from the mold, a draft angle had to be added to the edges shown in yellow in Fig. 33. The parting line is along the bottom edge of the part, similar to a lego.

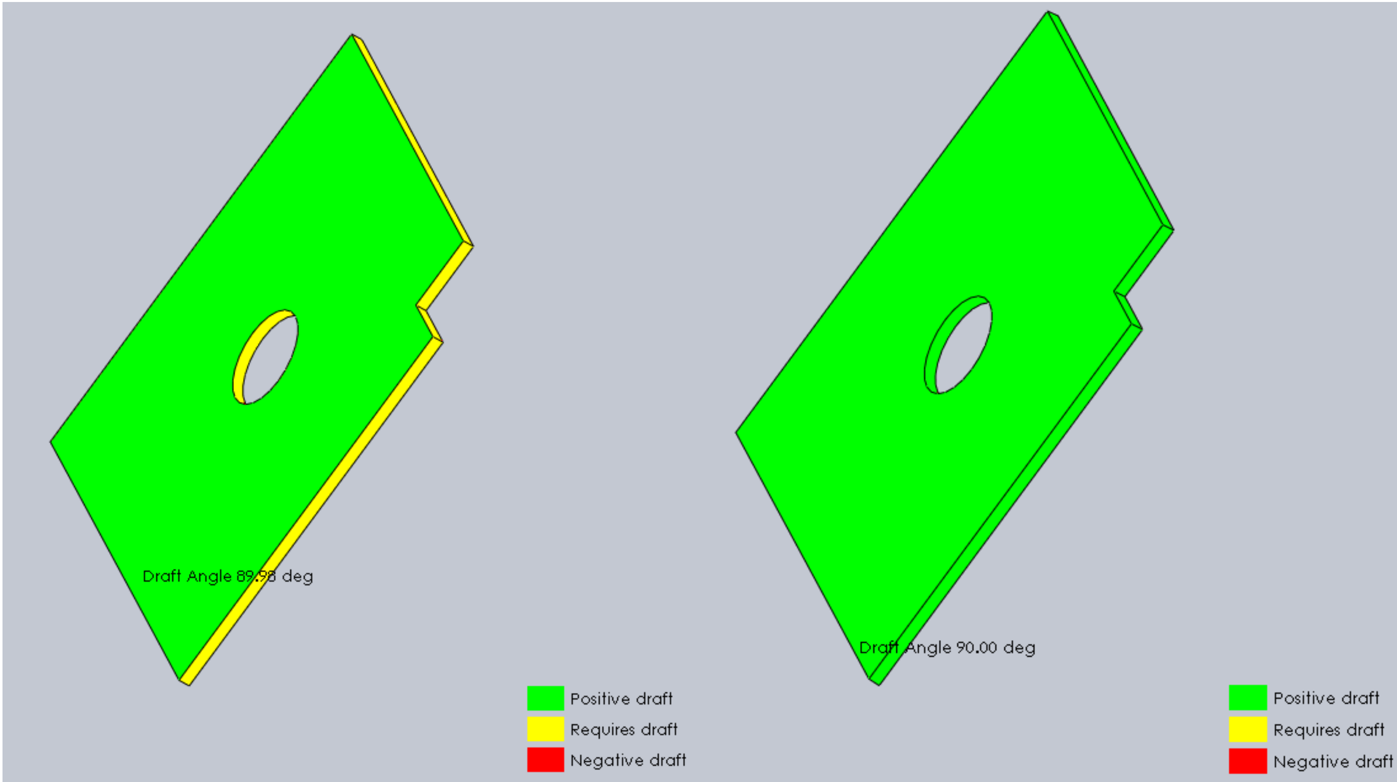


Figure 37 Before (left) and after (right) images of the dispensing cover using Solidworks "Draft Analysis"

7.3.2 DFM Analysis

Analysis for manufacturability was performed for the Misumi T-slot tubes for production by mill and drill or injection molding and shown in Figs. 34 and 35. This part is typically produced by extrusion, a process with different design restrictions. The instances of rule failures for the injection molding and mill and drill processes are a result of those differences. If we had to produce a substitute for these rails, we would likely change the design to be more machinable.

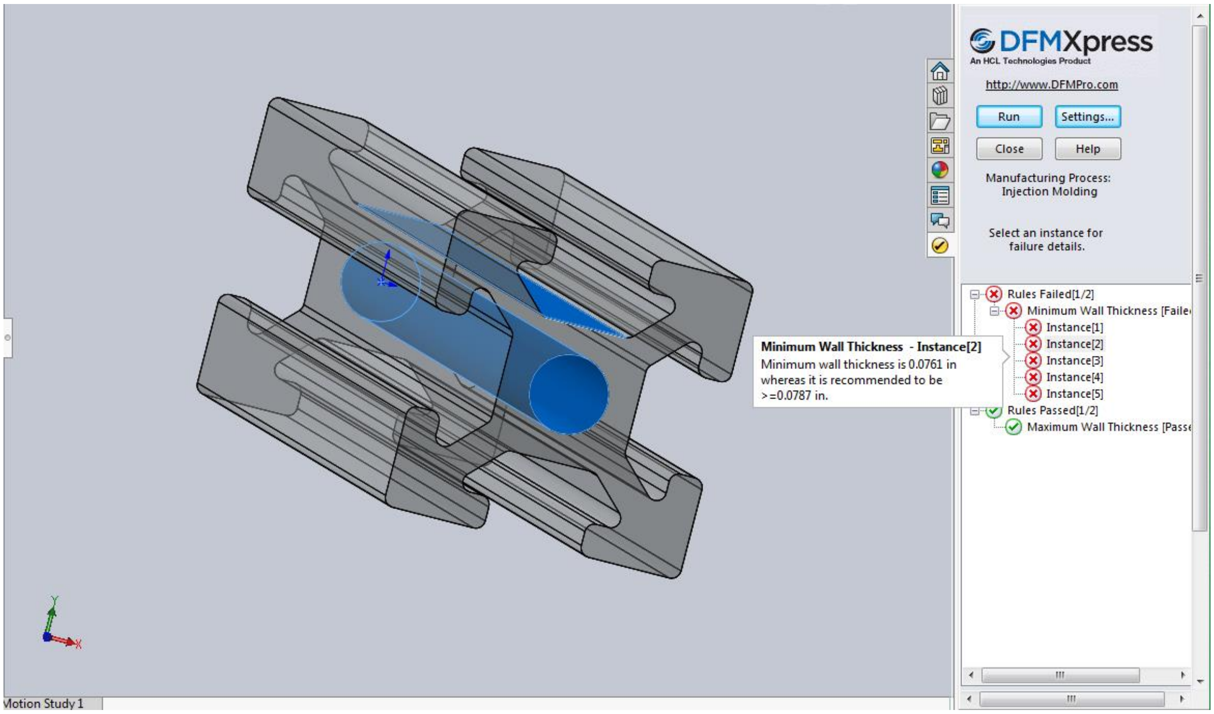


Figure 38 DFM analysis for Injection Molding process on the 80/20 frame

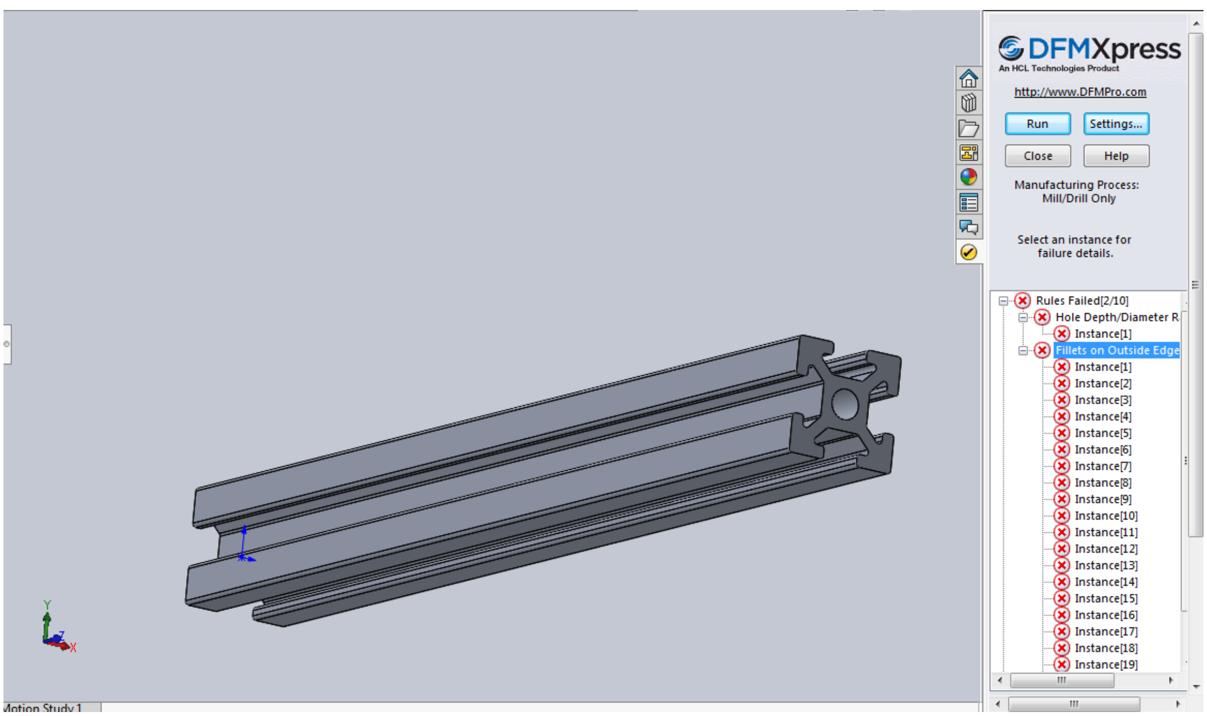


Figure 39 DFM analysis for a Mill/Drill Only process on the 80/20 frame

7.4 DESIGN FOR USABILITY

This section considers how the usability of the color mixer is influenced by impairments that might afflict the user. Vision, hearing, physical, language, and control are the impairments under review.

7.4.1 Vision

The color mixer design is meant to be a visual exploration of how primary colors mix to produce secondary and tertiary colors. So, visual impairments such as blindness or color- blindness would make the device unusable. Other vision impairments such as nearsightedness and farsightedness affect the usability less. The large button design makes it easier to see the button outline and different color options. Since the device is meant to be used in close proximity, this may cause problems of blurriness of the color wheel and color mixing for farsighted people.

7.4.2 Hearing

Hearing impairments do not affect the usability of the color mixer design. This is because the current design does not use any sound. In later iterations of the device design, sound might be used to signal warnings or give intermediate instructions, such as “wait 3 seconds to add more paint,” or “mixing complete. Please remove cup.” Usability can be improved in this scenario by using digital readouts to communicate the same information.

7.4.3 Physical

The user must be able to apply pressure to the button to use the color mixer. However, the pressure applied to the button is minimal. This minimal pressure means that physical impairments such as arthritis and muscle weakness does not pose a large problem to the usability of the device. Arthritis impairments can be addressed by using a large portion of the hand, perhaps the palm to press the button. Further, the button only needs to be pressed for a few milliseconds. This means that the hand does not have to stay in any position for a long time. In addition to this, the spacing of the buttons can be moved farther apart so that the entire palm may be used without pressing multiple buttons. Similarly, muscle weakness is addressed by the ease of which the button is pressed. So long as the hand can be lifted to the height of the button, a simple touch of the hand to the button will apply enough pressure to start the color mixer. Other impairments such as limb immobilization makes the color mixer unusable if the hands are affected, since there is no safe way to use other body parts to press the buttons and start the machine. However, immobilization of the legs, such that the person is at an overall low height does not pose a problem for the usability if the user is at least the height as an average five-year-old. Placing and removing the cup requires some fine motor skill with opening the proposed door and locating the cup within the receptacle. This could be improved by making the door easy to grasp and slide smoothly as well as making the opening large enough to allow hands of all sizes to place and retrieve cups.

7.4.4 Language

The usability of the color mixer will be affected by language barriers since the instructions will be written. However, some of these barriers can be addressed by copying the instructions into a few of the most common languages spoken in the region. Another way to address language barriers, is to use pictographs to show the steps to using the color mixer in the correct order.

7.4.5 Control

Impairments such as distraction, excessive fatigue, or medication side effects could affect the usability of the design. However, once a button is pressed, the machine will automatically dispense the paint. If no further color is selected for mixing, the user can take their cup. If the user is distracted at this point, then a line may form leading to impatient customers waiting. This can be alleviated by having a museum employee help the distracted person as they make their rounds through the exhibit room.

8 DISCUSSION

8.1 PROJECT DEVELOPMENT AND EVOLUTION

8.1.1 Does the final project result align with its initial project description?

The product was initially described as "a device with three colored liquids or paints (red, yellow, and blue) and a way to select a color from the color wheel. The device automatically dispenses the correct amounts of each colored liquid or paint into one container to produce the desired color. The electromechanical components should be easy to see, but shielded enough to maintain safety." The final project meets all these requirements. Paint was chosen as the colored liquid, and there is red, yellow, and blue. The user can select a color wheel using one of the twelve buttons arranged in a circle and color-coded to show what color it will dispense. When a button is pressed, the device will automatically dispense the correct amount of each color to produce the desired color. The housing of the device is made of acrylic, so all the components are visible but still protected.

8.1.2 Was the project more or less difficult than expected?

This project was chosen because we knew that we knew it should be within reach for us. three main components of the project were the housing, the paint dispensing mechanism, and the circuitry. In general, the project difficulty closely aligned with our expectations, except for the circuitry. The specification that was most relevant to the housing was that it be transparent, so the electromechanical components would be visible but still protected. That was met by choosing acrylic, a transparent material, for the housing. The specification that was most relevant to the dispensing mechanism was that they be able to pump paint, a relatively viscous liquid, and that the paint would not dry into the internal components of the mechanism and clog it up. This was solved early in the process by using peristaltic pumps, and they did not present any more issues. The most problematic part of the project was the circuitry, and it was more problematic than expected. The very low capacity of 9V batteries was not considered initially, so they started burning out quickly and we struggled to pinpoint what the issue was. Then, when we switched to using a wall adapter for power, the circuit got very testy. The takeaway from this is that we are not electrical engineers.

8.1.3 On which part(s) of the design process should your group have spent more time? Which parts required less time?

The two parts of the project that could have used more time were the circuit and the finishing touches on the casing. The circuit because it was inconsistent, and the casing because it did not get finished. While it was finished enough to be functional, the circuitry did not get completely finalized, so the back panel of the case was never put on. Additionally, the plan was to mount the pumps on the top panel of the case, but instead of formally mounting them, they were taped to the top. The small cutout box on the bottom right of the case was also intended to be formally assembled, but that ended up taped together as well. Ideally, there would have also been a divider between the part of the box where the paint was set and the part of the box with the electrical components.

8.1.4 Was there a component of the prototype that was significantly easier or harder to make/assemble than expected?

The circuitry was difficult. We had to scramble a bit at the end to get it working. We were working on it concurrently with the rest of the project; it just took so much longer than everything else to get it working. Finding pumps that would work was not too difficult, and once we found them we didn't have issues with them. Assembling the box was easy. Coding the paint dispensing took some time, but since it was started very early it came together with plenty of time. The circuit was a struggle. Unlike the mechanical components, it would sporadically just not work, and a lot of time was spent on several different occasions trying to figure out why. This process probably could have been much faster had we had someone with more knowledge of circuits. Unfortunately, as mechanical engineering students, none of us had much expertise. Had we had an electrical engineering student in our group, the troubleshooting likely would have been much more efficient.

8.1.5 In hindsight, was there another design concept that might have been more successful than the chosen concept?

Our design concept met all the goals, and except for our lacking circuitry experience came together very smoothly. The circuitry issue could potentially have been avoided by choosing a design with a simpler circuit. While that may have made it easier to assemble, it likely would have reduced, not improved, the quality of the final product. The 12 buttons make the circuit complicated, but they make the device very easy to use. That way, the user knows what color they will be getting, and they can see the amount of each primary color that goes into it. A three-button approach would lend itself to a simpler circuit, but then the user would have to learn through trial and error instead of observation. This is not inherently bad but give the amount of time we spent mixing precise ratios of colors, there would be a much smaller range of options. In some of our colors, the ratio approached 20:1, so those would likely be unachievable if only three buttons were available. This extreme ratio can still be observed in the 12-button approach, since the color is visible when it is dispensed. It is evident that a lot more yellow than blue is dispensed to achieve green, for example.

8.2 DESIGN RESOURCES

8.2.1 How did your group decide which codes and standards were most relevant? Did they influence your design concepts?

Our focus in choosing codes and standards was safety. Since this is a product that is geared toward children, the most important component is being child-safe and child-friendly. Two of the biggest components and the two biggest hazards of this project were the electrical components and the paint. For that reason, it was important for us to make sure the paint we were using was child-safe and that the electrical components met the child safety specifications.

8.2.2 Was your group missing any critical information when it generated and evaluated concepts?

No critical information was missing during the generation of our concepts, which all ended up with interesting designs that could be integrated into a final prototype. The biggest factors that went into our selection were what we would be able to accomplish in the time and resources we were given, and what we were confident could result in a successful working product that met the goals we set out. The information we had gained through the interview was indispensable to how we went forward with concept generation and evaluation.

8.2.3 Were there additional engineering analyses that could have helped guide your design?

The largest limitation we had was knowing whether our circuit was laid out correctly as we began designing it, we may have benefitted from a circuit analysis, so we could more accurately expect power draw and requirements, as well as garner a better understanding of how components affected the circuit. Much of the knowledge used came from some prior experience and from hobby electronics websites that we had to try to interpret as how they could be implemented in our required needs.

8.2.4 If you were able to redo the course, what would you have done differently the second time around?

Largely we think our project ended up as a success despite the electrical gremlins that we ran into after the prototype demo. We did have a pretty good Idea of what we wanted our design to be going into concept development so some of the more creative designs were not investigated thoroughly as possibilities. It could have been interesting to pursue a very creative product and risk not meeting the performance goals despite our happiness at the success and design of our current prototype.

8.2.5 Given more time and money, what upgrades could be made to the working prototype?

Given more time, there are several modifications that had been planned that could be implemented. They would mostly have centered around the receptacle from which the paint was collected. A sliding door would be added to prevent users from reaching in while the paint is dispensed, and there would be a sensor to make sure the door stays closed while the dispensing is in progress. There would also be a sensor under the cup to make sure it is in place before dispensing.

8.3 TEAM ORGANIZTION

8.3.1 Were team members' skills complementary? Are there additional skills that would have benefitted this project?

The team members' skills were complementary. Although there were no official assigned roles, there was a natural split in the tasks. The mechanical assembly work, the coding and circuitry, the accounting, and the write-ups and logistics always got done. It would have been nice to have a team member studying electrical engineering. The circuit did get put together, but a lot of troubleshooting time was spent on the circuit, and reassembling the circuit successfully after making changes was somewhat inconsistent.

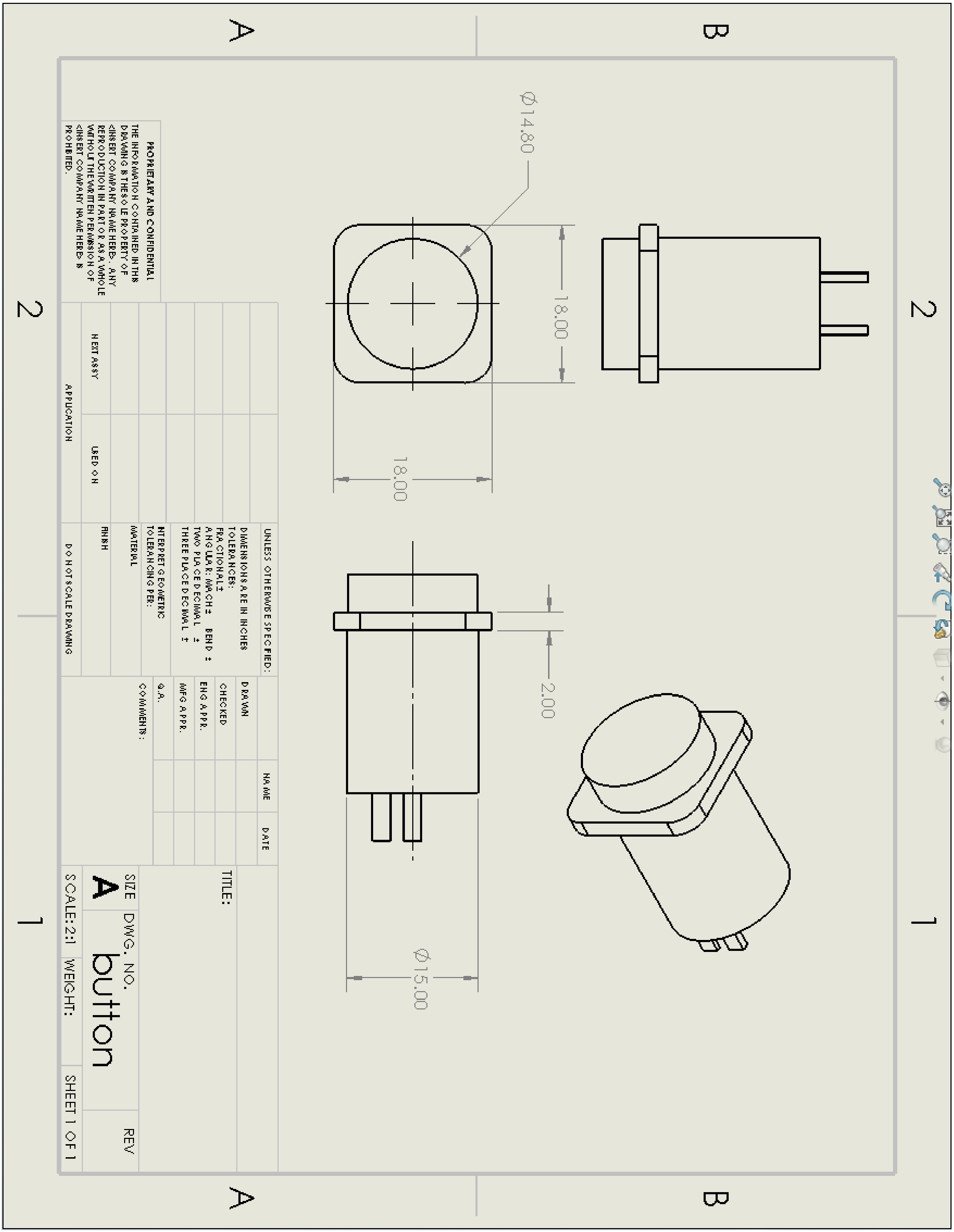
8.3.2 Does this design experience inspire your group to attempt other design projects? If so, what type of projects?

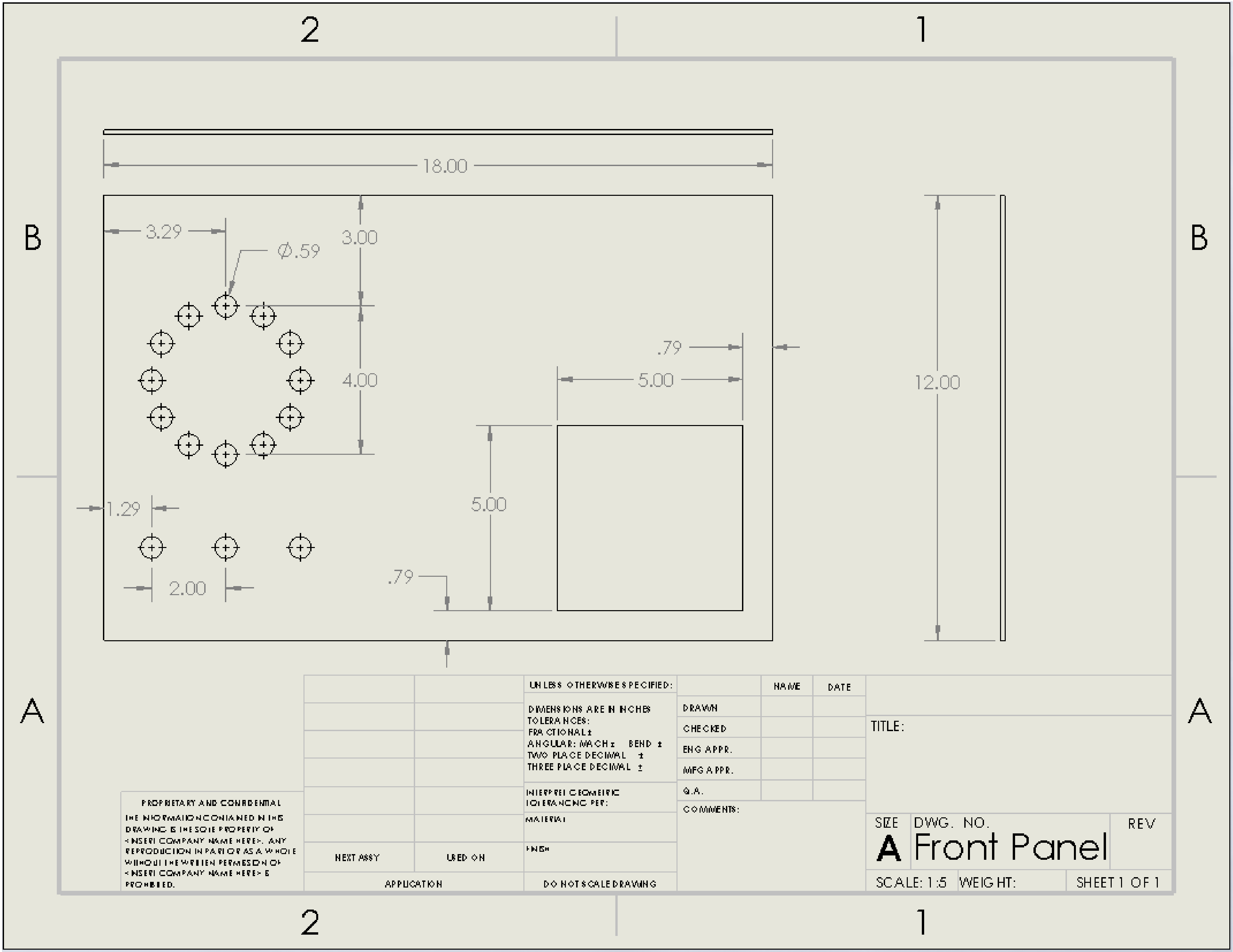
Yes, this project has inspired group members to continue on in other design endeavors Kelly and Michele both are a part of other design projects on campus, Wash U Racing and DBF respectively and enjoy their challenges. There has been discussion of taking our prototype and adapting it for other purposes or to use as our own learning experience for optimizing our prototype. We would like to consider achieving all of our original design considerations to see a fully operational version.

APPENDIX A – COST ACCOUNTING WORKSHEET

	Part	*Source Link*	*Supplier Part Number*	*Color, TPI, other part IDs*	*Unit price*	*Quantity*	*Total price*	*Added cost*	*Notes*
1	Peristaltic pump	Adafruit	1150	12V, DC power, silicon tubing	$24.95	3	$74.85	$9.76	shipping
2	Push-buttons	Adafruit	1479	16mm, white	$1.76	15	$26.40		
3	NPN Bipolar transistor	Adafruit	756	10 pack, PN2222	$1.95	1	$1.95	$10.90	shipping
4	Peristaltic pump	Adafruit	1150	12V, DC power, silicon tubing	$24.95	2	$49.90		
5	Acryclic sheet	Home Depot	SKU #659553	24 in. x 48 in. x .093 in.	$33.98	2	$67.96	$8.77	tax
6	3 pack of crayola paint	Michael's	10382699	Washable fingerpaint	$6.50	1	$6.50	$0.66	tax
7	Tempera paint, Red	Blick	00011-3006	Pint size	$5.99	1	$5.99	$0.61	tax
8	Tempera paint, blue	Blick	00011-5006	Pint size	$5.99	1	$5.99	$0.61	tax
9	Tempera paint, yellow	Blick	00011-4006	Pint size	$5.99	1	$5.99	$0.60	tax
10	D’Addario 9V Power Supply	Amazon	PW-CT-9V		$7.99	1	$7.99	$4.08	shipping
Total:							$203.62	$35.99	$238.61

APPENDIX B – FINAL DESIGN DOCUMENTATION

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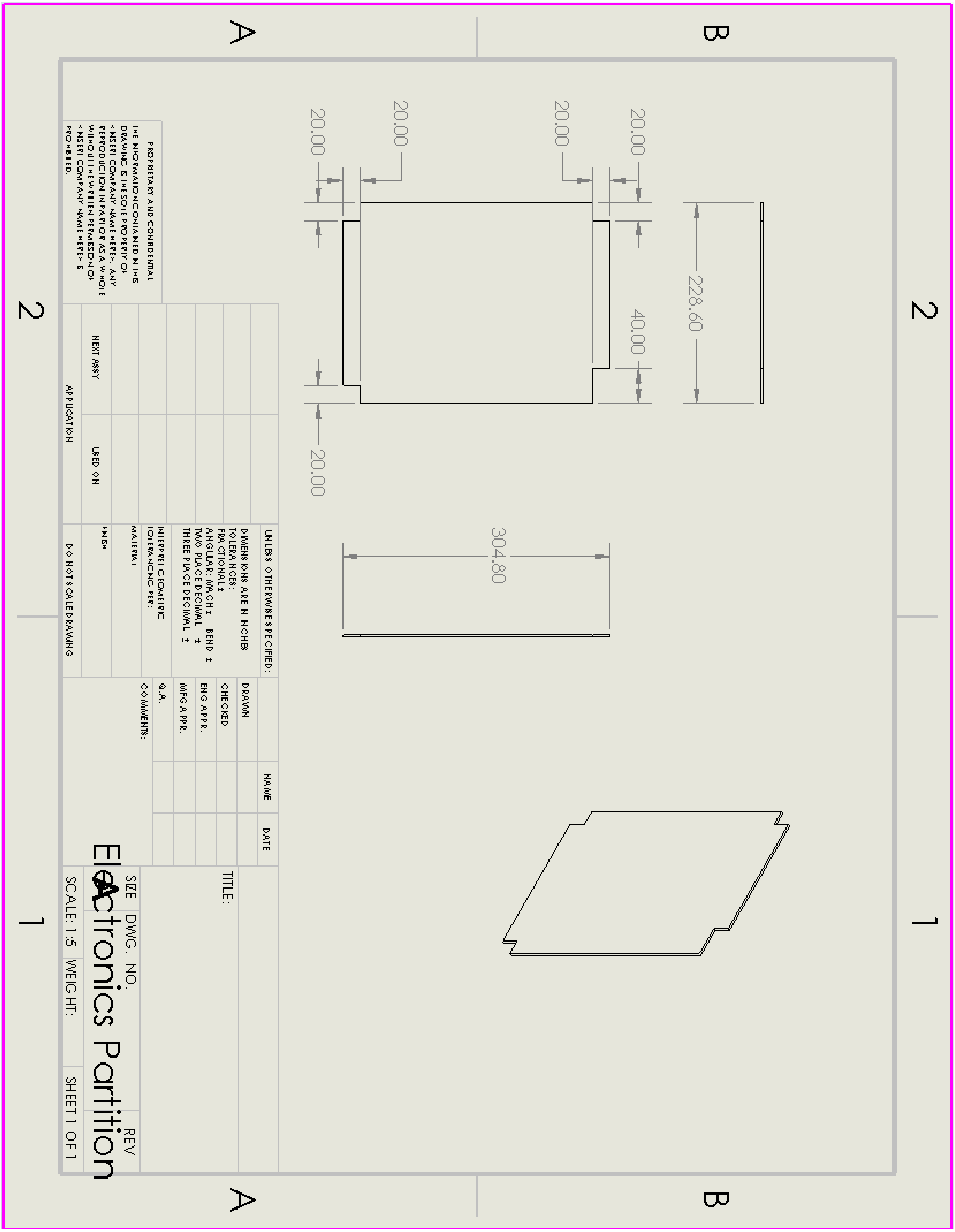

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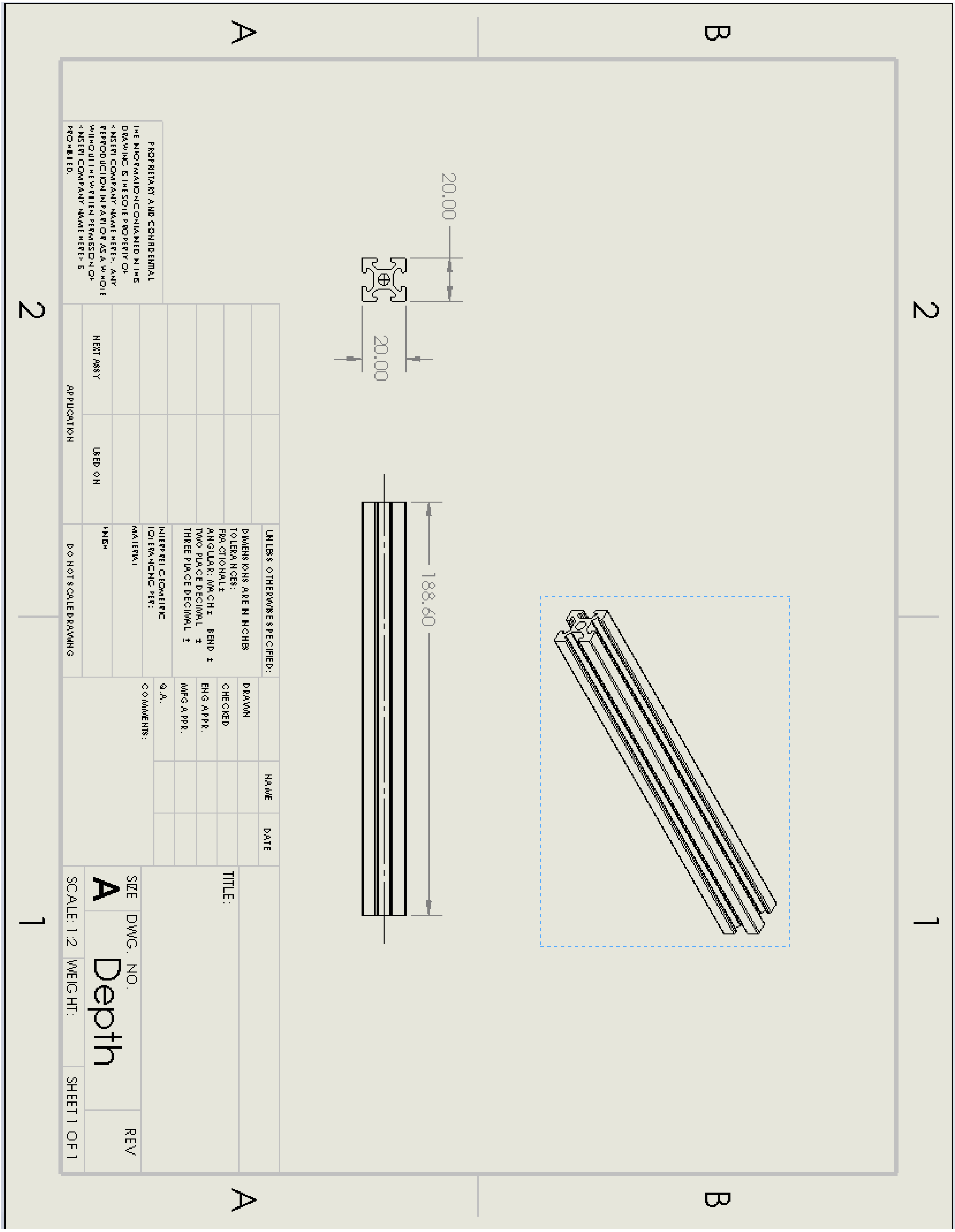
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REFERENCES

[1] "Amazon," Crayola, [Online]. Available: https://www.amazon.com/CrayolaMakerActivityKidPoweredBatteries/dp/B00KJG6WS4/ref=sr_1_3?s=toysandgames&ie=UTF8&qid=1536597635&sr=13&keywords=crayon+spin+art.

[2] "Amazon," Learning Resources, [Online]. Available: https://www.amazon.com/LearningResourcesPrimaryScienceColor/dp/B00I00NIAG/ref=sr_1_2_sspa?s=toysandgames&ie=UTF8&qid=1536592497&sr=1-2-spons&keywords=color+mixing&psc=1.

[3] "Amazon," Learning Resouces, [Online]. Available: https://www.amazon.com/LearningResourcesMixingLensesPieces/dp/B00ATM1NZA/ref=sr_1_1_sspa?s=toysandgames&ie=UTF8&qid=1536594569&sr=11spons&keywords=color+mixing&psc=1.

[4] L. Hellenberg, "Paint dispensing apparatus". United States Patent US4967938A, 17 07 1989.

[5] L. M. Currie, "Peristaltic pump". United States Patent US3140666A, 11 06 1962.

[6] CPSC, "REQUIREMENTS FOR ELECTRICALLY OPERATED TOYS OR OTHER ELECTRICALLY OPERATED ARTICLES INTENDED FOR USE BY CHILDREN". United States Patent 16 CFR PART 1505, 1 January 2016.

[7] ASTM, "Standard Practice for Labeling Art Materials for Chronic Health Hazards". United States Patent ASTM D4236, 2016.

[8] "Open Anasthesia," IARS, [Online]. Available: www.openanesthesia.org/poiseuilles_law_iv_fluids. [Accessed 11 October 2018].