Fall 2018

Group V: Color Mixer

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Executive Summary

This project was an exercise in product design, modeling, and prototyping. The result of this process was a partially-functional prototype which successfully met two of the three design goals. While paint capacity and dispensation time were satisfied by the design, the consistency of volume dispensed with each button presses was insufficient. There were several issues which resulted in inadequate performance. One of these was a faulty syringe which was significantly more difficult to press down than the other two. The primary issue, however, was the performance of the electronic components. Multiple Arduinos and easy drivers failed throughout the testing process, and limited time and money didn't allow for us to correct these problems.

If we were going to keep working on this project, the main changes would be the electronic components. Installing easy drivers that could supply more current would allow for the motors to put out more torque, and fixing heat sinks to the easy drivers may help prevent them from burning out. We would also need to implement more child-proofing features, since our final prototype was designed to make changing features convenient, not to be completely child-safe.

MEMS 411: MECHANICAL ENGINEERING DESIGN PROJECT
FALL 2018

Color Mixer

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1 INTRODUCTION

The Color-Mixing Station is an educational and interactive device meant for use in science center applications, where young children and adults alike will be able to learn about how the primary colors mix to form new colors. The device consists of 3 syringe reservoirs connected to a backboard with clamps. Each syringe holds a different primary color, red, yellow or blue. The plunger of the syringe is pressed down using a rack. The rack is inserted into a rack holder that is held flush against gear with guide rails. The gears are connected to three separate stepper motors, driven by easy drivers which are connected to Arduinos. The front of the device has three buttons, red, yellow and blue corresponding to each syringe. When the button is pressed the gear rotates a set amount, pushing down on the syringe plunger and dispensing paint through tubes into a cup. A clear acrylic frame is attached to the front of the device with velcro, allowing for easy modification and maintenance. The tubes are fed through an acrylic box where the cup is placed. The acrylic box keeps kids from reaching inside the device and accessing any electrical components. The design should require little maintenance and be easy for kids to operate without much additional guidance.

2 PROBLEM UNDERSTANDING

2.1 BACKGROUND INFORMATION STUDY

2.1.1 Existing Products

Product 1 – Automatic Condiment Dispenser:

a.

Figure 1 Automatic condiment dispenser

b. https://www.wunderbar.com/products/details/condiment-dispensers

c. The Wunder-Bar automatic condiment dispenser was designed so that restaurant owners can choose the amount of product coming out of the dispenser to save cost and avoid unnecessary waste. These machines can dispense a variety of condiments and sauces by pulling down on a handle. Because no electricity or CO2 is used in the design, the dispenser is much less likely than other products to break down or require service. For each nozzle there is an attached 3 gallon condiment bag that rests beneath the level of the counter.

Product 2 - Qualtech Products Automatic Paint Dispenser

a.

Figure 2 Qualtech Products Automatic Paint Dispenser

b. https://www.qualtechproductsindustry.com/products/stir-dispersion-milling/automatic-paint-dispenser/
c. This product is able to match, dispense and mix paint. Using a touchscreen to select a color, the machine matches that color and dispenses the correct amount of primary colors to create the desired color. The design is comprised of up to 16 paint reservoirs which can be mixed together to create a desired color combination. The machine allows for both automatic and manual refilling of paint and automatic and manual mixing after the paint is dispensed. On this system the mixing process can take anywhere between 1 and 20 minutes. The design is constructed to be user friendly and dispense highly accurate amounts of paint each time, as well as be able to accurately repeat past mixed colors.

Product 3 - Oceanpower DMA 16 Automatic Paint Dispenser

a.

Figure 3 Ocean Power DMA 16 Paint Dispenser

b. https://www.alibaba.com/product-detail/automatic-colorant-dispenser-tinting-machine-of_60374003816.html?s=p

c. The Oceanpower DMA 16 is a product that uses water-based colorants to dispense, tint, and mix paint. This machine works by connecting with any computer that runs a software that is provided by the company to check the color code, get distinct quantities of different colorants, and then dispense the mixed color automatically. It can contain 16 canisters of different colorants, with each canister having up to 2L of volume. Due to its modular design, the DMA 16 can be run independently and at a low cost, and with the intelligent color software on the PC it Is simple to use and operate. This product is also highly accurate and durable, making it a very good choice for a paint shop or distributor.

2.1.2 Patents

Liquid Mixer for mixing nail polish

a. CA2912556A1
b. No pictures given
c. This patent has two major components: a software part, and a hardware part. To begin, the user selects a color shade from the user interface in the software by either writing RGB code color or by choosing from a preset color list. The hardware will then mix the chosen color shade by using valves to drop paint from 5 different containers that contain the 5 basic colors (cyan, magenta, yellow, black and white). There are an additional two containers: one for glitter, and one for matte liquid. The valves that drop the paint are controlled by an Arduino microcontroller board. The paint is then mixed in a small plastic cup by a mixing stick which is rotated by a DC motor controlled by the Arduino.

Paint sample mixing and vending machine

a. US20130111849A1
b.

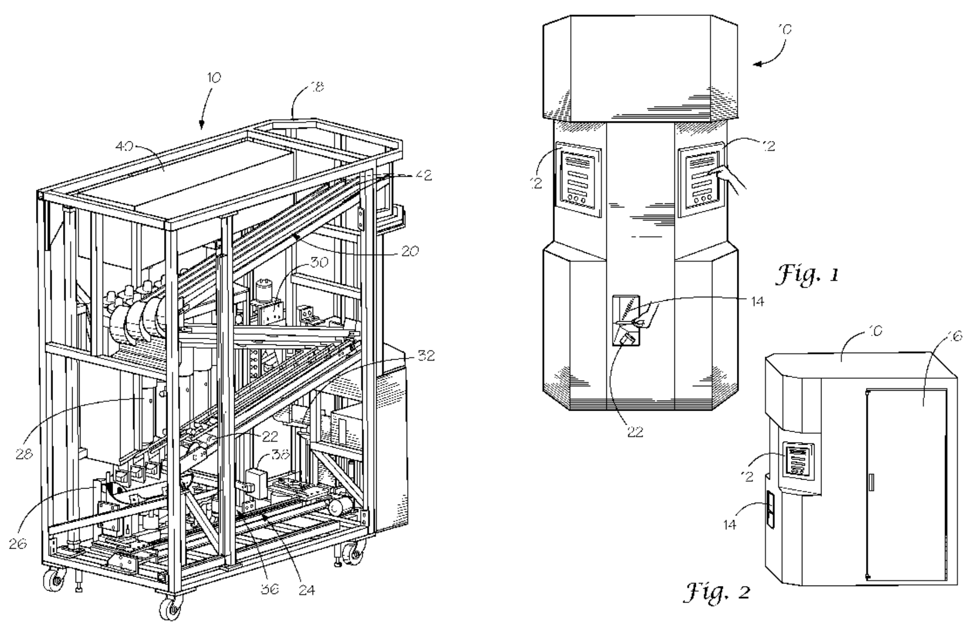


Figure 4 Paint sample mixing and vending machine

c. This apparatus has an inventory that holds a large amount of paint containers with a removable cap. Each container has a base paint solution that is later used to mix with a variety of colorant paint solutions to create a custom paint color. To operate, a user selects the color that they want through a user interface. After a color selection, paint containers are dispensed from the inventory section onto a shuttle unit that delivers the containers to a capping unit for both removal and attachment of the cap. The paint container is then shuttled to a colorant dispensing unit where the colorant paint solutions are injected into the base solution to provide the custom color. The container is then returned to the capping unit to reattach the cap, and then delivered to a shaker unit where the container is vigorously shaken to mix the paint solutions to achieve a single uniform color. Lastly, the container is then ejected for delivery to the customer through a delivery chute.

2.1.3 Standards and codes

a. ASTM F963-17: Standard Consumer Safety Specification for Toy Safety
b. This standard dictates the specification our color mixer must meet as it is intended to be an interactive learning device for children. Everything, including the paint will have to be nontoxic, free of small parts and sharp edges, and be safely secured to whatever it is mounted on especially since it is intended for ages 5+. This device would also have to be tested by a third party to ensure its safety.

a. DSF/FPREN 62115: Electric Toy Safety
b. This toy standard looks more specifically at the electric components of our color mixing device. This standard details requirements surrounding circuity and materials used with electric equipment. This standard might influence our device if we choose to have it operated by something like Arduino as it would likely require it being enclosed and the wires safely stored.

2.2 USER NEEDS

2.2.1 Table 1: Customer Needs

Question	Customer Statement	Interpreted Need	Importance
Does this product need to be portable?	It can be portable but that is not a necessary design requirement	Should be able to exist as standalone setup in science center	1
What is the targeted age range?	5-15yo but any age should be able to operate and enjoy the device	Device and all components should be safe for children and be easy to operate	5
Should colors be created based on input or output?	It is fine either way, however ideally the user can create any color in the rainbow. The design should be able to produce a minimum of 10 colors.	Freedom of color choice	3
How interactive should this design be?	This should be very interactive and educational. A transparent casing around the device would be nice.	Educational and interactive	5
How long should this design last?	About 10 years	The design should be durable	4
How large should this machine be?	The machine should be no larger than a standard doorway. If it is small enough to fit on a table that would be ideal	Ideally the device should be on a table	2
How long should the device be used before requiring maintence	The device should be able to be operated a minimum of 30 times before it needs to be cleaned or paint cartridges need to be replaced. Ideally the paint should last until the end of the day.	The device should be easy to clean and maintain	4

Table 1: Customer Needs Table

2.2.2 Table 2: Interpreted Customer Needs

Need Number	Need	Importance
1	Should be able to exist as standalone setup in science center	1
2	Device and all components should be safe for children and be easy to operate	5
3	Freedom of color choice	3
4	Educational and interactive	5
5	The design should be durable	4
6	Ideally the device should be on a table	2
7	The device should be easy to clean and maintain	4

Table 2: Interpreted Customer Needs

2.3 DESIGN METRICS

2.3.1 Table 3: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1,6	Total weight	kg	<15	<10
2	1	Total volume	m^3	<2	<1
3	2	Minimum age	integer	>5	>3
4	3	Number of colors	integer	>10	infinite
5	4	Rating of "entertainment" by class focus group	avg. score	>3/5	>4/5
6	5	Casing thickness	mm	3	5
7	7	Number of uses	integer	30	100

Table 3: Target Specifications

2.4 PROJECT MANAGEMENT

Date	24	1	8	15	22	29	5	12	19	26	3
Concept Selection	■	■									
Create Parts List		■									
Concept Embodiment Due			X								
Start Assembling Dispensing Mech.			■								
PoC Prototype Demo				X							

Start Assembling button Housing											
Create Paint Container Support											
Design Refinement Due						X					
Middle Structure/3dPrint											
Assemble Structure											
Working Prototype Demo								X			
Fix Electrical Issues											
ERB Summary Page Due									X		
Acquire acrylic, other materials											
Cut, assemble frame											
Final Presentation/Report due											X

Table 4: Gantt Chart

3 CONCEPT GENERATION

3.1 MOCKUP PROTOTYPE

After successfully completing our mockup, it quickly became clear that the general shape and design of our mockup was something that we wanted our final design to closely resemble. Additionally, the mockup brought up questions within our group on how we wanted to orient the base upon which our paint reservoirs, and possibly servo motors, would be established. We also agreed that the general size of the mockup was approximately the minimum size that we wanted our final product to be, since it was just large enough to fit every theoretical component inside. For our final design, we would want a little more room and leeway.

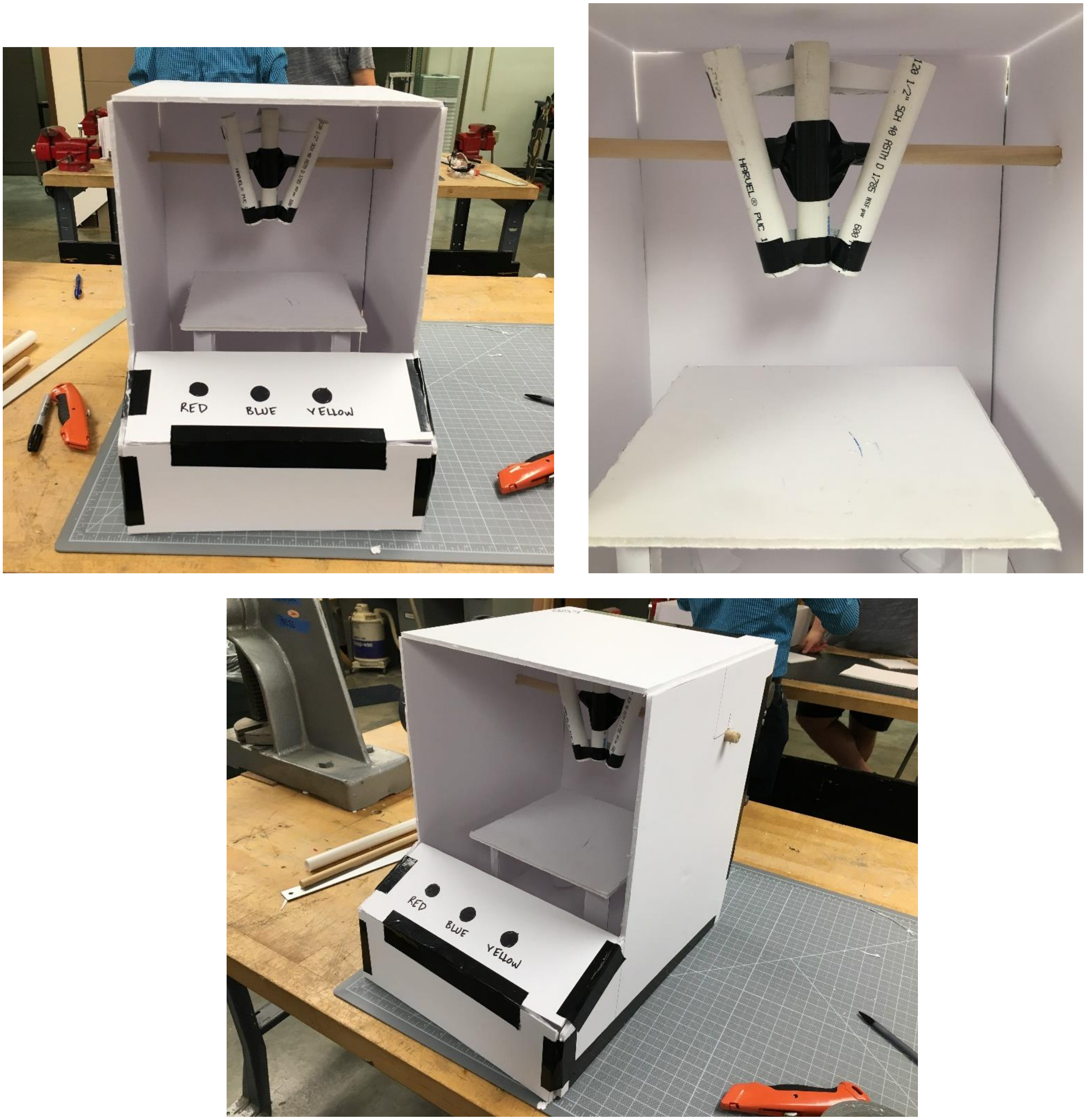


Figure 5: Color Mixer Mockup Photos

3.2 FUNCTIONAL DECOMPOSITION

3.2.1 Function Tree

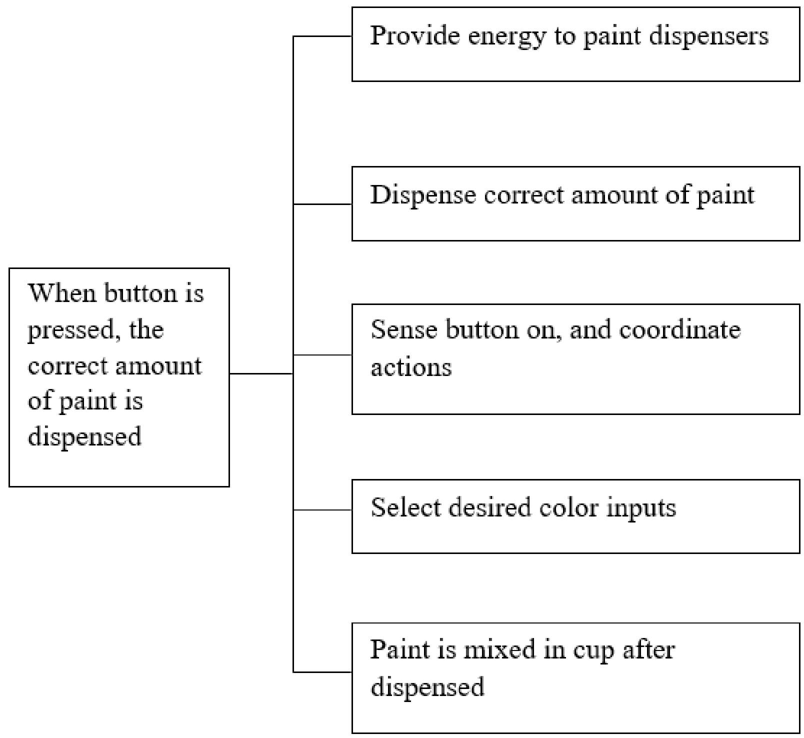


Figure 6: Color Mixer Function Tree

3.2.2 Morphological chart

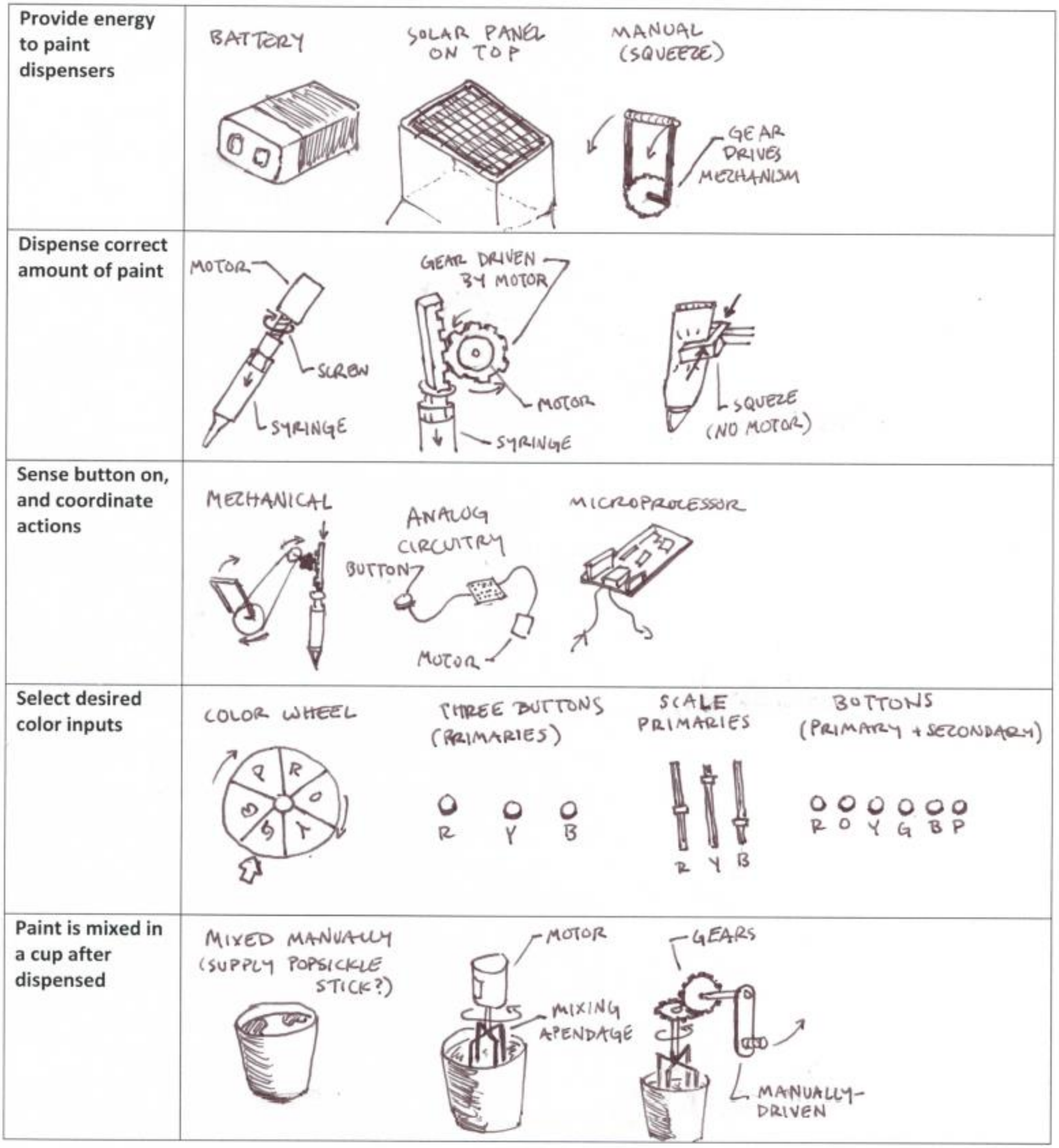


Figure 7: Color Mixer Morphological Chart

3.3 ALTERNATIVE DESIGN CONCEPTS

Concept Name: Manual Color Mixer

Group Member: Kate Baskin

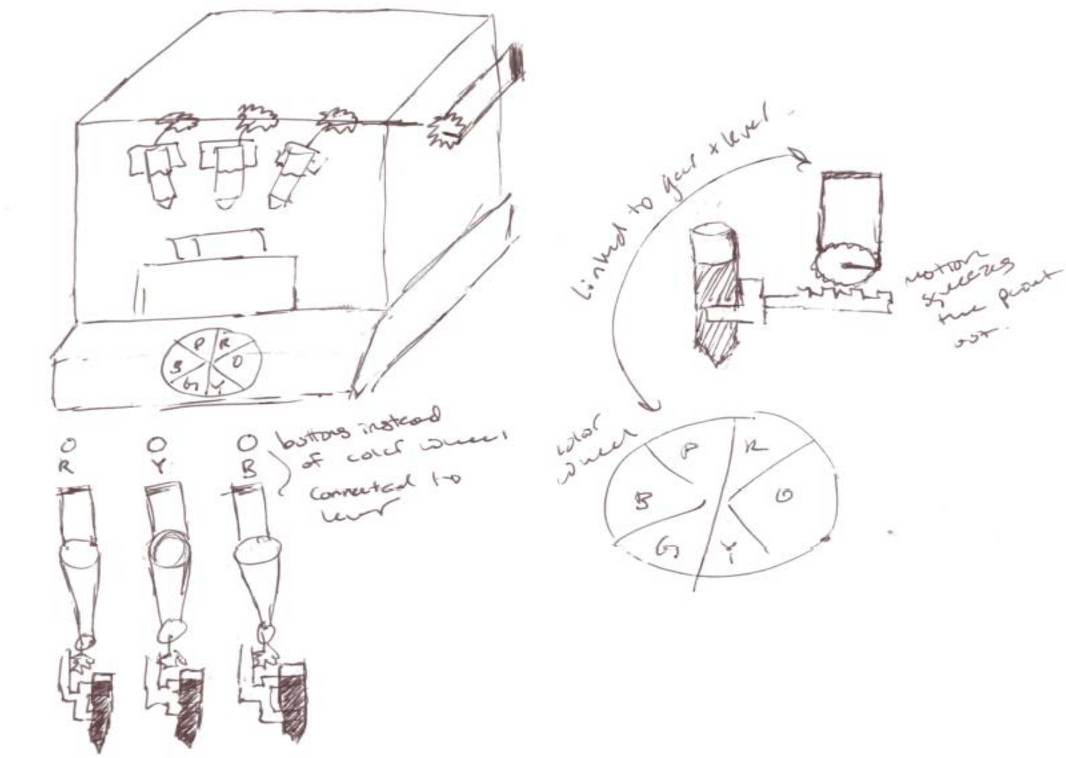


Figure 8: Preliminary Sketches of Manual Color Mixer

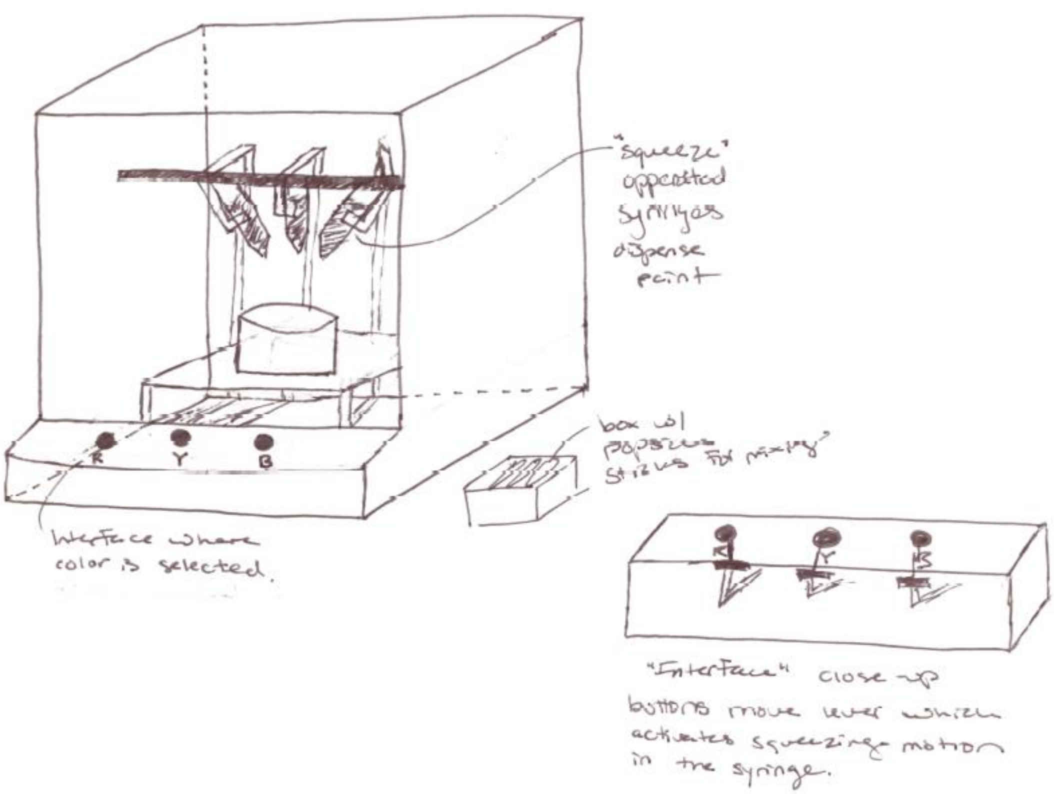


Figure 9: Final sketches of manual Color Mixer

Description: An interface with buttons allows for the selection of the three different primary colors. When a button is pressed a lever is activated which creates a squeezing motion in the arm grip around the paint filled tubes. This motion dispenses the correct amount of paint into a cup below which is then manually mixed with a provided popsicle stick.

Solutions:

1. Unit provides energy manually to dispenser
2. Unit uses a squeezing mechanism to dispense paint
3. Mechanically senses button press
4. Color selected from three primary buttons
5. Paint is manually mixed after dispense

Concept Name: Primary Color Mixer

Group Member: Andy Johnston

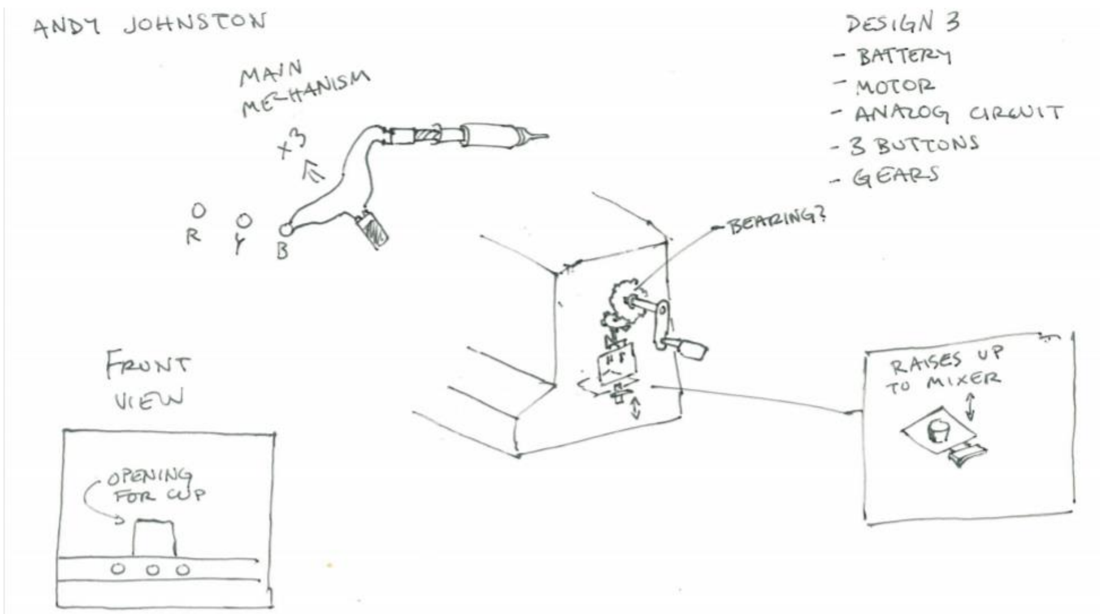


Figure 10: Preliminary sketches of Primary Color Mixer

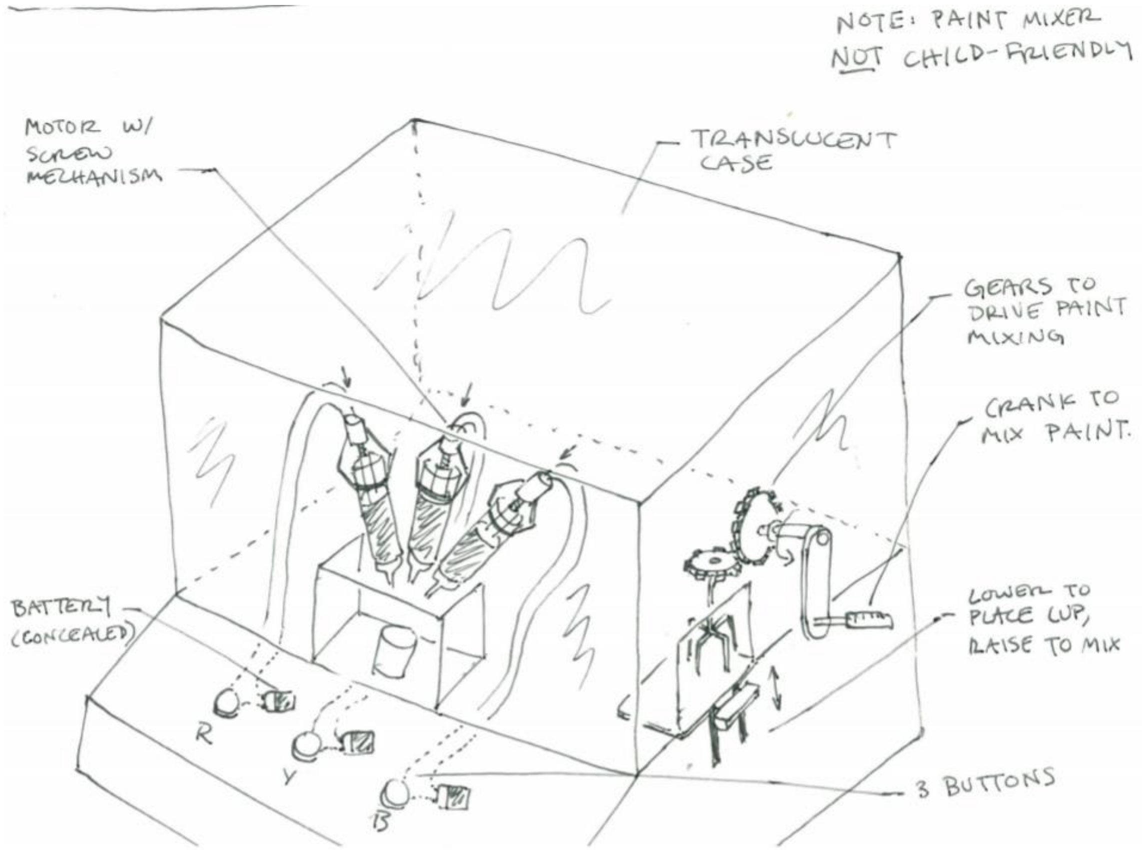


Figure 11: Final sketches of Primary Color Mixer

Description: In this design, the user is able to press a button representing one of the three primary colors. For as long as the user holds the button, a motor powered by a battery turns a screw mechanism that compresses a syringe plunger resulting in the dispensing of the corresponding color. The unmixed paint collects in a small cup, and that cup is then taken to a manually-operated mixing station on the side of the machine. There will be an opening for the user to place their cup on a platform that can be manually raised so that a mixing head contacts the paint. From this point the user can crank a handle to rotate the mixing head and stir the paint.

Solutions:

1. Battery
2. Motor
3. Analog Circuit
4. 3 Buttons
5. Gears

Concept Name: "Scaling, Self-mixing Color Mixer"
Group Member: Mark Livshin

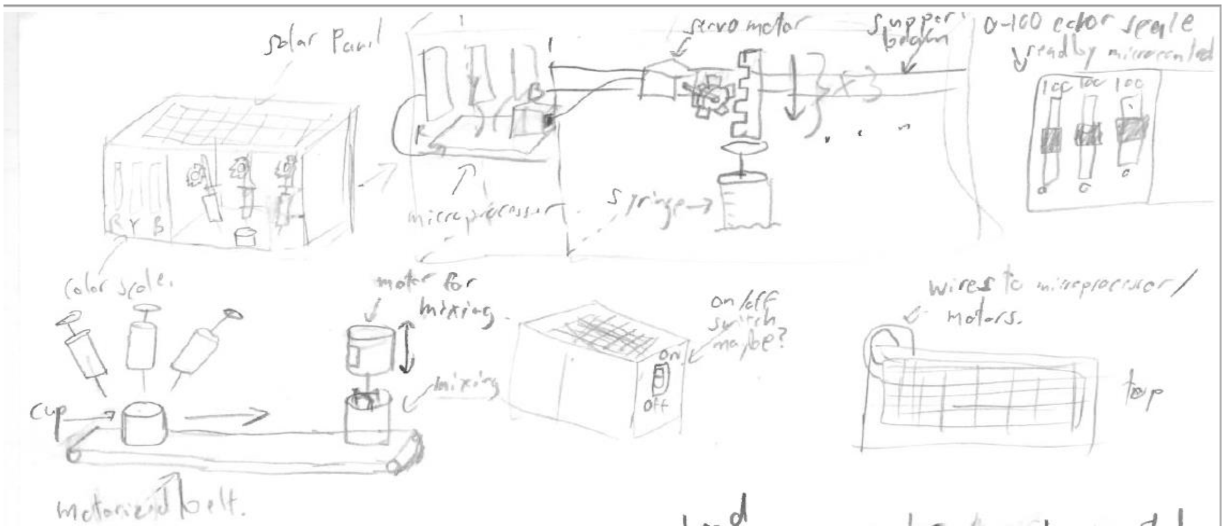


Figure 12: Preliminary sketches of Scaling, Self-mixing Color Mixer

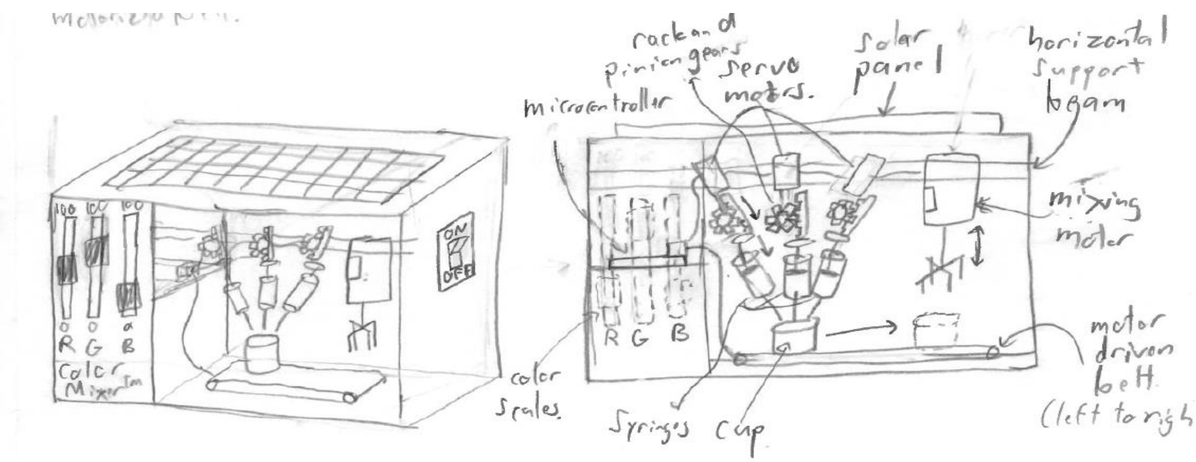


Figure 13: Final Sketches of Scaling, Self-mixing Color Mixer

Description: A user inputs their desired combination of each color using the color scale and then turns on the machine, using the on-off button, to begin the process. A microcontroller then moves three different servo motors that drive rack and pinion gears that, in turn, push down on syringes that dispense the chosen amounts of red, yellow, or blue paint into a cup. The microcontroller then tells the motor driven belt on the bottom to move to the right until the cup is under the mixing motor. The mixing motor, which is also driven by the microcontroller, then pushes down with the mixing prongs to mix the paint. The prongs are then lifted to allow the user to take the cup out of the machine.

Solutions:

1. Solar Powered
2. Gear Driven
3. Microprocessor
4. Scale Primaries
5. Motor driven

4 CONCEPT SELECTION

4.1 SELECTION CRITERIA

	Educational	Interactive	Portable	Cleanliness	Ease of Assembly	Child Proof	Row Total	Weight Value	Weight (%)
Educational	**1.00**	0.33	9.00	1.00	3.00	0.14	14.48	0.17	16.59%
Interactive	3.00	**1.00**	9.00	3.00	5.00	0.33	21.33	0.24	24.45%
Portable	0.11	0.11	**1.00**	0.11	0.14	0.11	1.59	0.02	1.82%
Cleanliness	1.00	0.33	9.00	**1.00**	3.00	0.33	14.67	0.17	16.81%
Ease of assembly	0.33	0.20	7.00	0.33	**1.00**	0.33	9.20	0.11	10.54%
Child proof	7.00	3.00	9.00	3.00	3.00	**1.00**	26.00	0.30	29.79%
						Column Total:	**87.26**	**1.00**	**100%**

Table 5: Analytical Hierarchy Process

4.2 CONCEPT EVALUATION

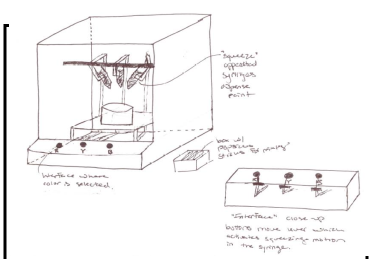
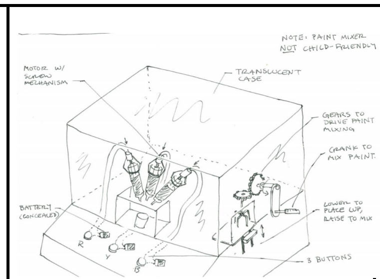
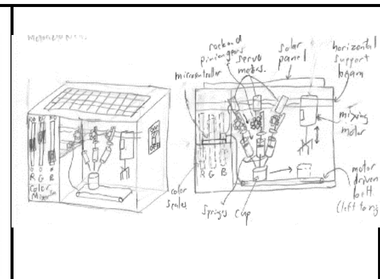
		Alternative Design Concepts					
							
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Educational	16.59	4	0.66	3	0.50	2	0.33
Interactive	24.45	3	0.73	5	1.22	2	0.49
Portable	1.82	3	0.05	3	0.05	3	0.05
Cleanliness	16.81	4	0.67	3	0.50	3	0.50
Ease of Assembly	10.54	2	0.21	3	0.32	1	0.11
Child-Proof	29.79	4	1.19	2	0.60	3	0.89
	Total score	**3.527**		**3.191**		**2.379**	
	Rank	**1**		**2**		**3**	

Table 6: Weighted Scoring Matric

4.3 EVALUATION RESULTS

Our analytical hierarchy process turned out as expected. From early design stages we determined that safety was the most important so it was not a surprise to see child proof have the highest ranking, at about 30%, of all the selection criteria. Interactive was ranked second highest of our selected criteria. This was also an expected result since the goal of this design is to be an interactive tool for children. Educational and cleanliness were weighted third highest of our selection criteria followed by ease of assembly and lastly portability. Applying these results to our alternative design concepts helped us select a concept through the weighted scoring matrix. This table determined the first design ranked the highest according to our selection criteria. This design is well contained. It does not have any loose parts or opening that kids to put their hands into making it child proof. Additionally it has a simple and interactive interface and has parts that could be easily disassembled and cleaned.

4.4 ENGINEERING MODELS/RELATIONSHIPS

Model 1: Tipping Force

a.

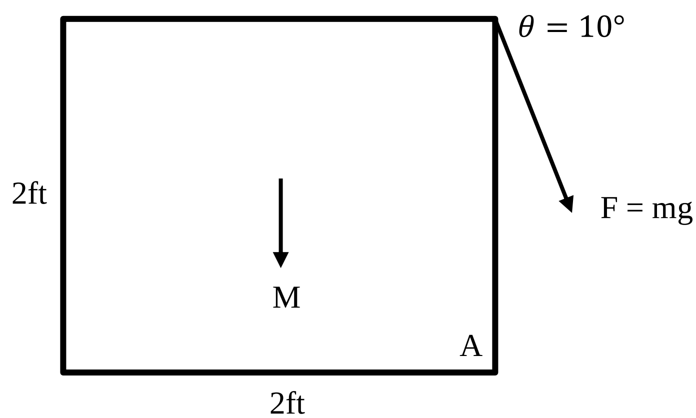


Figure 14: Tipping Model

This model is designed to determine the minimum mass of the color mixing device such that it does not tip over. To calculate this mass it is assumed that a child hangs off the edge of the device generating a force at an angle like shown above.

Assume angle of $\theta = 10°$

Mass of child: $F = 90lbs$

Take moment around corner A

$$1ft(M) = 2ft(\sin(10))(90lbs)$$

$$M = 31.25lbs$$

b. This model helps us to determine the mass that our device must be. Since safety is our priority with the color mixer it is important, any potential for the device to tip needs to be addressed. According to this model the mass of the device must be at least 31 lbs. In reality it would probably be less since it could be bolted to the table.

Model 2: Volume of dispensed paint

a.

$$Volume = \frac{(\#\ Rotations)(A)}{T.P.I.}$$

Volume – Volume of dispensed paint
Rotations – The number of motor rotations
A – Cross-sectional area of paint container
T.P.I. – Threads per inch

b. This equation is useful because it allows our team to decide how many turns of the motor would result in an appropriate amount of paint being dispensed. It will also allow us to calculate the number of button presses a given primary color can receive before running out of paint.

Model 3: Paint reservoir model

a. Assuming Each Container/Syringe is going to be used a minimum of 30 times a day, dispensing approximately 2ml of paint per button press.
   So Approximate size of container:
   Number of Uses Per Day X Amount dispensed per use = 30 * 2ml = 60ml
   To account for any unforeseen variability in our calculations we need to include a "factor of safety" so that there is still enough paint for a single day.
   F.o.S. = Maximum amount uses per day/ Assumed minimum number of uses = 2
   So:
   2*60ml = 120ml = Volume of Each Container
b. This model helps us determine the volume of the paint reservoirs around which we can determine the size of the rest of the model and design. Since portability is not a concern, we can afford to have large reservoirs. Because children are a wildly variable factor, and can skew the results of many designs, we decided to include a factor of safety of two so that if the children decide to wildly press buttons often and at random, there would be enough paint.

5 CONCEPT EMBODIMENT

5.1 INITIAL EMBODIMENT

This section of the report displays CAD embodiments of our Color Mixing station.

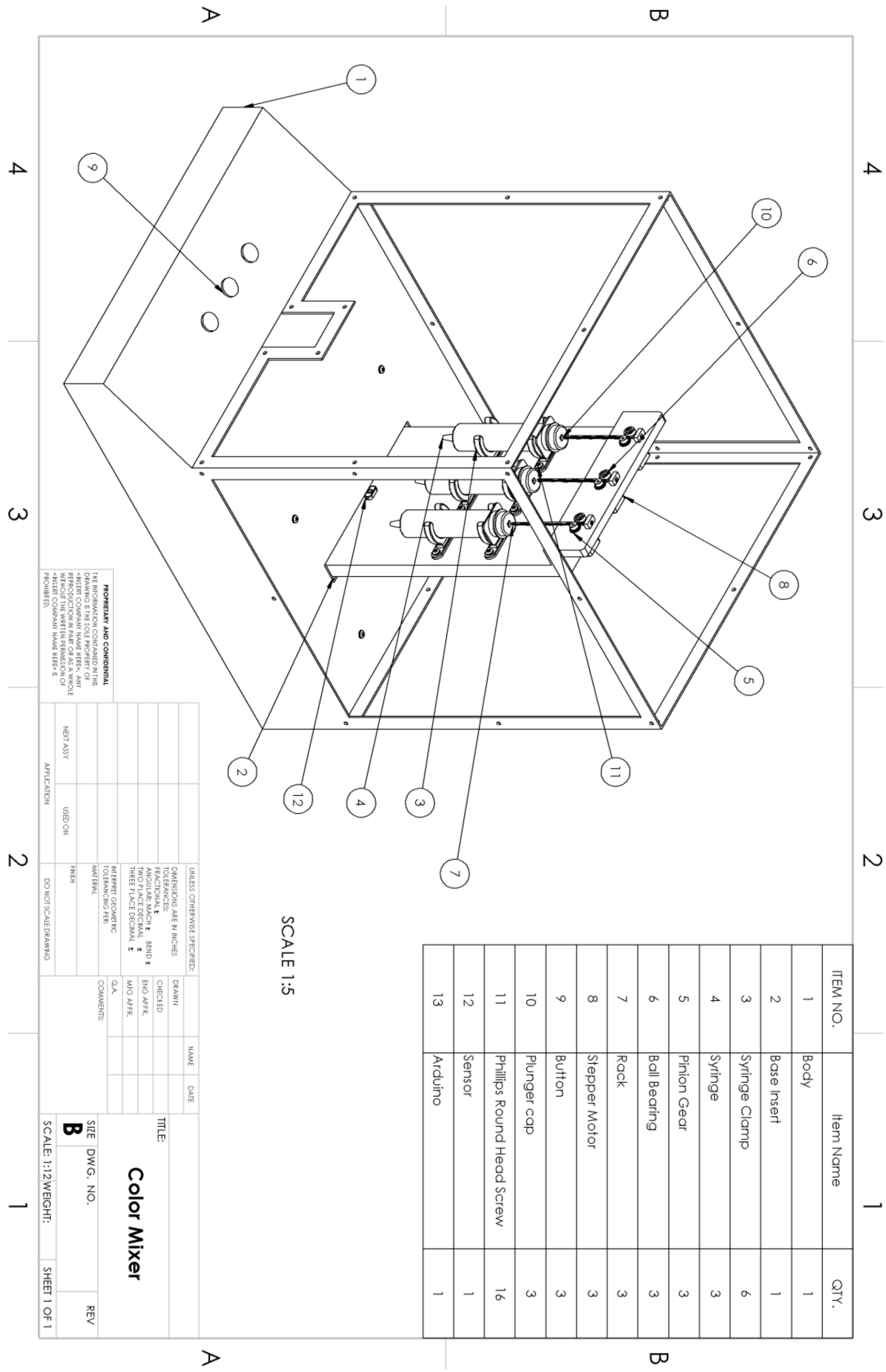


Figure 15: Color Mixer CAD embodiment with BOM and balloon

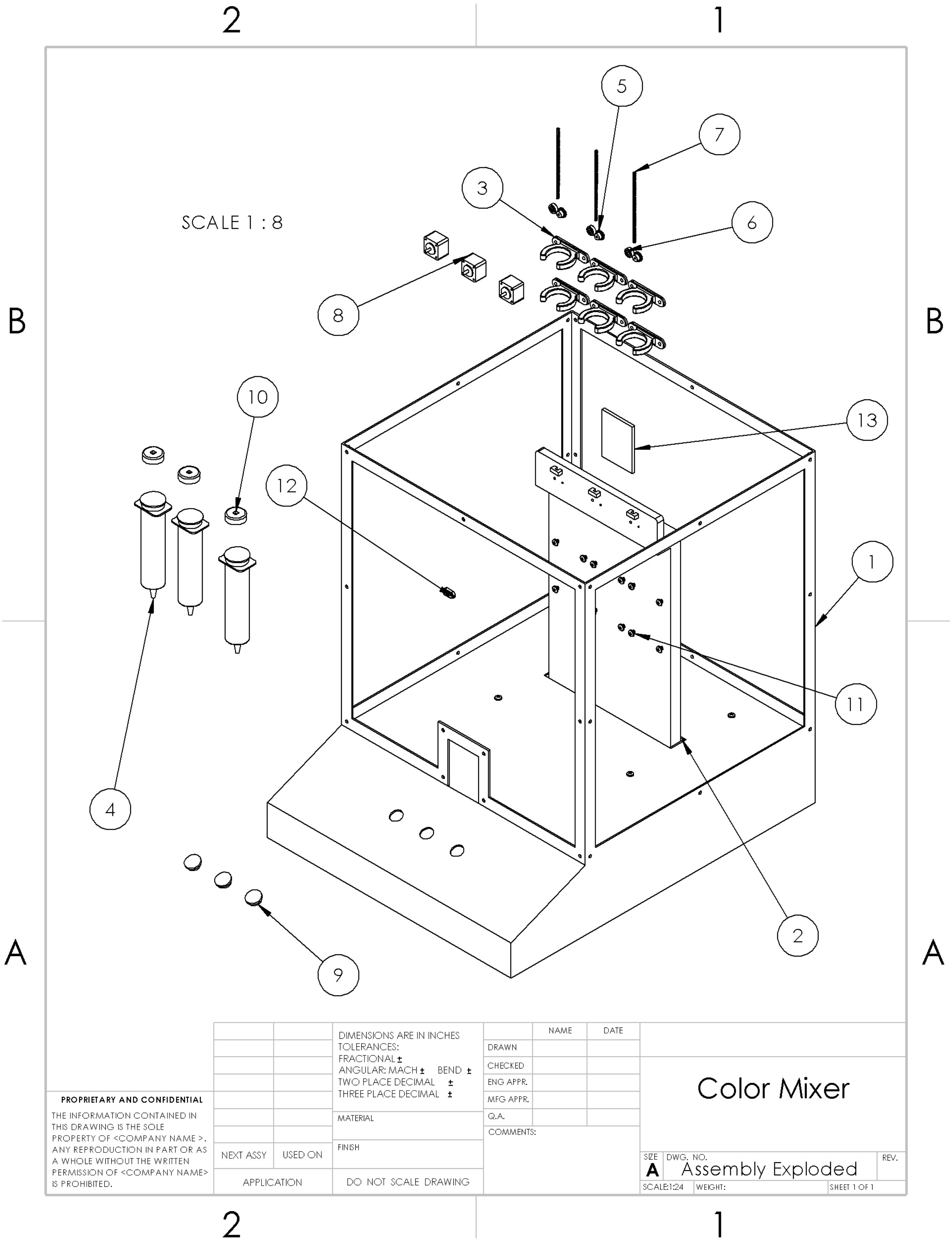


Figure 16: Color Mixer CAD embodiment exploded view with balloons

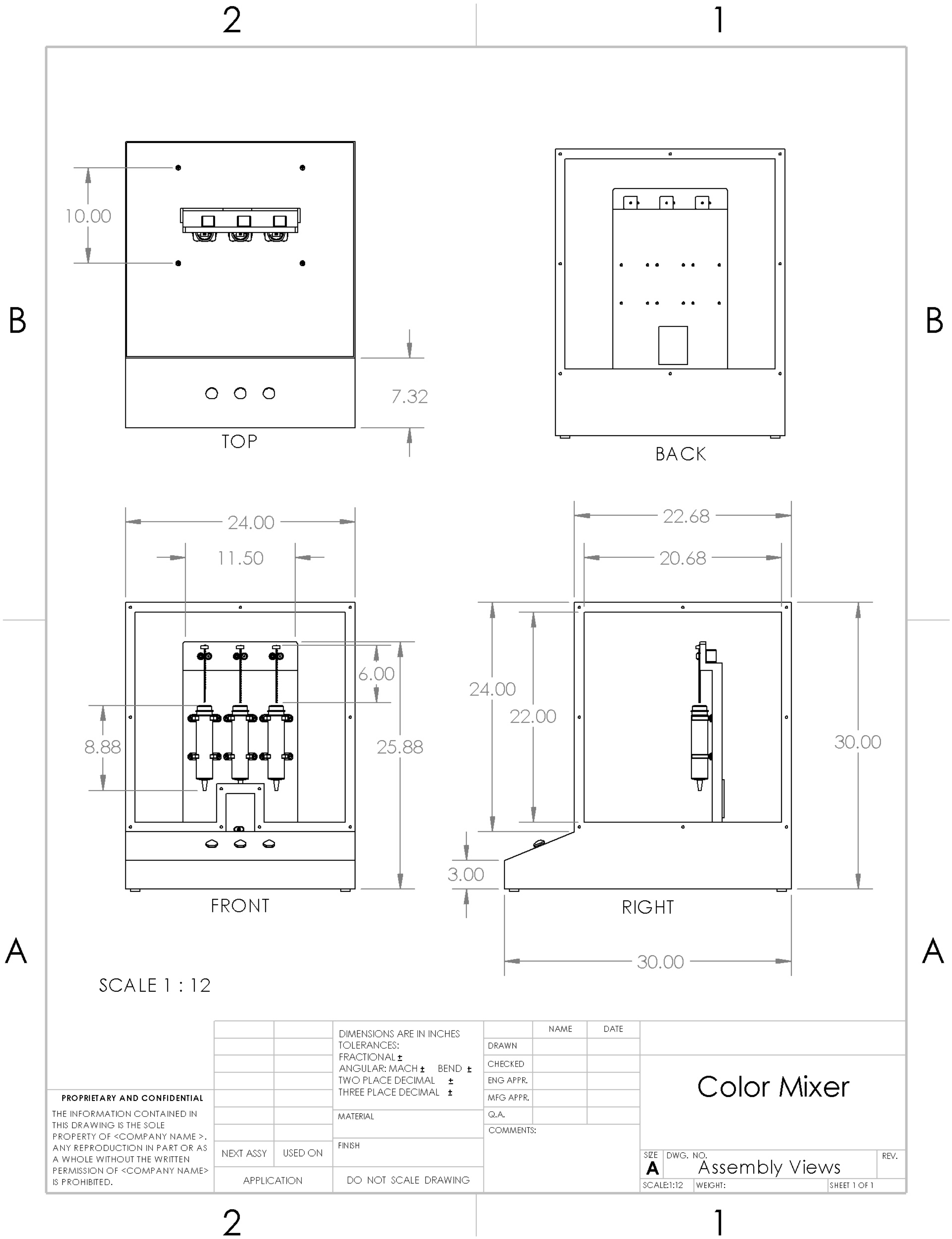


Figure 17: Color Mixer CAD embodiment top, front, back and side views with basic dimensions

Figure 17: Color Mixer CAD embodiment top, front, back and side views with basic dimensions

An initial parts list for our proof of concept prototype (POC) is shown below in the form of a cost accounting workbook.

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
1	Gear Rack	McMaster	57655K61	Plastic, 48 Pitch	$5.82	1	$5.82
2	Round Bore Gear	McMaster	57655K18	Plastic, 48 Pitch	$7.06	1	$7.06
3	Syringe	Amazon	B0779PYZR4	3 pack 150 mL, clear	$12.99	1	$12.99
4	Arduino	Amazon	EL-KIT-003	Starter Kit	$34.99	1	$34.99
5	Paint	Amazon	10795433	Tempera Paint	$9.34	1	$9.34
6	Stepper Motor	tbd	tbd	tbd		1	$0.00
Total:							$70.20

Table 7: Initial Parts cost accounting workbook

5.2 PROOF-OF-CONCEPT

5.2.1 Prototype performance goals

In order to test our prototype we had to come up with testable goals to evaluate the prototype. These goals need to be quantifiable and able to easily test in a studio setting.

Our prototype performance goals are outlined as follows:

1. Can complete 30 cycles without refilling, where each cycle is defined as 6 button press cups.
2. Dispenses correct amount of paint for each button press. This will be tested with 5 cups for a $\pm$10% weight difference.
3. Can create a finished color in a given time. The maximum time it should take to dispense a cup (6 button presses) is 15 seconds.

These goals were selected to ensure that the device is user friendly and educational for children as well as being easy to maintain. The syringe should not need to be refilled often and thus should be able to last for 30 cycles, with each cycle consisting of 6 button presses. In order for the device to be educational, it need to create consistent colors and thus dispense a consistent amount of paint which will be tested between 5 cups for a $\pm$10% weight difference. Children do not have long attention spans, so in order for the device to be user friendly we determined that it should not take longer than 15 seconds to dispense a cup of paint.

5.2.2 Design Rationale

In Section 4.4 we developed 3 different engineering models that influence design components. In this section we will look at how these models influenced design considerations and purchased parts.

The first model which again is shown here was used to determine the necessary weight of the color mixing station to prevent a child from tipping it.

Model 1: Tipping Force

a.

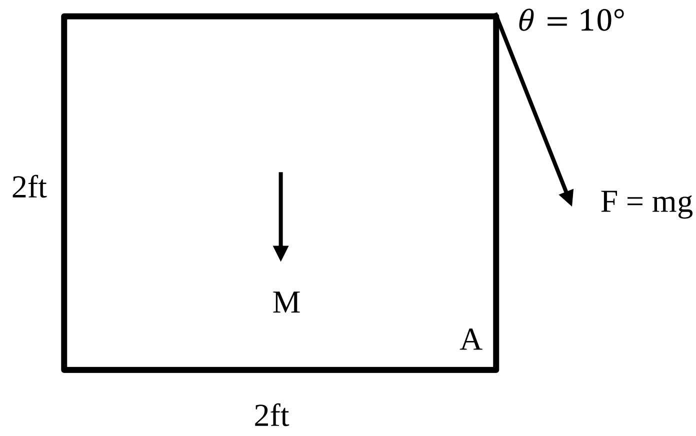


Figure 18: Tipping Force Model

This model is designed to determine the minimum mass of the color mixing device such that it does not tip over. To calculate this mass it is assumed that a child hangs off the edge of the device generating a force at an angle like shown above.

Assume angle of $\theta = 10°$

Mass of child: $F = 90lbs$

Take moment around corner A

$$1ft(M) = 2ft(\sin(10))(90lbs)$$

$$M = 31.25lbs$$

We plan on using sheet metal and acrylic to build our frame. This combined with the all of the internal mechanics would be very unlikely to reach 31lbs in weight thus we needed to find an alternative to ensure the safety of the device. To address this we added bolts to the bottom of our base. The bolts would go into the table on which the station is standing. This would prevent children from being able to move the device from the table.

The second model determined the volume of paint dispensed and is shown below.

Model 2: Volume of dispensed paint

$$Volume = \frac{(\#\ Rotations)(A)}{Pitch}$$

Volume – Volume of dispensed paint
Rotations – The number of motor rotations
A – Cross-sectional area of paint container
Pitch – Threads per inch [t.p.i.]

In this form, this model is no longer useful to us since this model was based upon a screw dispensing syringe system. Since then, we have updated our design to dispense using a rack and pinon, where the rack pushes down on the syringe plunger to dispense paint. The new equation for volume would be as follows

$$Volume = A(pitch\ dia.)(\pi)\left(\frac{\theta}{2\pi}\right)$$

A – Cross-sectional area [in^2]

Pitch dia. – pitch diameter [in]

θ – rotation of gear

We ordered a gear of pitch diameter .667 in. Knowing that the device must sustain 30 uses, using our 150 mL syringe, and 6 button presses per cup we determined the maximum volume that each button press can dispense.

$$\frac{150mL}{30\, uses\, (6\frac{presses}{use})} = .83\frac{mL}{press}$$

The cross-sectional area of the 150 mL syringe is 2.14 in^2. Using the known pitch diameter and volume of paint we can determine how much the gear must rotate with each button press.

$$\theta = \frac{Volume}{A(pitch\ dia.)(2)} = \frac{.83}{(2.14\, in^2)(.667\, in)(2)} = .291\, radians$$

This model determines that the gear would need to rotate a maximum of approximately .291 radians to dispense the correct amount of paint. This model was applied when choosing rack and pinions to order. We selected a gear and rack with a large pitch. We figured that a large pitch would allow for smoother a more accurate rotation and since .291 radians is not a large rotation accuracy and consistency is a very important design parameter.

The final model, shown below, determines the minimum volume of the syringe needed to last 30 uses.

$$Volume = k(N)(V)$$

K – factor of safety

N – number of uses

V – volume of paint dispensed in each use

Assuming that the syringe will theoretically dispense around 0.5 mL, as this seems like a reasonable value for each button press and will give a substantial amount of paint for the child to mix. Knowing that 6 button presses are used in each use we can assume that V = 3 mL. We assume a factor safety of 2 to ensure that there is enough paint.

$$Volume = 2(30\, uses)\left(3\frac{mL}{use}\right) = 180\, mL$$

This model determined that a reasonable syringe volume is 180 mL. This model was applied to select the proper syringe. The largest syringe we could find was 150 mL which seemed reasonable given the considerable factor of safety that was used to calculate the theoretical 180 mL.

6 WORKING PROTOTYPE

6.1 OVERVIEW

The proof of concept design consisted of a single syringe, rack and pinion system. It was able to dispense consistent amount of paint in an appropriate amount of time. However, some issues did exist with the proof of concept. The support that held the syringe in place allowed for too much movement of the syringe and did not hold it securely. The guiderail used to hold the rack in place was too big and did not hold the rack securely causing the system to wobble. The motor that we used was not high enough torque and the rotation of the gear needed to be adjusted to meet our first performance goal.

The working prototype consisted of three syringes and rack and pinion systems. The working prototype corrected many of the issues that we saw in our proof of concept. To fix the wobble of the syringe, 3D printed clamps were bolted to the backboard. Guide rails and rack holders were also 3D printer to hold the rack in place and prevent wobbling while holding the rack flush to the gear. The motor used in the proof of concept was replaced with 3 higher torque Nema 17 motors which are powered by three separate drivers using an Arduino.

In the final design a frame was built around the vertical backboard with the syringes. The front panel of the frame was made from acrylic and is attached with velcro so that it can be easily removed. The base rests on shelves so that the Arduino can be easily accessed and fixed if necessary. Tube were added to the ends of the of the syringes and connected to the acrylic frame dispensing the paint into a concentrated region

6.2 DEMONSTRATION DOCUMENTATION

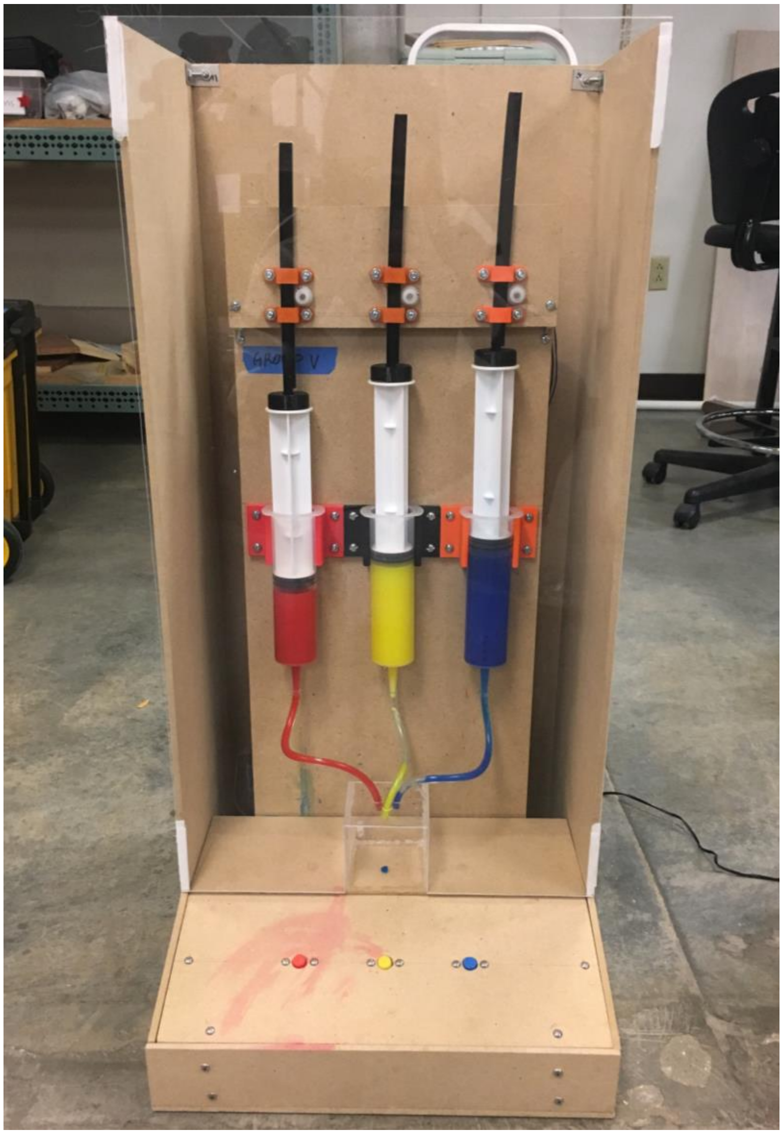


Figure 19: Color Mixer working prototype front view

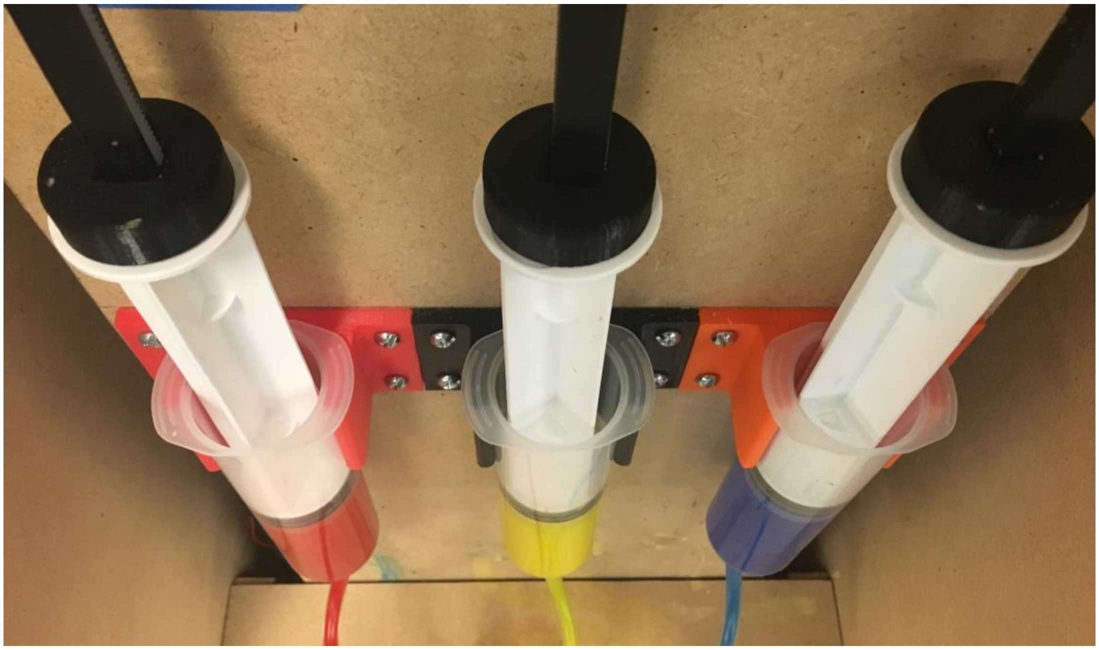


Figure 20: Color Mixer working prototype syringe and plunger caps

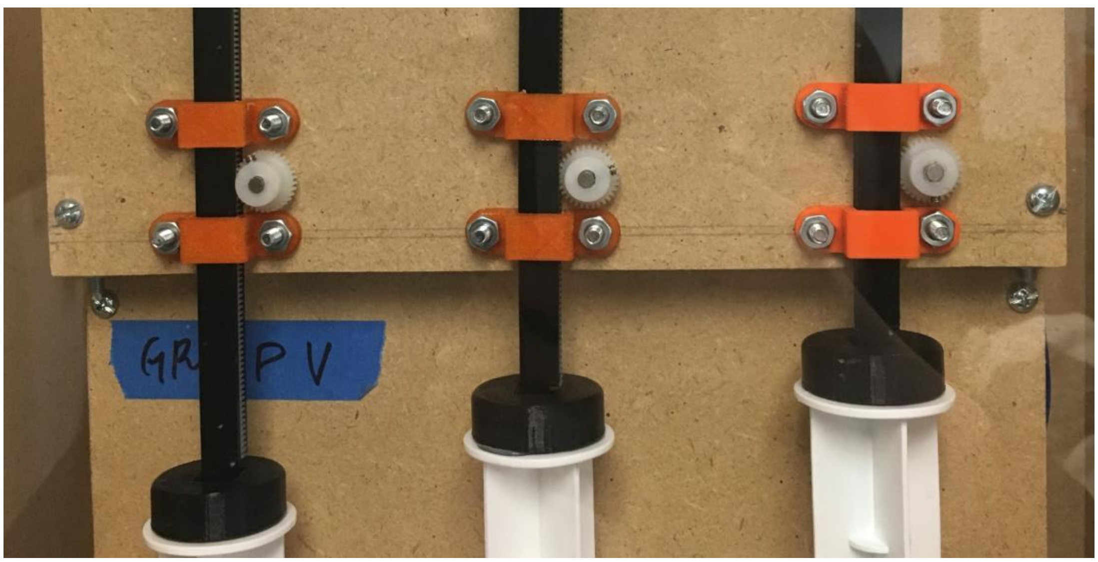


Figure 21: Color Mixer working prototype rack and pinion system with guide rails

6.3 EXPERIMENTAL RESULTS

Our working prototype was easily able to meet the first performance goal. To reiterate this performance goal, the device must be able to complete 30 cycles without refilling, where each cycle is defined as 6 button press cups. Our syringes were able to hold 150 mL of paint. Using the model based design decisions, we determined the maximum rotation of the gear to ensure that the reservoirs were able to last 30 uses. When tested we determined that the syringes held more than enough paint to last 30 uses. There was some discrepancy in the amount the syringes dispensed, but even with these differences, all of the syringes were able to last 30 uses.

The color mixer was unable to meet the second performance goal. To reiterate this performance goal, the device must dispense the correct amount of paint for each button press. This is tested with 5 cups for a $\pm$10% weight difference. All of the syringes dispensed inconsistent amounts of paint for the first handful of button presses. After that initial inconsistency the red and yellow began to dispense consistent volumes of paint. The issue lay with the third syringe which, for an unknown reason, required significantly more force to push down. Additionally, the drivers and Arduino's continuously burnt out. At times only one or two of the motors were able to rotate their respective gears.

The device was able to meet the final performance goal. To reiterate this performance goal, the device must be able to create a finished color in a given time. The maximum time it should take to dispense a cup (6 button presses) is 15 seconds. This performance goal was easily met by our working prototype. As soon as the buttons are released, they were able to be pushed again, rotating the gear. This feature allowed a cup of paint (6 button presses), to easily be dispensed within 15 seconds. Realistically, it could be done in less than 6 seconds. For the device to consistently work the drivers would need to be replaced and have heat sinks added to them.

7 DESIGN REFINEMENT

7.1 FEM STRESS/DEFLECTION ANALYSIS

In this section of the report we examine stresses in our design which might adversely affect the performance and safety. The clamps that hold the syringe in place have significant force applied to the top of them from the outer edge of the syringe. Using FEA we examined the stresses affecting this part and determined how that will influence our design.

a. For this simulation a standard mesh size was used as is provided sufficiently accurate results for this level of simulation. The model was bound at the holes since that is how the clamp is going to be attached to the rest of our design. A downward force of 4 N was applied to the top face of the clamp extension. The accuracy of this load is limited, as it is an estimate based on repeated tests of pushing down the plunger. Additionally, the force applied by the plunger onto the plunger clamp will only act on some regions of the top face, not the entire surface. This is another reason why this simulation isn't entirely accurate. However, considering how the plunger will ideally interact with the clamp, and assuming the 4 N of force is relatively close to the correct value, the analysis seems to be accurate enough to be useful to the project.

b.

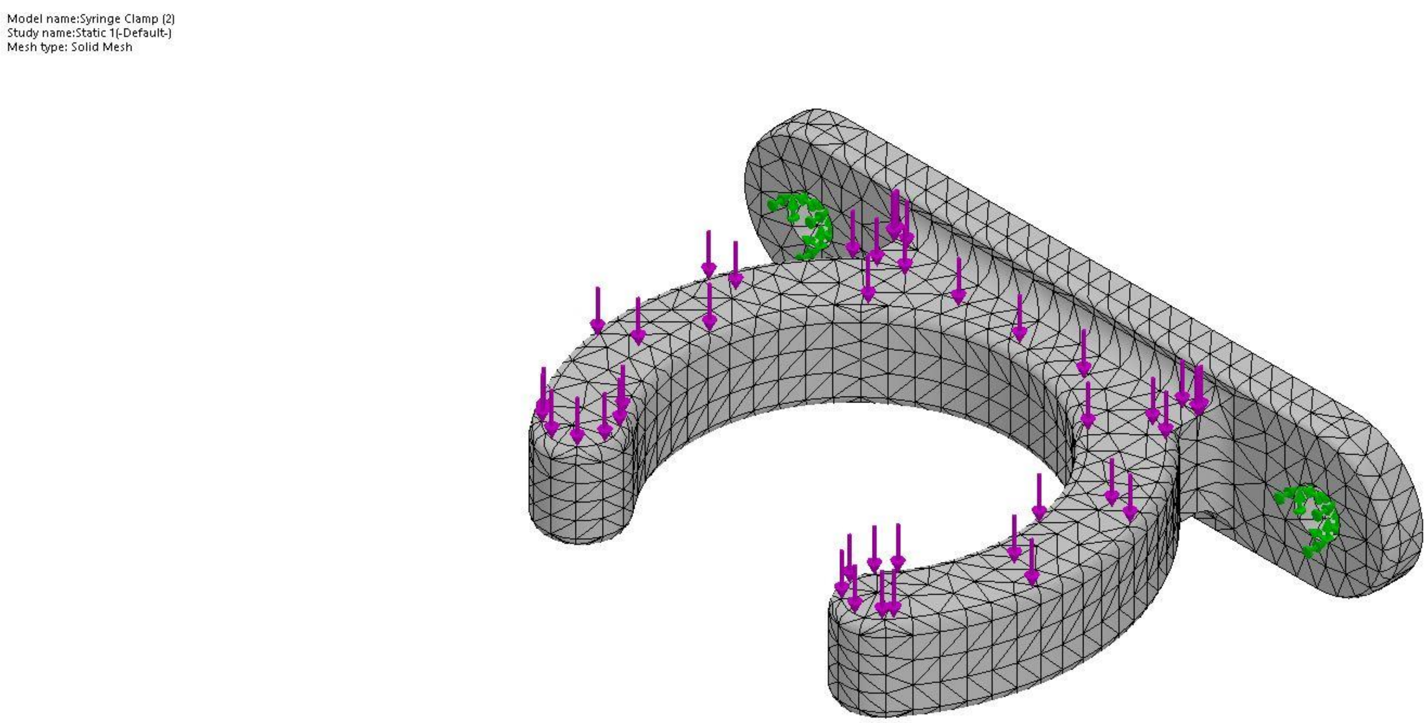


Figure 22: Mesh, loads and boundary conditions on clamping mechanism

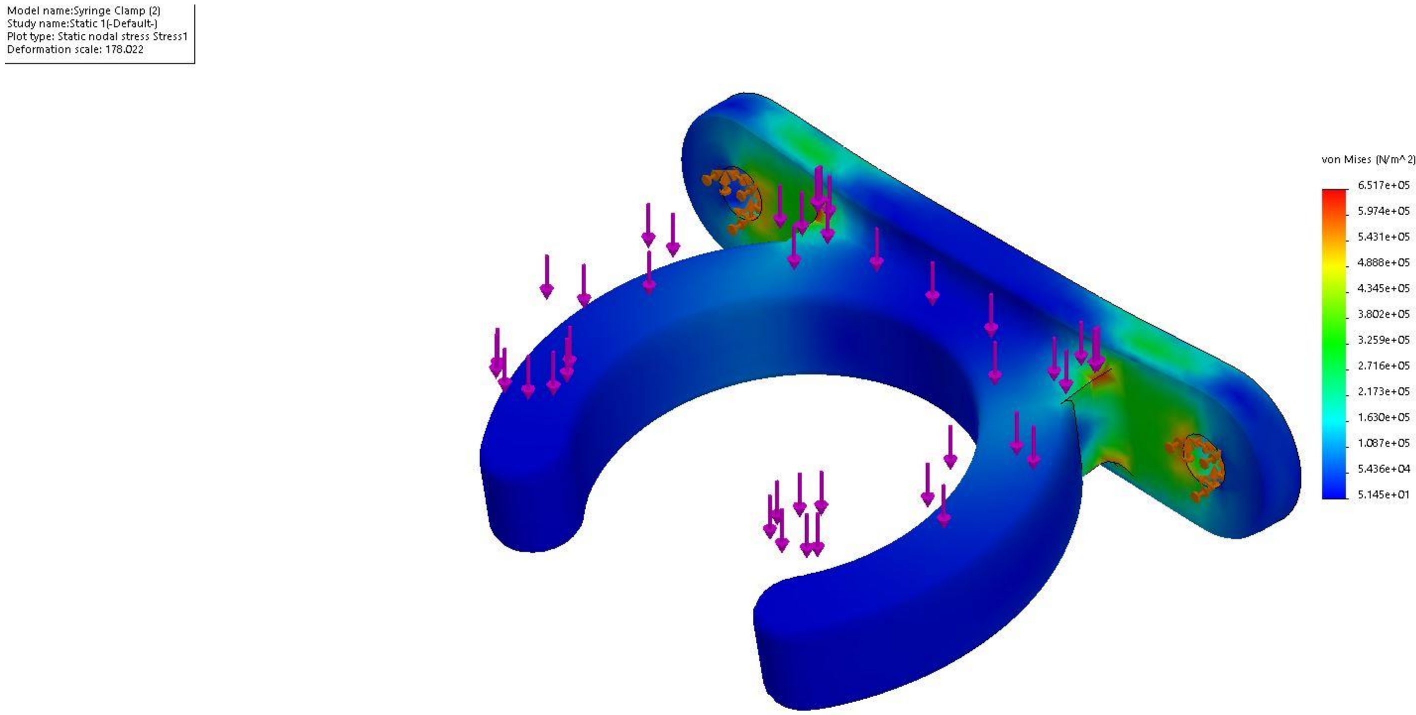


Figure 23: FEA stress analysis of clamping mechanism

c. Results interpretation

Based upon the results of our FEA analysis we were able to calculate a reasonable factor of safety for the clamping component on our device. The Young's modulus for this part is 2.0 GPa. According to our FEA the maximum stress on this part is 651.7 kPa. The factor of safety for this component is calculated as follows and was determined to be 3070.

$$F.S. = \frac{2x10^9}{6.517x10^5} = 3070$$

This is an unnecessarily high factor of safety. A factor of safety closer to 10 would be tolerable. We did not analyze deflection.

7.2 DESIGN FOR SAFETY

In this section we evaluate the ways in which the coloring mixing station might fail as well as any ramifications for the failure. As responsible engineers, we look at ways to improve our design to make it the safest and risk-free it can possibly be. Below outlines risk that we have identified for the color mixing station.

a. Risks associated with our device

Risk Name: Paint spill

Description: Paint could potentially spill or leak from the syringes. This could cause the paint to clog up making it harder to dispense paint. Additionally, spilled paint inside of the color mixing station would not be aesthetically pleasing. This could happen if the button is pressed too often or too many times. We hope that using syringes to dispense will control the amount and mitigate this risk.

Impact: 2 (Mild). Though it is inconvenient, paint spill would be easy to clean up, especially since we are using washable paints.

Likelihood: 3 (Medium). This risk could happen though we hope that using a syringe set up controls the amount of paint being dispensed. Additionally, we plan on setting a limit on how many times the button can be pressed to avoid excess paint spill.

Risk Name: Kids eat the paint
Description: Kids often have a tendency to eat things they should not. Paint presented in a cup could a tempting treat for them. There is little to do to prevent kids from doing this so all we could do is make the paint as safe as possible.
Impact: 2 (Mild). We have chosen non-toxic and washable paint so that worst case the kids might get an upset stomach if they eat too much. Hopefully they will be accompanied by parents who would stop them from eating it.
Likelihood: 4 (High). It is very likely that kids will eat the paint, there is not much to do to stop that.

Risk Name: Sharp corners
Description: Our device will tentatively have a sheet metal frame with acrylic sheets covering it. This presents the risk of sharp corners which users could cut or scrape themselves on. This risk can be prevented by covering the corners to ensure they are not sharp.
Impact: 3 (Moderate). The consequences to the risk would likely be very minor cuts, and even less if we cover the corners as we plan too. This not a detrimental consequence but is significant as we do not want users to be hurt.
Likelihood: 4 (Medium-High). It is pretty likely that a user will cut themselves on the mixing station at some point. Though we plan to mitigate this risk by adding covers to the corners it could still pose a issue.

Risk Name: Electrical components
Description: Electrical components such as Arduino, the stepper motor, driver and loose wires present risk of electric shock. This would be most likely if the motor failed or is wires came loose from the breadboard.
Impact: 4 (Significant). Electrical shock is a significant risk and could result in severe consequences. If the device is placed in a science center and shock occurs users could file lawsuits or complaints as well as be injured.
Likelihood: 2 (Low-Medium). Currently we have to plan all wires and electrical components stores below the device in a storage chamber. Any loose wires of motors will be placed behind the syringe area and will not be within reach of users. These design specifications make the likelihood of electric shock unlikely.

Risk Name: Device instability
Description: There is a risk that the color mixing station could be pushed off or tipped onto the floor. This would require significant force, depending on the eight of the device, which is not determined yet. If the station were to fall it could hit someone causing injury or cost a lot of money to replace. This scenario could occur if a kid grabs onto the edge of the station and it falls over.
Impact: 5 (Catastrophic). The device falling would have a significant impact. It could fall on a user causing significant injury and potential lawsuits. The station would probably break and require complete rebuilding which would be costly.
Likelihood: 1 (Low). Because the impact of this is so severe, we want to minimize the chance that it could ever happen. In our final design we plan to have the station bolted to the table so that it cannot be moved. While testing we will have our design clamped to the table so that it does not fall and break.

b. Heat Map

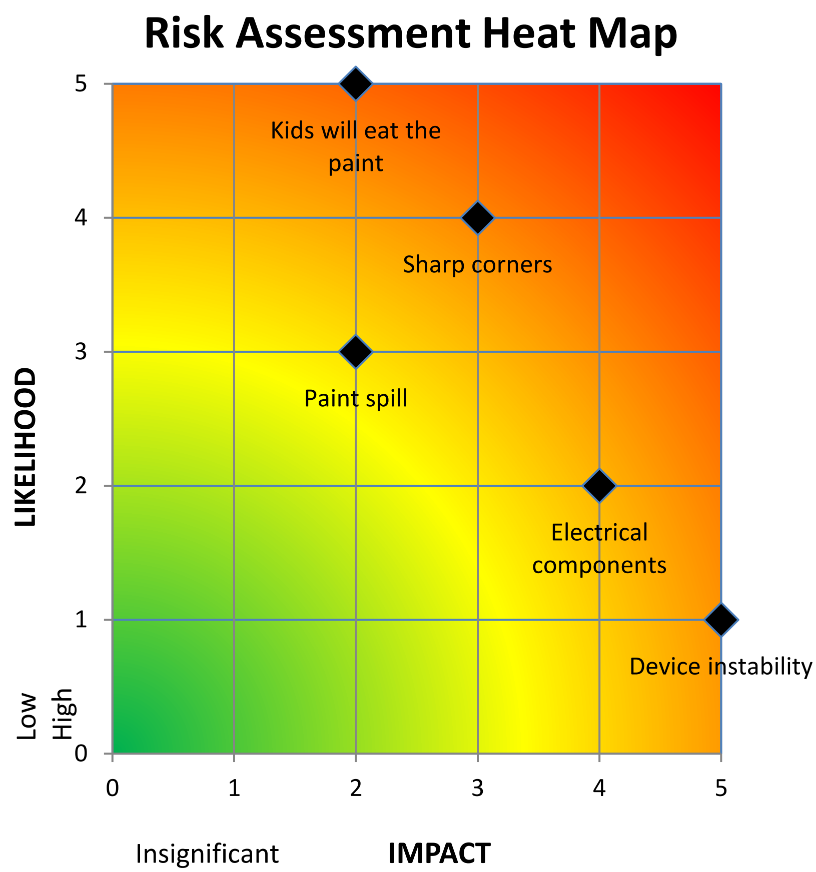


Figure 24: Risk Assessment Heat Map of Color Mixer

c. Risk prioritization

According to the heat map, we should prioritize the issue of sharp corners. After that the electrical components should be prioritized as we can easily modify design to minimize both of those risks. Device instability should be the next priority, followed by paint spilling and keeping the users from ingesting the paint.

7.3 DESIGN FOR MANUFACTURING

In this section of the report we examine the guidelines for making manufacturable parts. Using the draft tool in Solidworks we modified our part to make it more appropriate for manufacturing.

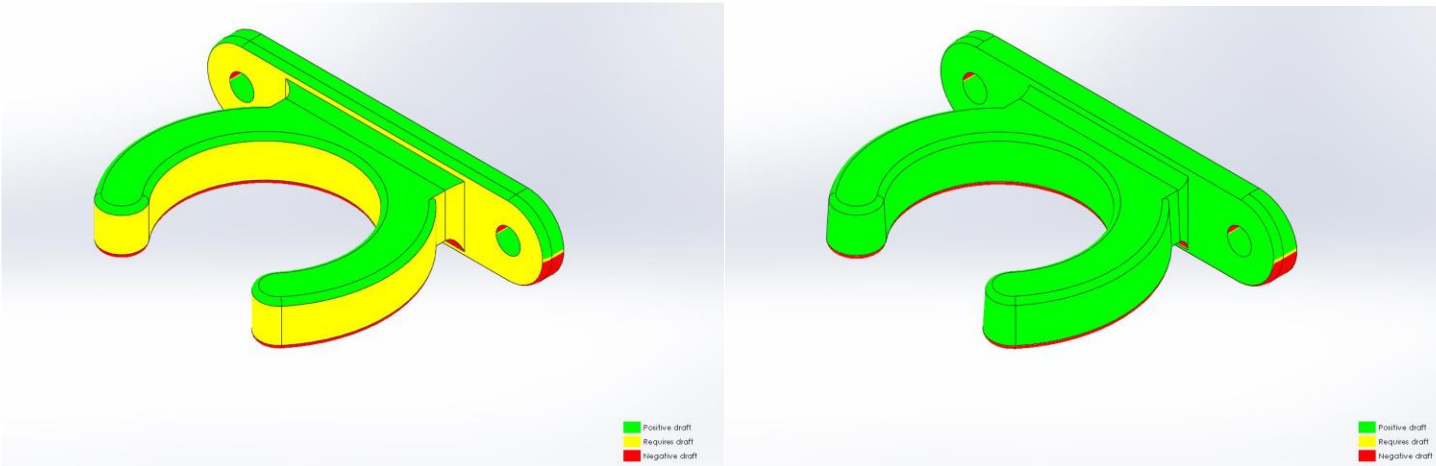


Figure 25: Before and after images from clamping mechanism using Solidworks "Draft Analysis"

Next we examined we used the DFM analysis tool in Solidworks. We analyzed the gear component on the Color Mixing station. We analyzed based on Milling and Injection molding.

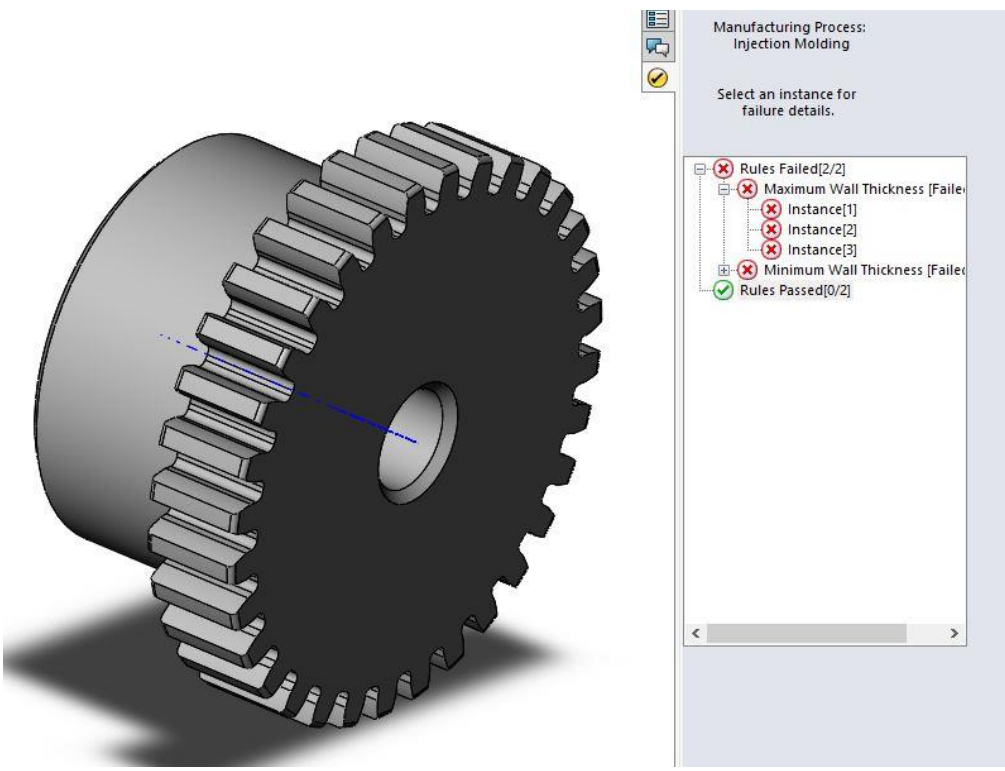


Figure 26: DFM analysis of gear using injection molding

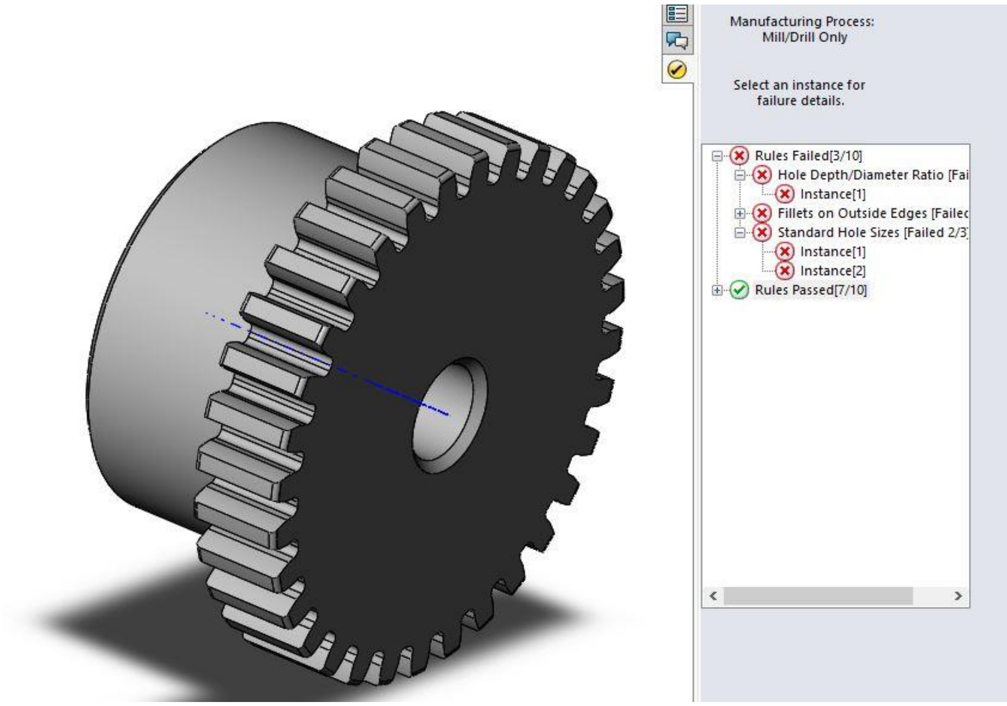


Figure 27: DFM analysis of gear using mills and drills

The analysis showed that both mills/drills and injection molding had failures. The injection molding had 2 failures and passed 0/2 rules. The mills/drills had 3 failures but passed 7/10 rules. It is important to note that in both manufacturing processes not all failures were expanded as they occurred on every tooth of the gear. We determined that while injection molding had less failures in did not pass any rules and thus mills/drills is a better manufacturing method.

7.4 DESIGN FOR USABILITY

In this section we evaluate our project on its usability and determine how these considerations will influence our design.

1. A visual impairment, such as colorblindness would influence the usability of our device. Our device is based on mixing colors and people with an impairment might not be able to tell the difference between the different colors. To accommodate this impairment, we are planning to add a chart on the side of the stand that shows the different color combinations in both color and written form.
2. A hearing impairment would not influence the usability of our device. Sound is not an important aspect of our design since our design is mostly visual. If the user had an impairment they might not able to hear the motor rotate but they would be able to see the paint dispense which is the most important part of the device.
3. Physical impairments would not have much influence on the usability of the device. The device only requires the user to push a button which requires very little force or fine motor skills. It is possible that some users might not even be able to do that but in this case we assume they could ask someone around them for help as there is really nothing more we could incorporate into the device to make it more accessible for those with physical impairments
4. A language impairment could potentially influence the usability and design of our device. Currently we have a plan that would accommodate for this need. Next to the color mixing station we plan to put a chart showing color mixing "recipes". These would be shown with both words and visuals of the colors which would make it easy to follow for someone who could not speak English.
5. A control impairment might influence the design and usability of our device. Depending on how long the color mixing stations take to dispense the paint one might become distracted from the process. To accommodate for this

we are planning to have the station dispense as quickly as possible. Fatigue and medication side effects should not impact the usability of the device.

8 DISCUSSION

8.1 PROJECT DEVELOPMENT AND EVOLUTION

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

The final product remained aligned with the initial product description. The main aspects of the design were decided shortly after learning about the design requirements, and although some tweaks were made throughout the design/build process these aspects remained a part of the final product. We utilized the main components, like the rack and pinion and syringes in both the initial project description and the final project result.

8.1.2 Was the project more or less difficult than expected?

The project was more difficult than anticipated. A relatively simple design was intentionally chosen to account for future difficulties, but even with the lack of complex components this project was not easy. Primarily the electrical side of the project was most challenging, since nobody in the group had any prior knowledge or experience working with Arduinos or motors and we ran into a lot of issues with the Arduino and drivers burning out. Simple assembly also ended up being more time consuming than we initially anticipated.

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

Our group should have spent more time learning about how to wire our motor system. This proved to be the component of the project which had the most issues. Shifting the focus to learning more about the basic electrical equipment would have helped in the long run. Taking attention away from the physical construction of the project would have allowed that to happen. We also should have spent more time on concept generation as our ideas lacked variation.

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

Running the motors consistently was the biggest issue we faced in this project. We figured setting up the circuitry and motors wouldn't be too complex, however a number of recurring issues, like burnt easy drivers and arduinos, proved this to be false. It took longer than expected to assemble the outer frame of the device. A lot of time was spent screwing something in, realizing we had forgotten to drill a hole, unscrewing the whole design and then reassembling. Assembly like this, though mindless, was time consuming.

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

Utilizing pumps instead of syringes likely would have been a better option. The space efficiency of that approach combined with the increased consistency of the pumps could have resulted in a better final project. Using pumps would have also eliminated the issues we ran into with the stepper motors, driver and Arduino. The syringes were not consistent or accurate in the amount of paint they dispensed.

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?

We determined relevant codes and standards by considering the safety and usability of the device. The first standard we selected was ATSM F963: Standard consumer safety specification for toy safety. Because our device targets children having it meet these standards was very important. This code influenced our choice of paint. We purposefully chose a non-toxic and washable paint, in compliance with this standard, so that kids would not get sick if they ate the paint. The second standard we chose was the DSF/FPREN 62115: Electric Toy Safety standard. Though it is unlikely we met this standard, it influenced our design decision as we kept all electrical components covered and out of reach.

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

Our group was not missing any critical information when evaluating concepts. At that point it was hard to know how things would work and play out once we started building but we had all the necessary information. When generating concepts, we were not missing information, but it does seem like we did not think outside of the box enough and all of our ideas were very similar. Had we varied our designs more our evaluation might have been different as well.

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

We do not feel that any particular engineering analyses would have helped to guide our design, however, it would have been helpful to have more knowledge about Arduino and microprocessors going into the course. The electrical components seemed to be the backbone behind most, if not all projects, and that was the first time in our academic careers that many of us had seen Arduino. It was difficult to navigate the stepper library and power our motors without burning out the drivers or Arduinos.

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

If we were able to redo the course the main change would be to spend more time and be more creative with concept generation. The concepts that we generated were all pretty similar and then when it came time to concept selection we felt pretty limited in what we had to choose from. We would probably end up going with a pump design instead of our current one. Additionally, we should have researched more about Arduino, stepper drivers and compatible motors. We ended up burning through a lot of driver and Arduinos because we were unfamiliar with the stepper library and circuitry. Ideally, we would find a better alternative to the syringe since the syringes we used did not dispense equal or consistent amounts of paint.

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

Given more time and money we would upgrade the drivers that burnt out and invest in heat sinks. We would also modify the syringe component of our design since there was variation between syringes and they did not seem very reliable. We might replace the current plunger syringe design with a screw syringe. If the plunger part was "screwed" down instead of pushed we think this might dispense consistent and equal amounts of paint. If budget allowed, the sides and back of the device would be made from acrylic instead of wood for a more aesthetically pleasing look.

8.3 TEAM ORGANIZTION

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

We feel that our team members skills were complementary. Mark focused on the Arduino and electronic aspects of the project as he was both interested and wanted to learn more about it. Andy and Kate focused on making the CAD, models, 3D printing and assembly of the prototype. They worked more hands on with the frame and mechanics of the device while Mark focused on the electronics. It would have been helpful to have someone with more knowledge of Arduino as it was difficult for everyone to figure out since we had never been exposed to it before.

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

None of our group is very interested in design as a career path and while we enjoyed this project, we would not say it inspired us to design other projects. Maybe, if we were given more time and a larger budget we would feel differently.

APPENDIX A – COST ACCOUNTING WORKSHEET

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
1	Gear Rack	McMaster	57655K61	Plastic, 48 Pitch	$5.82	4	$23.28
2	Round Bore Gear	McMaster	57655K18	Plastic, 48 Pitch	$7.06	4	$28.24
3	Syringe	Amazon	B0779PYZR4	3 pack 150 mL, clear	$12.99	1	$12.99
4	Arduino	Amazon	EL-KIT-003	Starter Kit	$34.99	1	$34.99
5	Paint	Amazon	10795433	Tempera Paint	$9.34	1	$9.34
6	Adafruit Nema-17 Stepper Motor	MicroCenter	647095	200 Steps/Revolution	$14.30	1	$14.30
7	12V Power Supply	MicroCenter	825935	Cyberpow	$24.21	1	$24.21
8	Nema 17 Motors	Amazon	202465-US1	59 N.cm torque	$34.99	1	$34.99
9	Easy Drivers	Amazon	CYT1072	A3967 Driver	$9.99	1	$9.99
10	Arduino	Amazon	A000066	Arduino R3	$19.97	1	$19.97
12	Wood and Acrylic	Home Depot	--	1/2" medium desnity fiberboard and acrylic	$44.34	1	$44.34
Total:							$256.64

Table 8: Final Cost Accounting Worksheet

APPENDIX B – FINAL DESIGN DOCUMENTATION

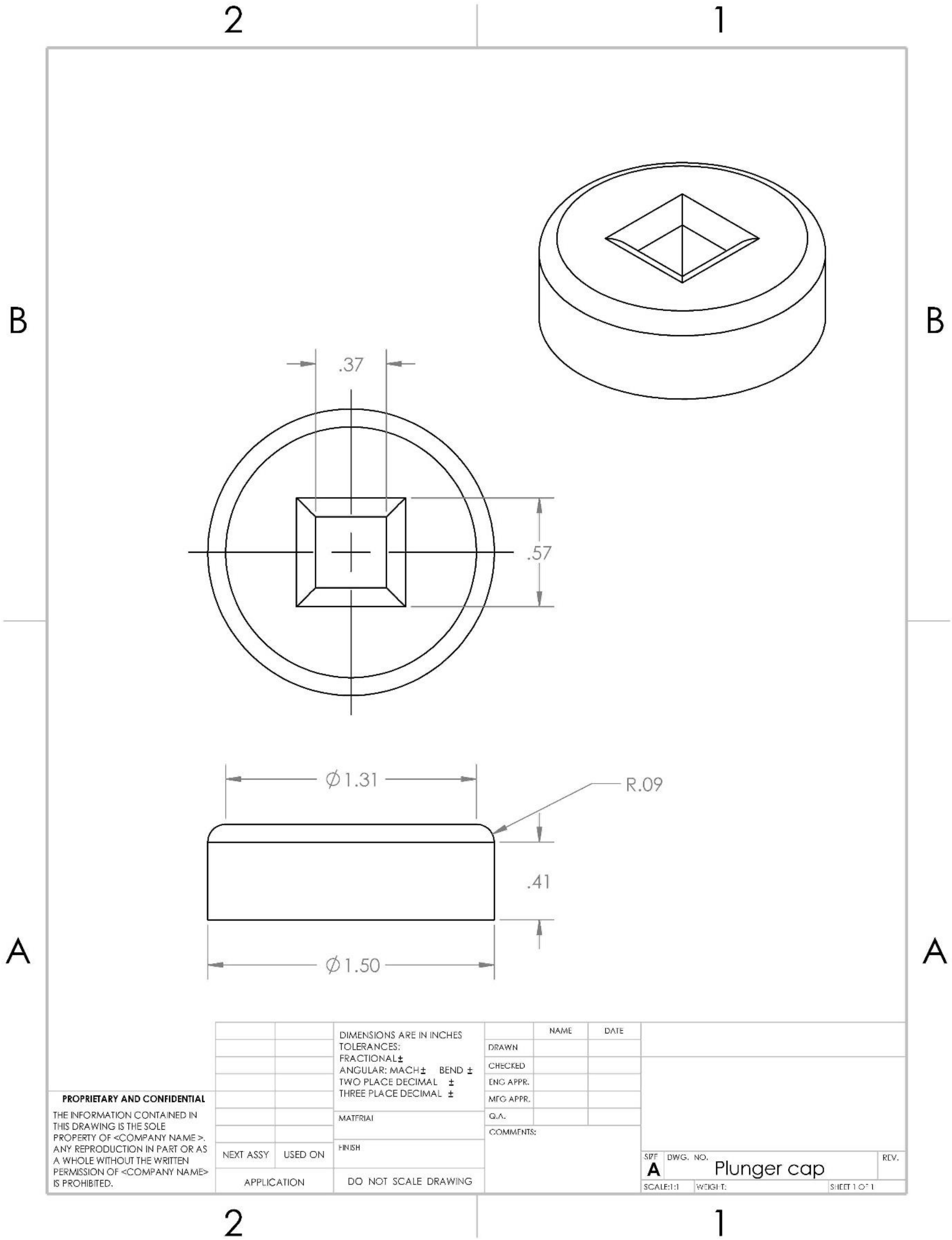


Figure 28: Plunger cap CAD

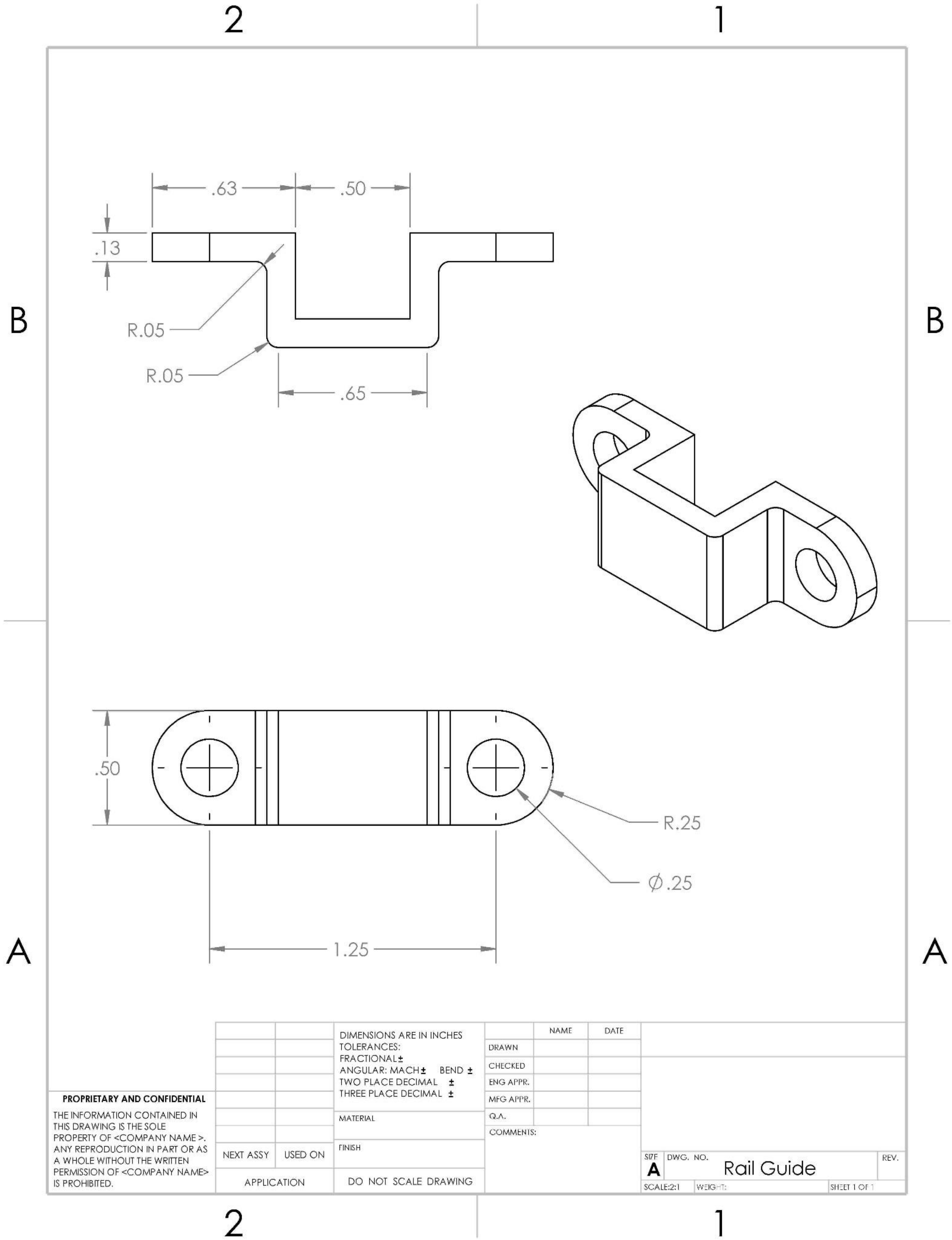


Figure 29: Rail Guide CAD

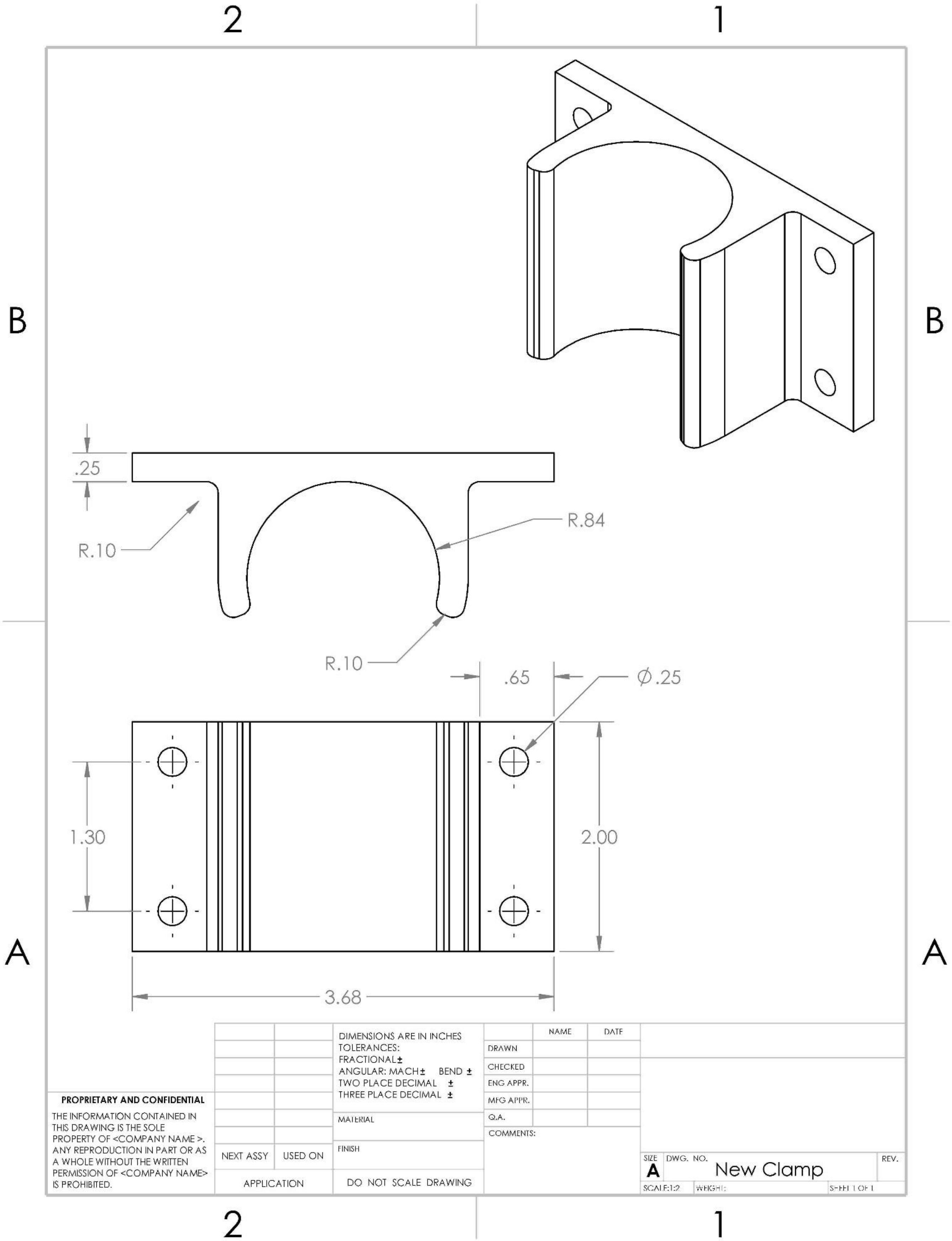


Figure 30: Clamp CAD

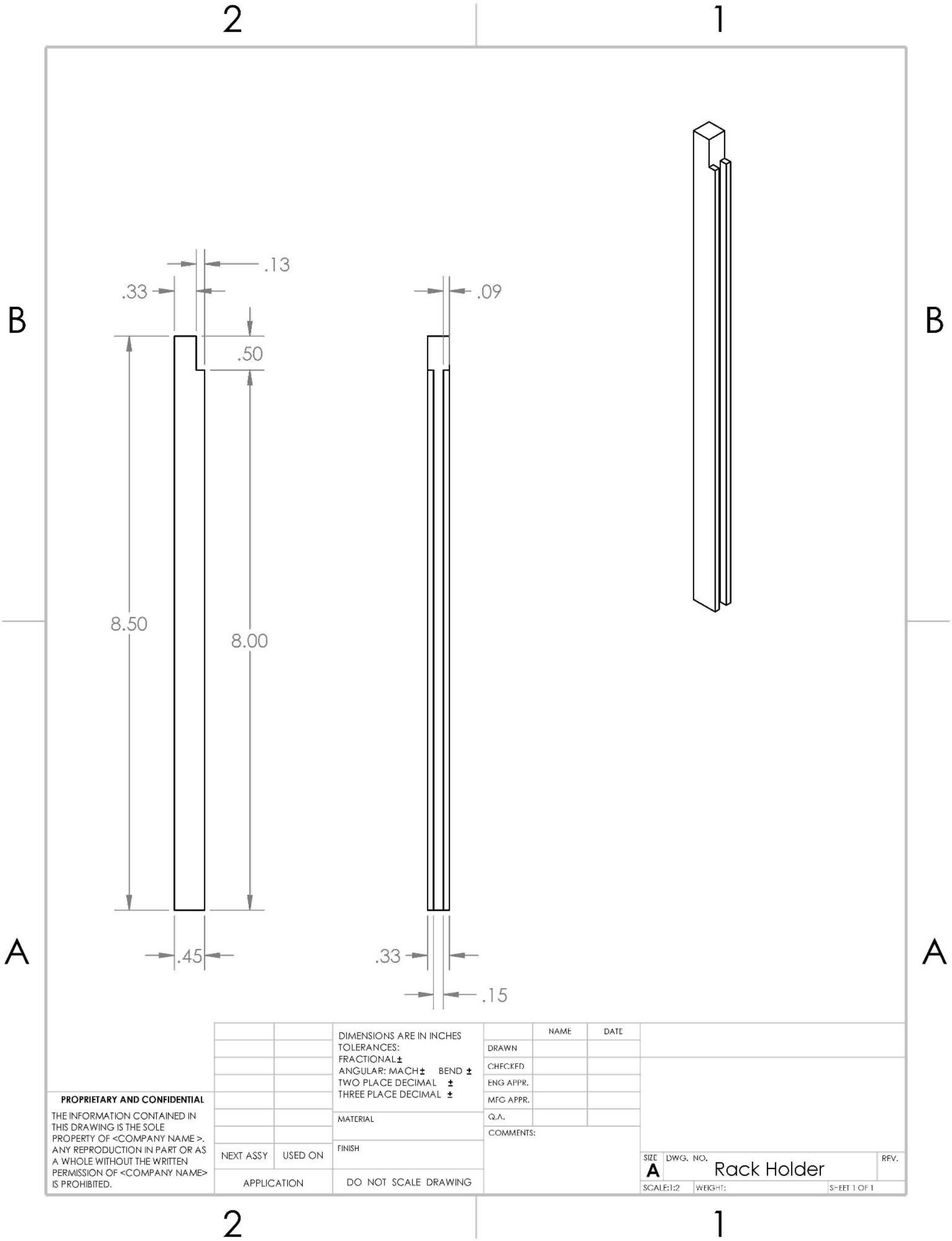


Figure 31: Rack Holder CAD

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