Fall 12-6-2019

3D Chocolate Printer Dropper

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FL19 MEMS 411 Mechanical Engineering Design Project

3D Chocolate Printer Dropper

The focus of this project was to develop the dropper component of a 3D chocolate printer device to be used in a mechanical engineering introductory course, with the purpose being to use the device in a lab to spark interest in thermo-fluids among undergraduate students. The dropper was designed to be integrated with a base plate built by a separate team, thus forming the complete 3D printing system. As per the client and functional needs, the design goal was to create a dropper that could melt and drop chocolate within a reasonable amount of time and at various, controllable drop rates and drop heights.

Though most 3D chocolate printers on the market today utilize a mechanical pumping system to extrude drops, this device utilized gravity to create a controllable drop system. The chocolate extruder of the device consisted of a heating basin, tubing, a rollerclamp, and a nozzle. Solid chocolate would be melted in the heating basin and flow into rubber tubing that ran through a rollerclamp into the nozzle. The rollerclamp could be manipulated to adjust the flow rate of chocolate, including stopping the flow. The entire extruder was supported by a frame with an adjustable sliding clamp that allowed for the user to variate the dropper height up to 35 cm above the base plate.

While the initial prototype met all of the previously set design goals, other issues arose including vibration of the extruder, clogging in the nozzle, and unstableness of the circuit board. As a result, many design adjustments were made between the initial and final prototypes, including resizing of the nozzle and extruder holder, positioning of the circuit board, and shaped of the roller clamp. The final result was a device that performed the basic functions of a chocolate dropper, though future improvements could be made for precision and durability.

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Contents

List of Figures

List of Tables

1 Introduction

The Mechanical Engineering Department at Washington University in St. Louis is working to stimulate interest in the fields of fluid dynamics and thermal sciences, as students are not typically exposed to these topics within the first two years of school. Dr. Okamoto, Jeff Krampf, and Dr. Weisensee of the Mechanical Engineering Department would like to remedy this situation by developing a laboratory experiment for first year students that utilizes a 3D chocolate printer to teach thermal-fluid concepts in a fun and engaging manner [1].

The goal of this project is to build a chocolate droplet dispensing system, which is a part of the 3D chocolate printing machine. The device must be able to melt chocolate and generate droplets in consistent and adjustable time intervals. The dispensing height of the nozzle should be manually changeable so that the students can understand how height and frequency influence the droplet impact. While the primary function of this device is to help students learn thermal-fluids in a fun yet educational environment, it is also imperative that the device is safe for students to use.

2 Problem Understanding

2.1 Existing Devices

A range of 3D chocolate printers are already in circulation for commercial and professional use. Though this project aims to create the dispenser and not the build plate or cooling system, a variety of dispensers and substrate heating systems are present in the examples showcased in this section.

2.1.1 Existing Device #1: Choc Creator V2.0 Plus

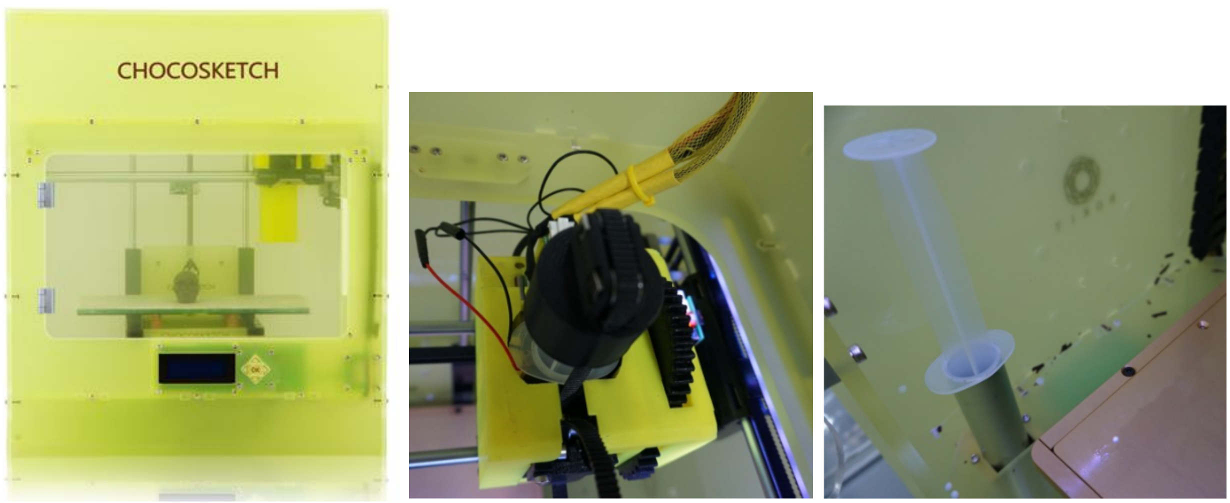
(a) (b)

Figure 1: The Choc Creator V2.0 Plus (a) with and (b) without housing

Link: http://chocedge.com/buy/ccv3-landing-page.html

Description: The Choc Creator V2.0 Plus is a multi-dimensional printer for construction of 2D, 2.5D, and 3D chocolate models with maximum dimensions of 18 x 18 x 4 cm. It features a single 30 ml stainless steel syringe and nozzle to dispense chocolate lines of 0.8 mm. The syringe and nozzle are reusable, detachable, and food-graded for ease of use and cleaning. Pre-tempered chocolate is hand-drawn into the syringe before being placed into the printer, where a barrel housing the syringe keeps the temperature warm to prevent re-solidification. An accompanying LCD touchscreen allows the user to adjust temperature, speed, and accuracy requirements. The device also features an emergency stop button.

2.1.2 Existing Device #2: ROKIT CHOCOSKETCH



(a) (b) (c)

Figure 2: (a) The ROCKIT CHOCOSKETCH 3D printer and close-up shots of (b) the extruder and (c) the cartridge warmer

Link: http://en.3disonprinter.com/product-chocosketch.php
Description: The ROKIT CHOCOSKETCH prints 3D chocolate figures up to 240 x 120 x 70 mm in size. It operates using a cartridge system, where pre-loaded syringes provided by the company are heated to 40 degrees Celsius in a cartridge warmer on the inner left side of the printer frame. Warmed cartridges are placed in a syringe-equipped extruder that utilizes a belt-and-plunger system to force liquid chocolate out. An additional heating system in the extruder keeps the syringe and nozzle warm to prevent hardening of the chocolate. The printer also has a built-in fan to help set the chocolate on the stainless steel build plate, as the plate itself does not have an active cooling system.

2.1.3 Existing Device #3: Mmuse Chocolate 3D Printer

(a) (b)

Figure 3: (a) The Mmuse Chocolate 3D Printer and a close-up of (b) the bean-loading slot

Link: https://www.3dprintersonlinestore.com/mmuse-touch-screen-chocolate-3d-printer
Description: The Mmuse Chocolate 3D Printer uses a single extruder to dispense chocolate for three-dimensional configuring at a speed of 30 to 60 mm/s. It features a slot at the top of the extruder where semi-processed chocolate "beans" can be inserted and melted at a working temperature between 15 and 30 degrees Celsius. The heating temperature can be controlled using the touchscreen interface for deliberate chocolate tempering. Additionally, the 0.8 mm diameter split nozzle is designed for easy removal and thus convenient for cleaning and changing of parts. The anodized aluminum frame of the machine adds to its strength and durability.

2.2 Patents

For this section we analyzed existing patents for devices that would specifically control the flow rate of the droplets.

2.2.1 Chocolate 3D printer syringe formula constant temperature extrusion system (CN205512096U)

This utility model for the extruder of a 3D chocolate printer features a syringe as a dispenser as opposed to a screw extruder. The compressor of the syringe is comprised of a clamp plate with attached slide nut, rails, screw, and W-axis motor. The motor drives the screw and rails which motions the nut down and applies a downward force on the plunger of the syringe. An additional heat pad, temperature sensor chip, and heat resistant wiring completes an automated controlled heating system around the syringe to keep chocolate liquified.

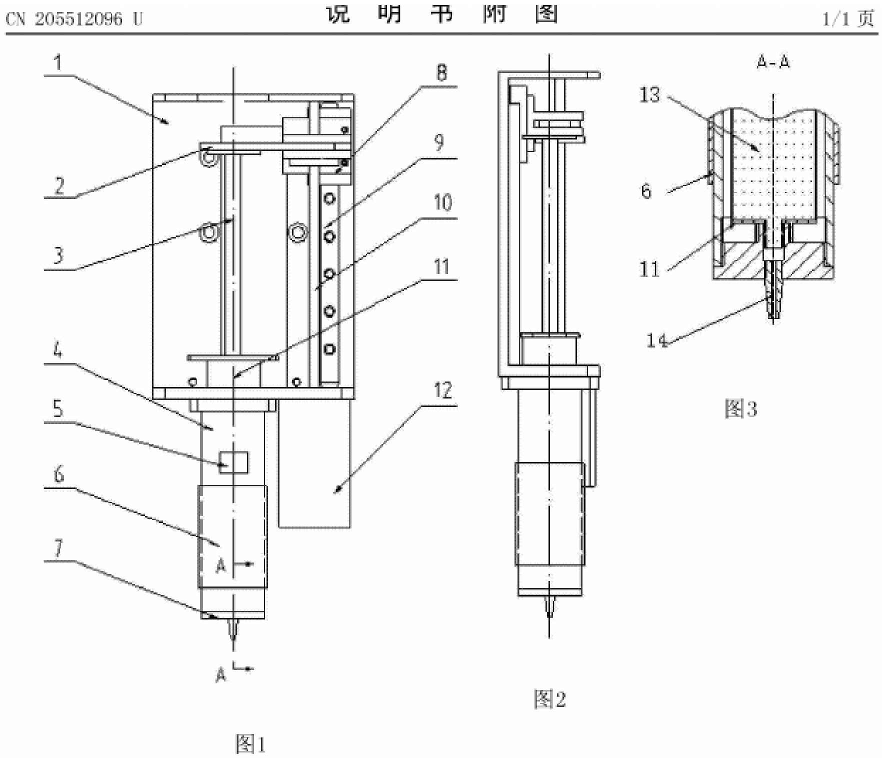


Figure 4: Patent Images for chocolate 3D printer syringe

2.2.2 Roller clamp for tubing (US3900184A)

This patent showcases a design that includes features typical in a roller clamp used for fluid control in IV tubing. The casing has openings where a small-diameter tube may be inserted and houses two control rollers. The large roller extends outside of the housing and can be manipulated by fingers to position a smaller roller that applies pressure on the connected tubing. This in turn opens or closes the tubing to varying degrees which changes the flow rate of the fluid passing through the tubing.

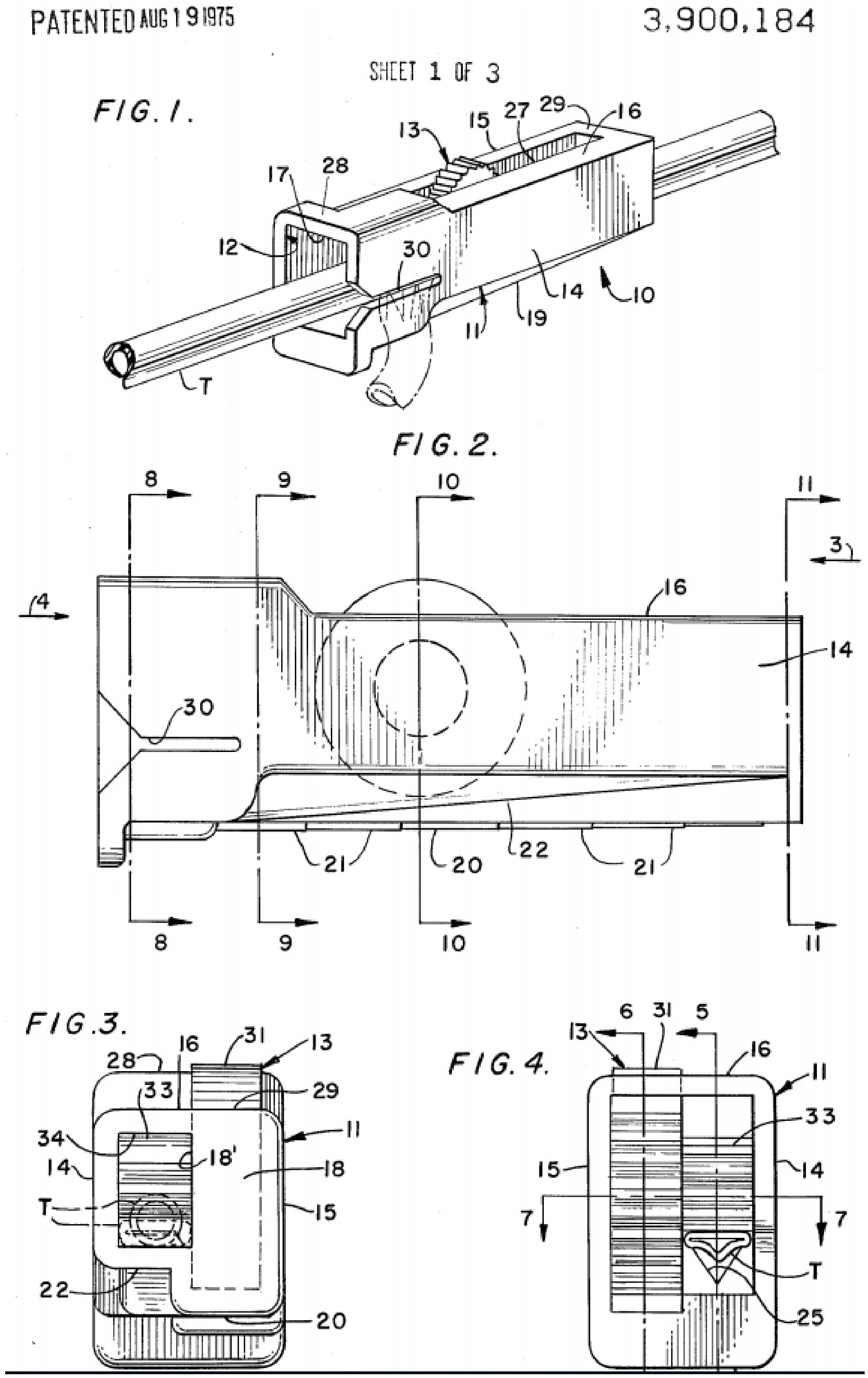


Figure 5: Patent Images for Roller clamp

2.3 Codes & Standards

2.3.1 Commercial Cooking, Rethermalization, and Powered Hot Food Holding and Transportation Equipment (NSF/ANSI 4-2016)

This standard sets requirements for material, design, construction, and performance of commercial cooking, rethermalizaiton, and powered hot food holding and transportation equipment. Specifically, the standard is intended to protect food from contamination in the process of cooking and transporting. Since the chocolate dropper will melt chocolate and create edible chocolate figures, our design will have to meet this standard.

2.3.2 Manual Food and Beverage Dispensing Equipment (NSF/ANSI 18-2016)

The standard describes requirements for equipment and devices that manually dispenses food and beverages. It requires that food shall be easily added and dispensed, food-zone shall be easily cleaned, and product reservoirs shall be capable of holding hot food up to 60°C. This standard ensures the melted chocolate maintains in a liquid state and dispenses easily. The sanitation requirements also makes sure the chocolate is safe to eat.

2.4 User Needs

A customer interview was conducted with Dr. Patricia Weisensee to determine user needs for the chocolate dropper. The needs were then tabulated and scaled on their level of importance.

2.4.1 Customer Interview

Interviewee: Dr. Patricia Weisensee
Location: Jubel 133, Washington University in St. Louis, Danforth Campus
Date: September 6^{th}, 2019
Setting: The customer gave us a paper with background information, a proposed experimental set up, and potential experiments to be executed in MEMS 101. She then explained her product expectations to us and two other groups. We asked follow up questions to get a more detailed scope of the project and she gave some suggestions. The interview took place in a conference room and lasted approximately 40 min.

Interview Notes:
What aspects of the device should be variable?

- Impact Height: The height at which the chocolate is dropped will create varying velocities and varying impacts onto the platform (e.g. may cause splashes).

- Droplet size (not required, but could be interesting): This does not have to be software controlled; it could be accomplished by manually changing the nozzle.

Does the type of chocolate matter?

- Type does not matter: We can research the differences in white, dark, and milk chocolate and how that will affect the design.

- Bulk pieces can be used: We can break up a chocolate bar and place it in the dropper; it does not have to be an entire chocolate bar. Half of a typical sized chocolate bar should give one printing cycle.

Should the dropper be portable?

- It will be used in MEMS 101, so it should be easy to transport in and out of a classroom. We should work with the other groups to develop a frame structure to easily integrate the dropper with the platform.
- Heaters are not very battery friendly, so we will want to plug it in.
- Detachable parts will help with portability as well as clean-ability.

2.4.2 Interpreted User Needs

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The dropper is easy to transport	3
2	The dropper can be easily cleaned	4
3	The dropper is food compatible	4
4	The dropper has height variability	5
5	The dropper prints multiple images in a class period	1
6	The dropper can be easily integrated with the platform	5

2.5 Design Metrics

From the interpreted user needs, a list of measurable properties was created. This was used in future design evaluations to determine whether all needs were met.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1,4	Total Height	in	< 8	6-8
2	1,2,6	Detachable parts	integer	2-8	4
3	5	Images printed per class period	integer	> 2	5
4	3	Commercial Cooking, Rethermalization, and Powered Hot Food Holding and Transportation Equipment (NSF/ANSI 4-2016)	binary	Pass	Pass
5	3	Manual Food and Beverage Dispensing Equipment (NSF/ANSI 18-2016	binary	Pass	Pass

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

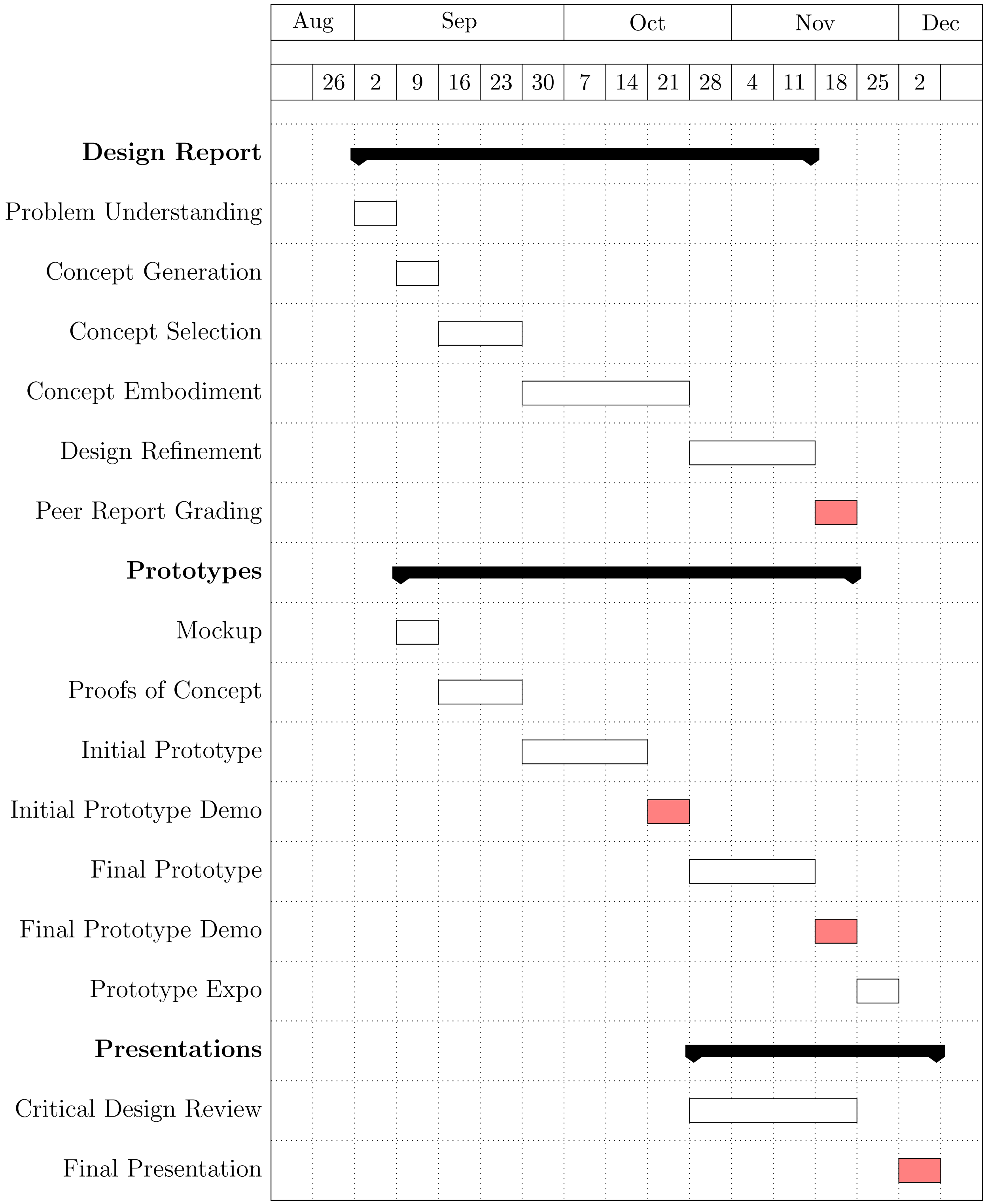


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

A mockup was created to allow us to consider various aspects of what our design will look like. Since this studio session did not concern the heating aspects of our design, we decided to use water instead of chocolate for the mockup. We started with a few tubes of varying diameters and flexibility to observe their effects on the droplet rate and the ease with which we were able to control it.

With this, we began thinking about how we will want to control the drip of the chocolate. In the mockup, we attempted to use small clasps on a harder, smaller tube. We found that the tube was not flexible enough for us to tighten it, and it was difficult to create droplets rather than a steady stream. We attempted the same clasp idea with a more flexible tube, but still had a hard time creating anything other than a steady stream.

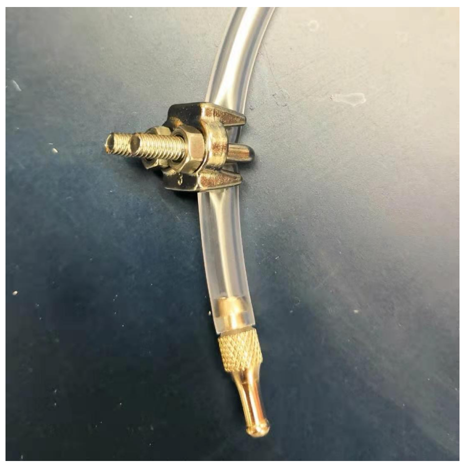


Figure 7: Image of the clasps on the smaller tubes

We then decided that our best idea for mockup given our time constraints would be to cut a hole in a tube with a larger diameter and insert something to block our desired levels of water. We cut part of a foam board and inserted it into the hole, hot glued it, then tilted it up and down to control the amount of water that would be allowed to flow freely.

(a) (b) (c) (d)

Figure 8: (a)The mockup of tube and nozzle, (b) Top view of tube when the blocker is open, (c) Top view of tube when the blocker is closed, (d) Final mockup with a holder

While this was not the same approach we would use in our actual design, it was helpful to use these mockups to get us thinking about future design challenges, especially in regards to controlling the flow rate of chocolate, preventing the chocolate from solidifying, and creating droplets at a steady rate. While looking for parts, we also found a device that we could attach our tube/nozzle system to and allowed us to adjust the height with a small crank. We thought that we may want to model our frame similar to it but on a smaller scale. This would give the dropper easy height variability and nozzle removal, as well as easy integration with the chocolate printer platform.

3.2 Functional Decomposition

It was determined that the most essential features of the automated Chocolate 3-D Printer Dropper would be based around the variability of heating and dispensing a chocolate substrate.

The functional decomposition for the device is represented in Fig.9 below.

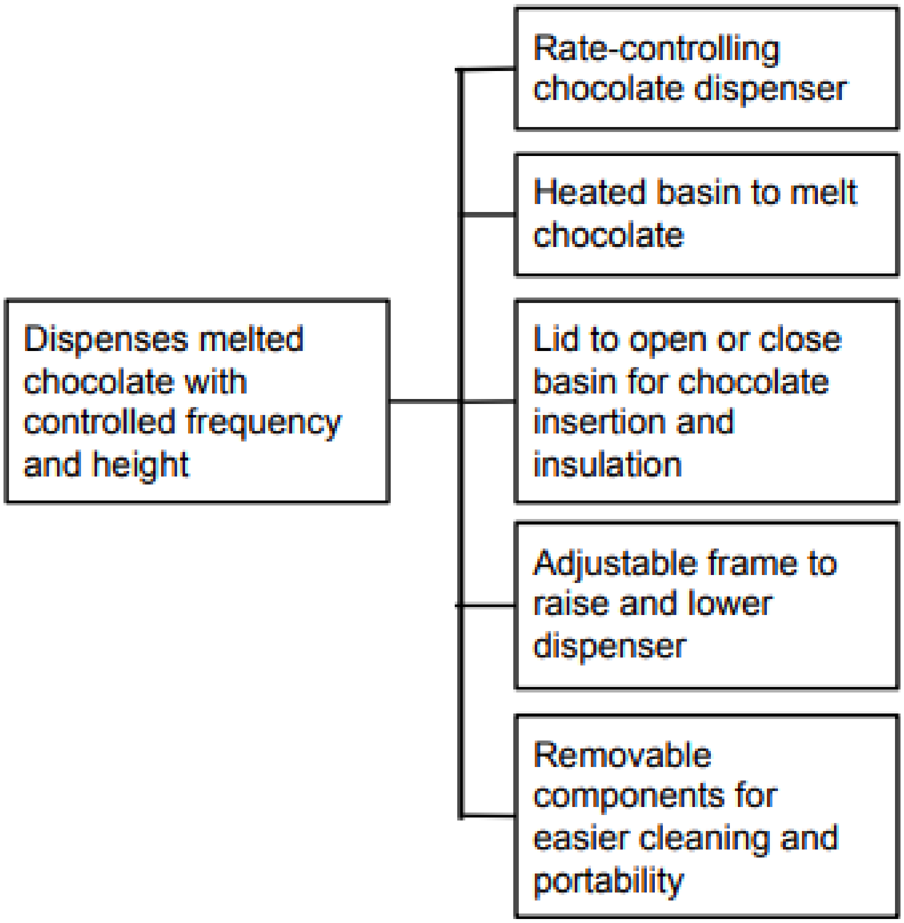


Figure 9: Function tree for Chocolate 3-D Printer Dropper

3.3 Morphological Chart

From the functional decomposition, we came up with a few different component designs that would satisfy each function. The morphological chart is presented in Fig.10 below.

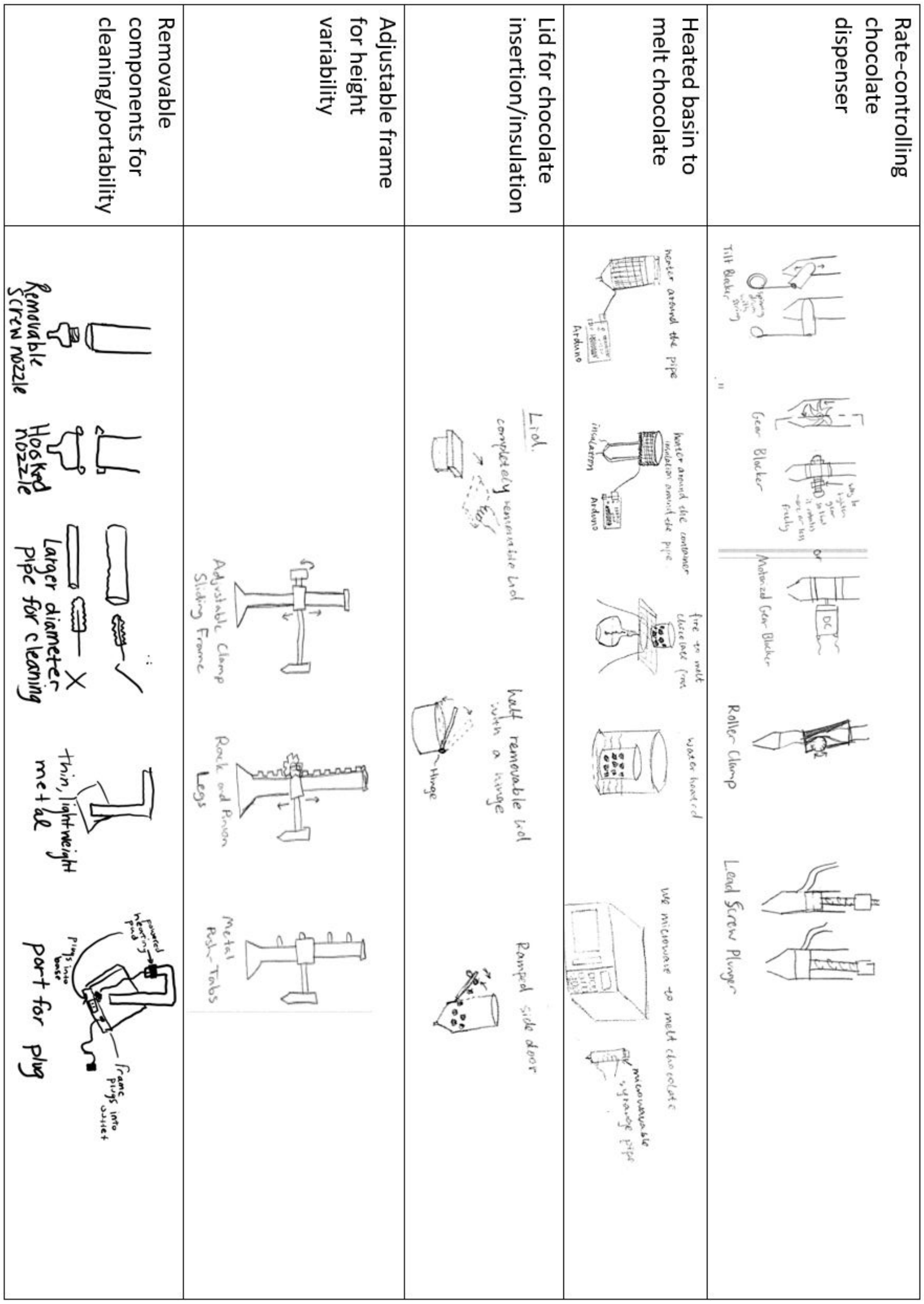


Figure 10: Morphological Chart for Useless Box

3.4 Alternative Design Concepts

3.4.1 IV Dropper with Surrounded Heating

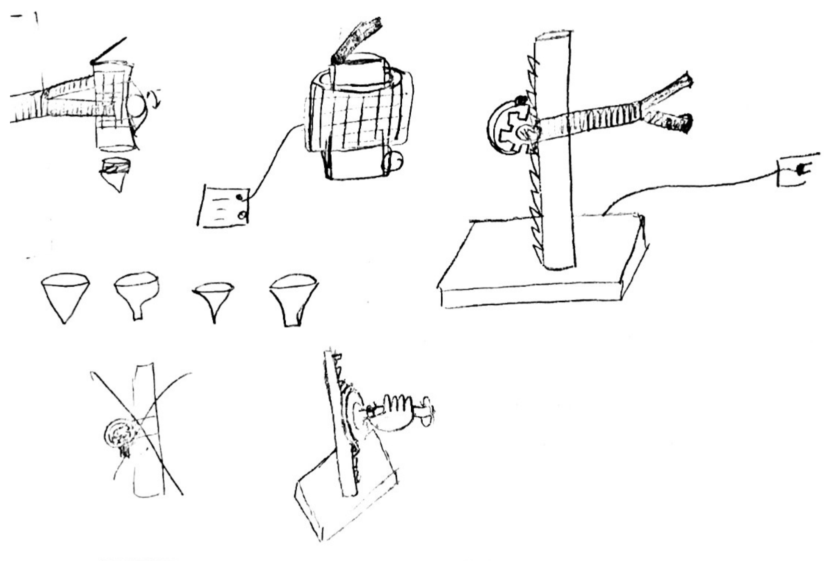


Figure 11: Preliminary sketches of IV Dropper concept

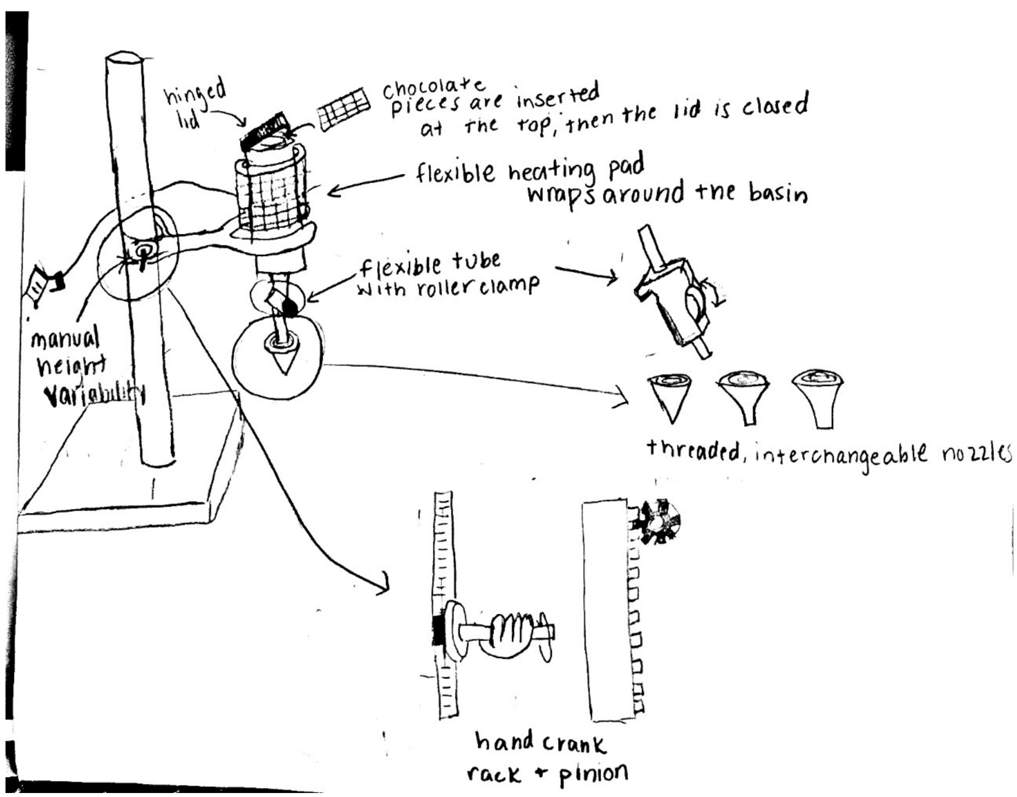


Figure 12: Final sketches of IV Dropper concept

Solutions from morph chart:

1. Roller clamp
2. Heating pad around the pipe
3. Hinged lid
4. Rack and pinion
5. Removable screw nozzle
6. Lightweight metal

Description: Chocolate pieces are inserted to the basin at its top, where there is a lid with a hinge to contain the heat during the printing process, and a heating pad surrounds the basin to allow for even melting throughout. The rate at which the melted chocolate droplets are released is controlled by a roller clamp on a flexible tube, much like an IV at a hospital. The threaded nozzles screw on to the tube for cleaning and portability. This also allows for nozzles of various sizes to be easily interchanged, providing students with additional opportunities to learn about fluid dynamics. The overall heating/dropping system is attached to a lightweight aluminum frame, where the height is adjusted manually with a rack and pinion hand crank rather than selecting from a predetermined set of heights.

3.4.2 Tilted blocker dispenser with surrounded heating around the container

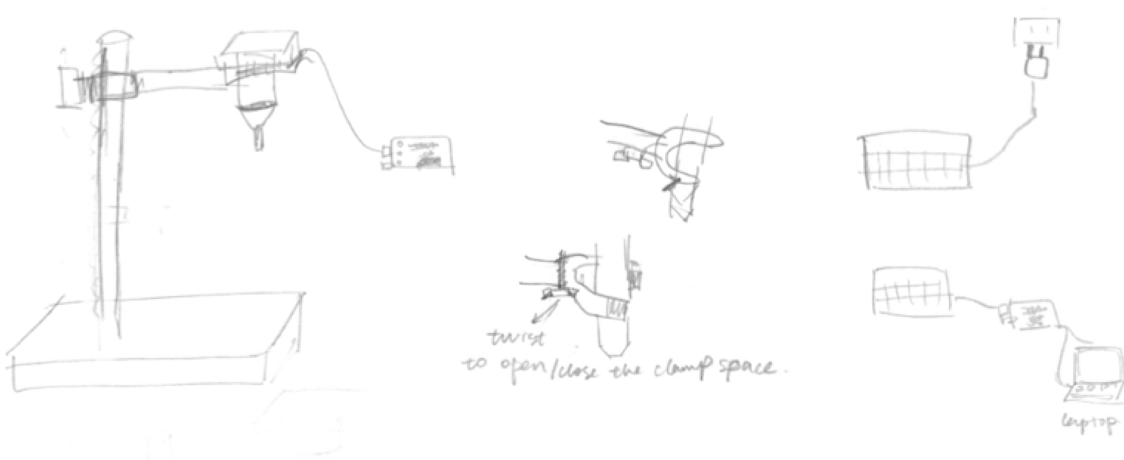


Figure 13: Preliminary sketches of tilted blocker dispenser concept

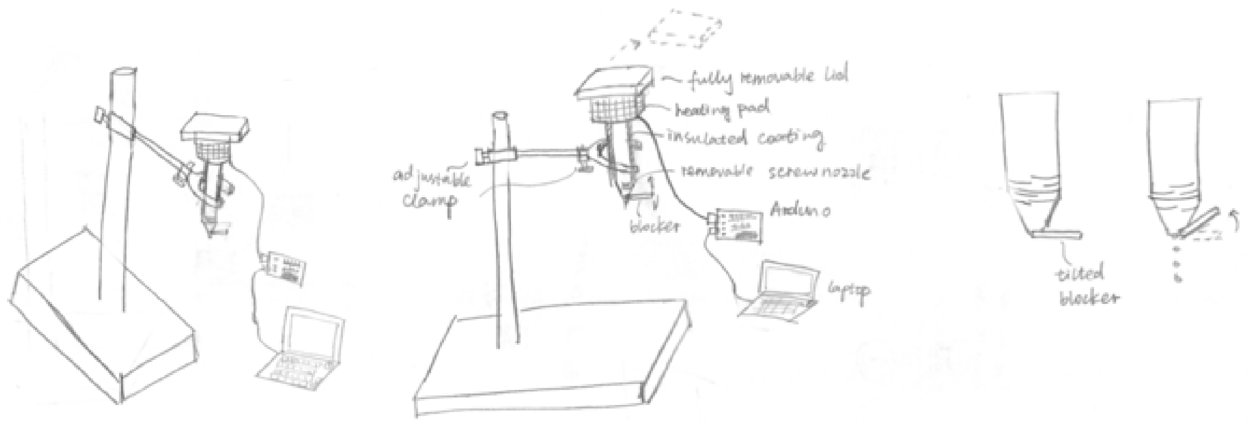


Figure 14: Final sketches of tilted blocker dispenser concept

Solutions from morph chart:

1. Tilted Blocker
2. Heating pad around the container and an insulation around the pipe
3. Fully Removable lid
4. Adjustable clamp
5. Removable screw nozzle
6. Lightweight metal

Description: This chocolate dispenser has three main components: a supporter, a dispenser and container, and a heating system. The supporter uses lightweight metals, making it easier to carry. An adjustable clamp is added to the supporter, so that the height of the dispenser can be changed based on users' needs. The lid of the container can be fully removed, which allows users to insert chocolate and clean the container easily. A heating pad, which is controlled by an Arduino, is attached around the container and melts the chocolate. The frequency of the melted chocolate droplets is controlled by a titled blocker at the end of the removable screw nozzle. When the blocker stays horizontal, it blocks the droplets from falling down. When the blocker is tilted, the droplets can fall down with different frequencies with respect to the tilted angles.

3.4.3 RichRap with pre-heated syringe

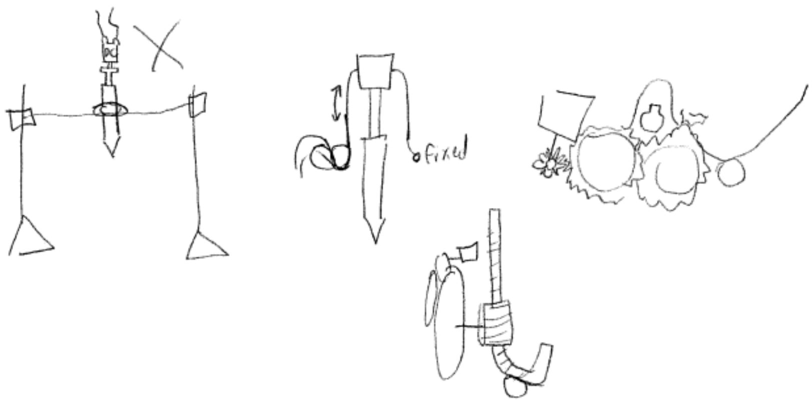


Figure 15: Preliminary sketches of RichRap design concept

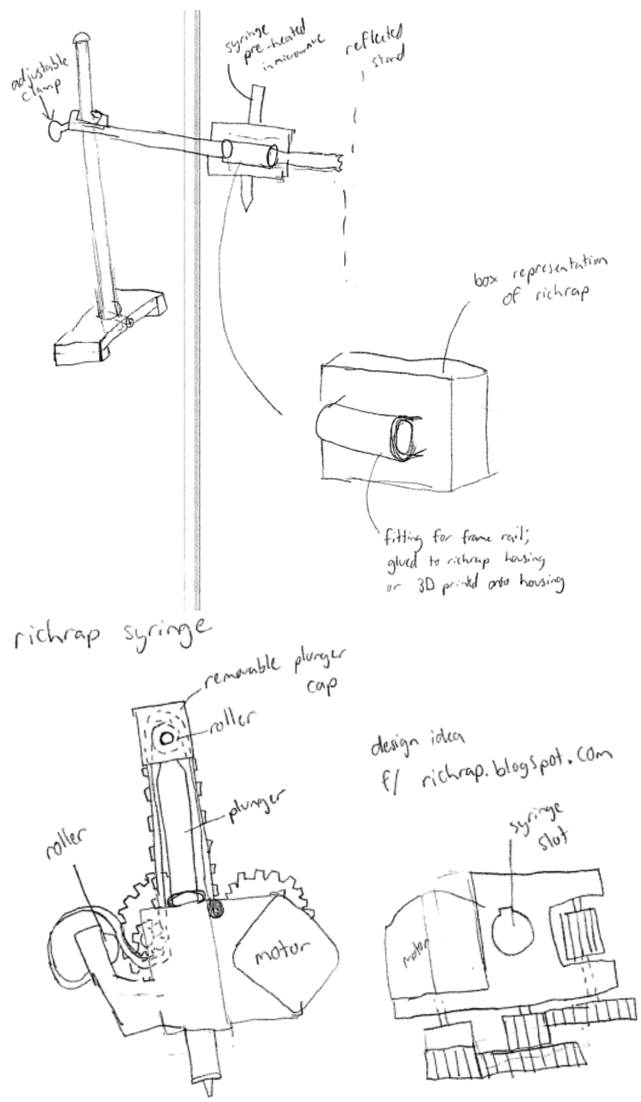


Figure 16: Final sketches of RichRap design concept

Solutions from morph chart:

1. RichRap plunger (new) (variation of lead screw plunger)
2. Microwave to melt chocolate
3. Pre-loaded syringe
4. Adjustable clamp sliding frame
5. Large diameter syringe for cleaning
6. Removable plunger and syringe (similar to removable nozzle)

Description: The main components of this device are the frame, RichRap syringe and the syringe-to-frame fitting. The RichRap syringe is named and designed after the existing device, which utilizes gears driven by a motor to shorten or extend a toothed belt[2]. This belt interfaces with a sold cap placed on top of a syringe plunger, and when the belt shortens a force is applied from the cap to the plunger to compress it into a syringe. The RichRap syringe has removable parts, including the syringe, plunger, and plunger cap to allow for easy cleaning and exchange of pre-loaded syringes. The syringes would be pre-loaded with melted chocolate that could be tempered by microwaving or double-boiling. A cylindrical tubing fixture is attached to the RichRap syringe housing so that the part may be fitted around an arm extending from two frame legs located at each end. The diameter of the fitting would need to closely match that of the arm so that the RichRap syringe would not rotate from the force of gravity. The frame of the structure is comprised of the arm with adjustable clamps on each end clamped around two bottom-heavy legs. The clamp would allow for easy changing of the syringe drop height.

4 Concept Selection

4.1 Selection Criteria

To determine which design concept would best achieve our goals, we came up with six selection criteria. We compared them pair-wise through an analytic hierarchy process (AHP) shown below.

	Easy to clean	Portable	Ease of use/adjustable parameters	Integration w/ platform	Safe to eat/operate	Quickly melts/insulates chocolate	Row Total	Weight Value	Weight (%)
Easy to clean	1.00	5.00	7.00	0.50	3.00	1.00	17.50	0.24	24.47%
Portable	0.20	1.00	0.20	0.14	0.33	0.14	2.02	0.03	2.82%
Ease of use/adjustable parameters	0.14	5.00	1.00	1.00	6.00	3.00	16.14	0.23	22.57%
Integration w/ platform	2.00	7.00	1.00	1.00	3.00	2.00	16.00	0.22	22.37%
Safe to eat/operate	0.33	3.00	0.17	0.33	1.00	0.20	5.03	0.07	7.04%
Quickly melts and insulates chocolate	1.00	7.00	0.33	0.50	5.00	1.00	14.83	0.21	20.74%
						Column Total:	**71.53**	**1.00**	**100%**

Figure 17: Analytic Hierarchy Process (AHP) used to determine scoring matrix weights

4.2 Concept Evaluation

We used the weights from the AHP to compare each design concept against each selection criterion. This weighted scoring matrix (WSM) is shown below.

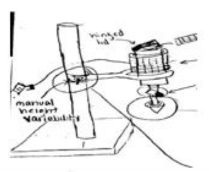
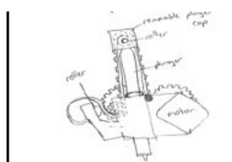
Alternative Deisgn Concepts							
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Easy to clean	24.47	3	0.73	3	0.73	3	0.73
Portable	2.82	3	0.08	3	0.08	2	0.06
Ease of use/adjustable parameters	22.57	4	0.90	2	0.45	2	0.45
Integration w/ platform	22.37	3	0.67	3	0.67	3	0.67
Safe to eat/operate	7.04	3	0.21	3	0.21	4	0.28
Quickly melts and insulates chocolate	20.74	3	0.62	4	0.83	2	0.41
	Total score	**3.226**		**2.982**		**2.609**	
	Rank	**1**		**2**		**3**	

Figure 18: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

From the Weighted Scoring Matrix, it was determined that best design concept was the IV Dropper with Surrounded Heating. For this concept, each selection criterion was given a rating of 3 except for ease of use and adjustable parameters, which was given a rating of 4. We concluded that the removable nozzle and heated basin could be easy to clean with a bottle brush and water, but it would be more difficult to clean the small tube that connects the two. As for portability, the 3 rating was decided again due to the removable parts. We determined that while the nozzle, tubing, heater, and basin would be small and somewhat easy to transport, it may be difficult to do so when the stand is bulkier. Integration with the chocolate printer platform was given a rating of 3 for all the design concepts. This was mainly because we had not yet discussed with the platform group how to proceed with the integration of the two systems, and each of the design concepts had similar stands that would be used to hold the heating mechanism. Since we had not yet discussed exact materials for our heating basin, we did not feel confident in rating the safe to eat portion as a perfect 5. Additionally, this design did not provide any barrier between the heating pad and the exposed air, so while we had observed that it would most likely not cause major burns, the possibility of someone's skin meeting the hot surface would be present. The last criterion to be rated a 3 for the IV Dropper concept was the ability to quickly melt and insulate the chocolate. From our proof of concept, it took only a few minutes for the heating pad to reach the melting temperature of chocolate. However, with the longer distance from the heated basin to the nozzle, there would be a higher chance of the chocolate solidifying before it could be dropped. Finally, the one criterion that was rated a 4 was ease of use/adjustable parameters. The height would be easily adjustable with a hand crank, the nozzles would be interchangeable to allow for adjustable droplet sizes, and the flow rate would be controllable by a roller clamp on the tubing. However, we decided not to give it a perfect 5 since during our proof of concept we found that the roller clamp did not have as much range as we anticipated and there was no way to precisely measure the droplet rate.

4.4 Engineering Models/Relationships

The following three subsections discuss common engineering models that would be relevant for defining and modifying certain design parameters, specifically those of the frame and arm, heating basin, and nozzle.

4.4.1 Arm Support as an End-Loaded Cantilever Beam

Modelling the arm supporting the chocolate extruder as an end-loaded, cantilever beam allowed for the estimation of deflection, slope, and shear force of the arm. To maintain the extruder in a vertical position these measurements would need to be minimized. The extruder would be placed at the furthest end of the arm away from the frame leg supporting the arm up. The extruder was treated as a point mass, as this would give an overestimation rather than an underestimation of the deflection, slope, and sheer stress. The leg of the frame was designed to weigh significantly more than the arm and the extruder combined and to be completely rigid, thus it was modeled as a wall and the moment of the cantilever beam was neglected. Ultimately, this model would allow us to test various lengths of beams to inform our final decision on the arm dimensions. Figure 19 below depicts the free body diagram and shear distribution diagram of an end-loaded cantilever beam.

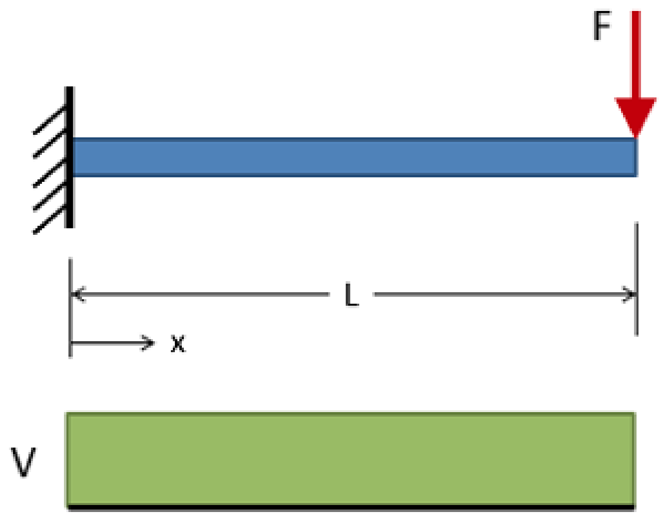


Figure 19: Beam Deflection and shear stress of a cantilever beam with an end load [3]

Below, the maximum beam deflection (δ) was calculated as a function of the force of the extruder (F = mg, where m is the mass of the extruder), the length of the beam (L), the modulus of elasticity (E), and the area moment of inertia of the beam (I). The area moment of inertia would be determined from the decided shape of the arm after a conclusive review of available materials and resources was conducted.

$$\delta = \frac{FL^3}{3EI} \tag{1}$$

The maximum slope of the beam deflection (ϑ) and maximum shear stress (V) were modeled in the equations below[3]:

$$\theta = \frac{FL^2}{2EI} \tag{2}$$

$$V = +F \tag{3}$$

4.4.2 Heating Basin through Conduction

Conduction is the energy transferred due to particle interaction, and moves from a more energetic (hotter) to a less energetic (colder) area [4]. The heating mechanism of our chocolate dropper was treated as a cylinder with a radial temperature gradient and no heat generation, or a one-dimensional, steady-state conduction process through a cylindrical wall.

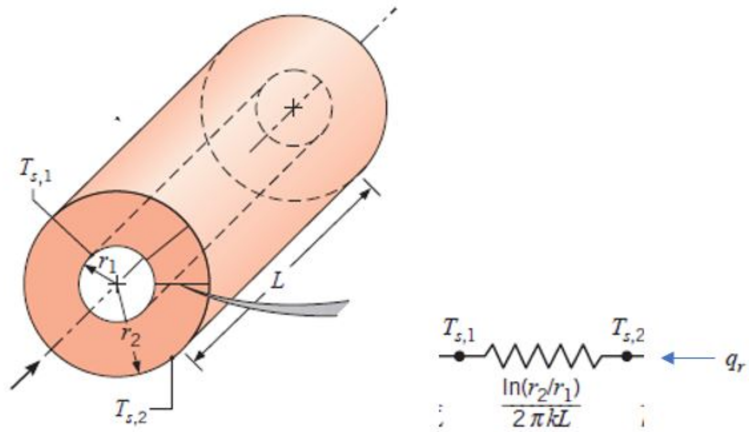


Figure 20: Conduction through a cylindrical wall [4]

As shown in Fig. 20, this heat transfer process could be modeled as a thermal resistor connecting two surfaces. From this, we can found the heat rate from the heating pad to the chocolate [4]:

$$q_r = \frac{T_{s,2} - T_{s,1}}{R} \tag{4}$$

where $Ts,2$ and $T_{s,1}$ are the temperatures of the heating pad and the chocolate, respectively, and R is the thermal resistance of the heating basin which was calculated using the equation below:

$$R = \frac{ln(\frac{r_2}{r_1})}{2\pi kL} \tag{5}$$

where r_2 and r_1 are the outer and inner diameters, respectively, k is its thermal conductivity, and L is its length. After selecting a material for the basin in which the chocolate will be melted, we would be able to determine its thermal conductivity. With this we could find an ideal heat rate to help us in optimizing the size of our basin or the temperature at which the heating pad is set to effectively melt the chocolate.

4.4.3 Droplet Formation from Surface Tension with Nozzle

The falling speed of droplets is highly related to the surface tension of chocolate and the weight of liquid at the nozzle[5]. At the liquid-air interface, the attraction of liquid molecules to each other is larger than to the air molecules. Thus, this imbalanced force at the surface is called surface tension (γ). Initially, the inward force causes the chocolate to form a stretched membrane at the surface. As shown in Figure 21 below, the liquid at the nozzle continuously gains mass until it is stretched to a point that the surface tension can no longer link the droplet to the nozzle.

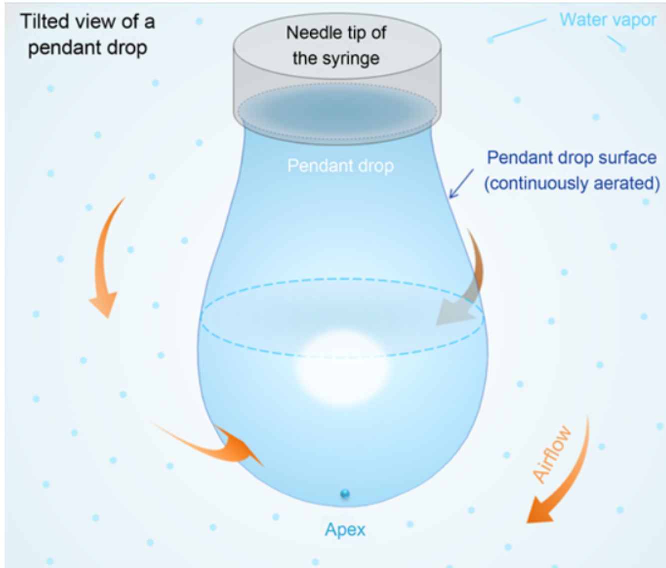


Figure 21: Formation of droplet at the nozzle [6]

Surface tension (γ), which is a physical property of a liquid, is force per unit length. If the measured tension (σ)is larger than its surface tension, the droplet would fall from the nozzle. The measured tension was calculated as:

$$\sigma = \frac{F_w}{L} = \frac{F_w}{2\pi r} \tag{6}$$

where F_w is the weight of the liquid, L is the perimeter, and r is the radius of the nozzle. After the size of nozzle is selected, the falling speed of droplets would depend on the speed of liquid reaching the required weight. Therefore, determining the size of nozzle and controlling the weight of liquid chocolate would help us to know the falling speed of the droplets.

5 Concept Embodiment

5.1 Initial Embodiment

A mock-up of the initial prototype was created in SolidWorks and is presented in the following three pages.A list of parts and description of design rationale are also present in this section.

5.1.1 Top, Right, and Side View Drawings

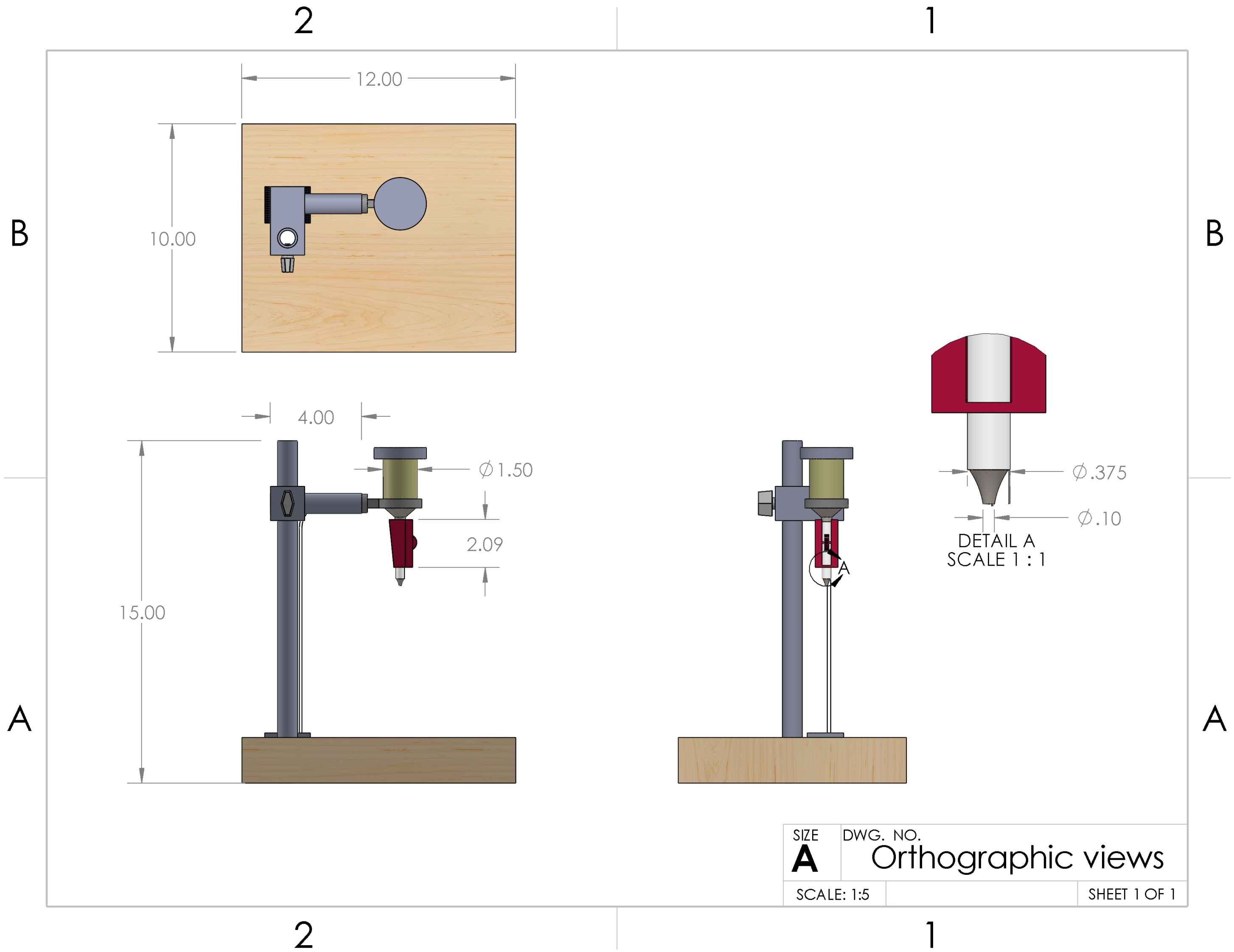
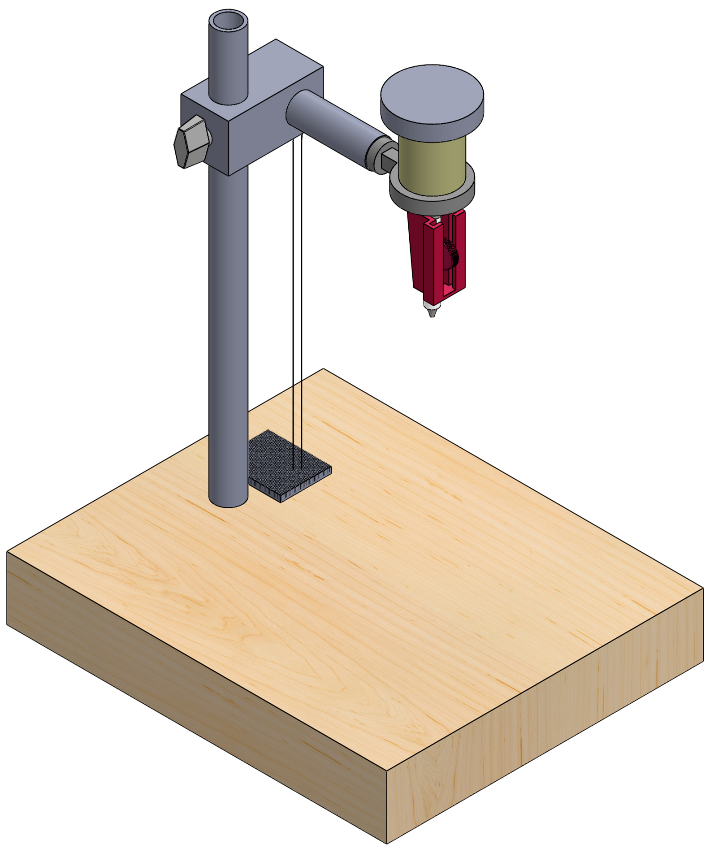


Figure 22: Assembled projected views with overall dimensions

5.1.2 Assembly View and BOM



ITEM NO.	PART NUMBER	QTY.
1	Base	1
2	Long Vertical Pipe	1
3	Clamp	1
4	Short Horizontal Pipe	1
5	Head Bolt	1
6	Fork	1
7	Funnel	1
8	Copper Pipe	1
9	Cap	1
10	Plastic Tube	1
11	Roller Clamp	1
12	Electric Board	1
13	Heating Pad	1
14	Gear	1
15	Nozzle	1
16	Wire	2

SIZE A DWG. NO. BOM
SCALE: 1:10 SHEET 1 OF 2

Figure 23: Assembled isometric view with bill of materials (BOM)

5.1.3 Exploded View

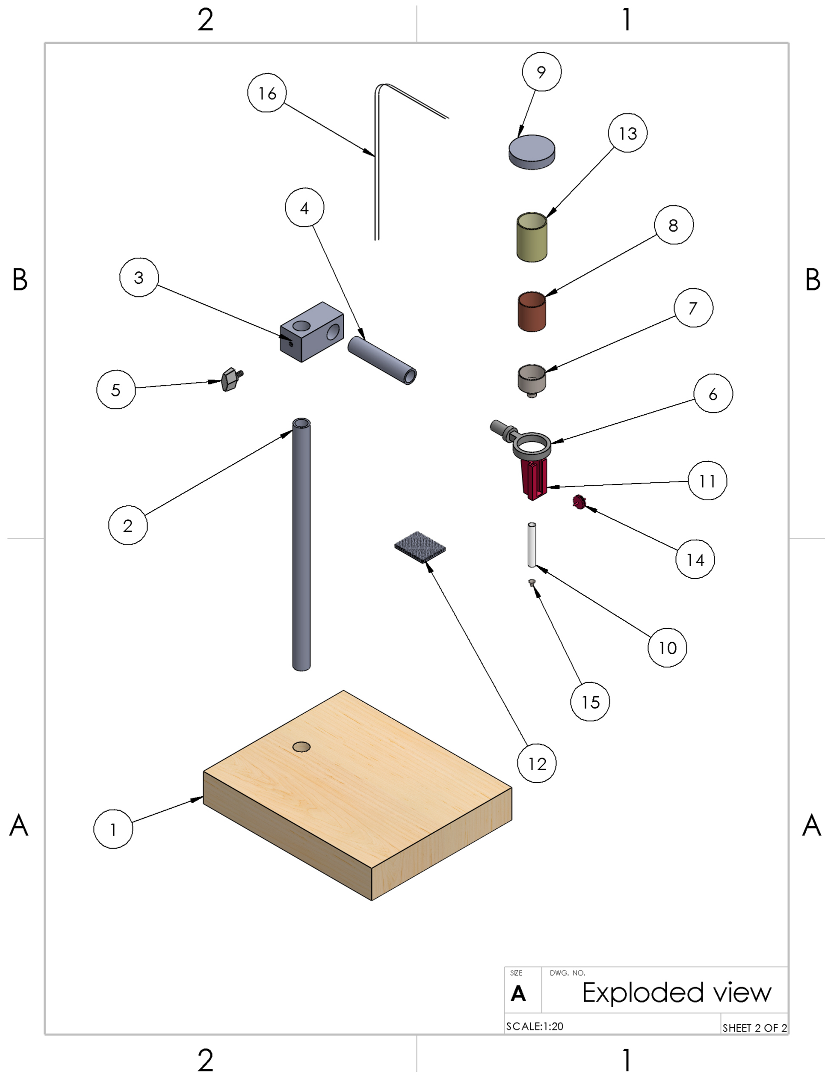


Figure 24: Exploded view with callout to BOM

5.1.4 Initial Parts List

The purchased parts for the initial prototype are listed below. The list does not include the parts that were manufactured in Studio such as the 3D-printed models and common materials available in the work space.

5.1.5 Design Rationale for PoC Components

To justify and verify design decisions in the arm of the frame, setup of the heating basin, and size of the nozzle, we analyzed beam deflection, heat transfer, and surface tension based on the models introduced in Section 4.4. Some estimated dimensions and part measurements were recorded in imperial units, though all were converted to metric for use in the following models.

Table 3: Initial parts list of prototype components

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
1	Funnel	Amazon	HQ93	Stainless Steel, 2" x 1.5" x 1.5"	\$4.49	1	\$4.49
2	IV Roller Clamp	Amazon	B01G41-KBM0	-	&6.76	1	&6.76
	(Amazon Shipping)	-	-	-	-	-	\$3.99
3	Heating Pad	Sparkfun	COM-11289	5V DC, 600mA(8.3Ω), 5 x 15cm	\$4.95	3	\$14.85
	(Sparkfun Shipping)	-	-	-	-	-	\$3.99
4	Two Arm Knob	McMaster	6477K32	Black Phenolic Plastic, 1/4"-20 Thread x 1/2" Long Stud	\$1.12	2	\$2.24
5	Super-Soft Tubing	McMaster	5234K66	Rubber, Semi-Clear, 1/8" ID, 3/8" OD, 5ft. Length	\$7.85	1	\$7.85
6	HVAC Tape	McMaster	76145A19	Reinforced Fsk Aluminum, 3" x 30' x 0.0068"	\$7.86	1	\$7.86
7	Solid Tubing	McMaster	5175K137	Copper,1-1/4 Tube Size, 1-3/8" OD, 2ft. Long	\$12.89	1	\$12.89
8	Clear Tubing	McMaster	5233K54	PVC, 3/16" ID, 3/8" OD, 25 ft. Length	\$9.50	1	\$9.50
Total							\$66.94

Arm Length

Again, we revisited our model in 4.4.1 to calculate the total deflection in the frame arm that holds the extruder above the base plate. In order to accurately position the height of the extruder relative to the plate, the deflection would need to be known and added to height markers along the leg of the frame supporting the arm. The arm, made from PVC pipe, was modeled as a beam with a single free-end with a point-mass and another end attached to a wall. Though the leg of the frame in our project is also a PVC pipe, we planned to force fit the leg to a heavy base and the arm to the leg. Given the relatively short arm length and low relative mass of the extruder, the deflection in the leg would be negligible and thus the beam-wall model was justified (see section 4.4.1 for diagram).

The deflection(δ) and angle(ϑ) of the arm were calculated using Eq. 1 and Eq. 2 from Section 4.4.

The weight of the extruder was found by multiplying the mass of the extruder by gravity. The mass of the extruder was found as a sum of all of the parts ordered or created for intended use (flask, cap, rollerclamp, nozzle, tubing, heating pads, aluminum pipe, etc) plus the mass of the chocolate to be melted (23 g). In total, the mass was calculated to be 0.251 kg and the weight of the extruder to be 2.46 N.

The moment of inertia was calculated as that of a tube, which closely resembled the PVC pipe used for the arm. Using the formula

$$I = 0.049(d_o^4 - d_i^4) \tag{7}$$

where d_o is the outer diameter of the pipe (1 in) and d_i is the inner diameter of the pipe (0.75 in), the moment of inertia was found to be 1.39x10^4 m^4.

Plugging in these values as well as 3 in for L and 2.4 GPa for Young's modulus of PVC [7] produced values of 0.0108 mm of deflection and 0.0002°for the angle of the arm. Both values indicated that deflection would be negligible given the setup of our project, and thus would likely not need to be accounted for when labeling drop heights on the leg of the frame.

Heating Basin

The heat transfer through a copper pipe and the energy needed to heat chocolate to a desired temperature were calculated to determine the amount of time needed to melt the chocolate in the heating basin. As in the heat transfer model from section 4.4.2, the heat transfer (q_r, in W) through the cylindrical pipe was derived from Eq. 4, where $T_{s,2}$ and $T_{s,1}$ were the temperatures on the outside and inside of the pipe (in K), respectively, and R was the resistance (in K/W). The recorded maximum temperature of the heating pad (50 °C) was used as the outside temperature and the room temperature (67 °F) was used as the inside temperature. R was derived from Eq. 5, where r_2 and r_1 were the outer and inner radiuses of the pipe in m, k was the thermal conductivity of copper in W/mK, and L was the length of the pipe in m. Plugging in the values 0.0349 m, 0.0318 m, 205 W/mK and 0.1016 m, R was determined to be 728 K/µW and q_r to be 42.77 kW. The energy needed to heat chocolate from room temperature to melting temperature was found using the heat capacity formula

$$Q = mc(T_f - T_i) \tag{8}$$

where Q is the energy in J, m was the mass of the chocolate in g, c was the specific heat of chocolate in J/g°C, and T_f and T_i were the melting temperature of chocolate and room temperature in °C. The same mass and room temperature from before were used, along with a chocolate melting temperature value of 30 °C [8] and specific heat value of 2.535 J/gC [9], to find an energy value of 615 J.

By dividing the energy by the heat rate, we found the time needed to melt the chocolate in the heating basin to be 70 s. This value verified that our material choices and product specifications would melt the chocolate in a reasonable amount of time. It should be noted that these calculations only took into account the melting time of chocolate assuming the heating basin had already reached its maximum temperature. If the chocolate were to be placed in the heating basin as the heating pad is first turned on, the melting time would take significantly longer.

Nozzle Dimension

To find the minimum diameter needed for the nozzle of the extruder we utilized the surface tension model of a droplet from section 4.4.3. The chocolate drop was modeled as a sphere with a diameter, and thus radius, equal to that of the nozzle. This was a conservative estimate, as a larger drop would be more likely to fall from a nozzle diameter of the same size. A droplet would fall if the measured tension in the drop (σin N/m) exceeded that of the surface tension (γin N/m), or:

$$\gamma > \sigma \tag{9}$$

The measured tension in a droplet was defined by Eq. 6, where F_w is the weight of the droplet in N and r is the radius of the nozzle in m. The weight of the droplet was defined using the formula

$$F_w = gV\rho \tag{10}$$

where g is the gravitational acceleration in m/s^2, V is the volume of the droplet in m^3, and ρ is the density of chocolate in kg/m^3. The volume of a spherical droplet is defined as

$$V = \frac{4}{3}\pi r^3 \tag{11}$$

By subbing in the volume and weight formulas into that of the measured tension and rearranging, we found the equation for the nozzle of the radius to be:

$$r = \sqrt{\frac{3\sigma}{2\rho g}} \tag{12}$$

Since the measured tension must exceed the surface tension, the equation became:

$$r > \sqrt{\frac{3\gamma}{2\rho g}} \tag{13}$$

Plugging in 0.0226 N/m for $\gamma$and 1270 kg/m^3 for ρ[10], we calculated the minimum nozzle radius to be 0.00165 m, or a diameter of 0.065 inches.

5.1.6 Prototype Performance Goals

In order to quantify the success of this project, three performance goals were agreed upon. This list was approved by Dr. Potter, a Mechanical Engineering Design professor and project consultant.

1. Device can start up, melt chocolate, and extrude chocolate under 10 minutes for one new print cycle.

2. Drop flow rate is defined and use-controllable for a minimum 4 different drop rates, including a drop rate of 0 (completely stopped).

3. Height of dropper can be adjusted to at least 3 different heights between 5 cm and 30 cm above the base plate.

5.2 Proofs-of-Concept

5.2.1 Images

After selecting the best design, we made a more realistic model of the mockup using a stand we found in the Jolley basement, a medical IV kit, and a heating pad which was connected to a power supply via breadboard. This proof of concept is shown below.

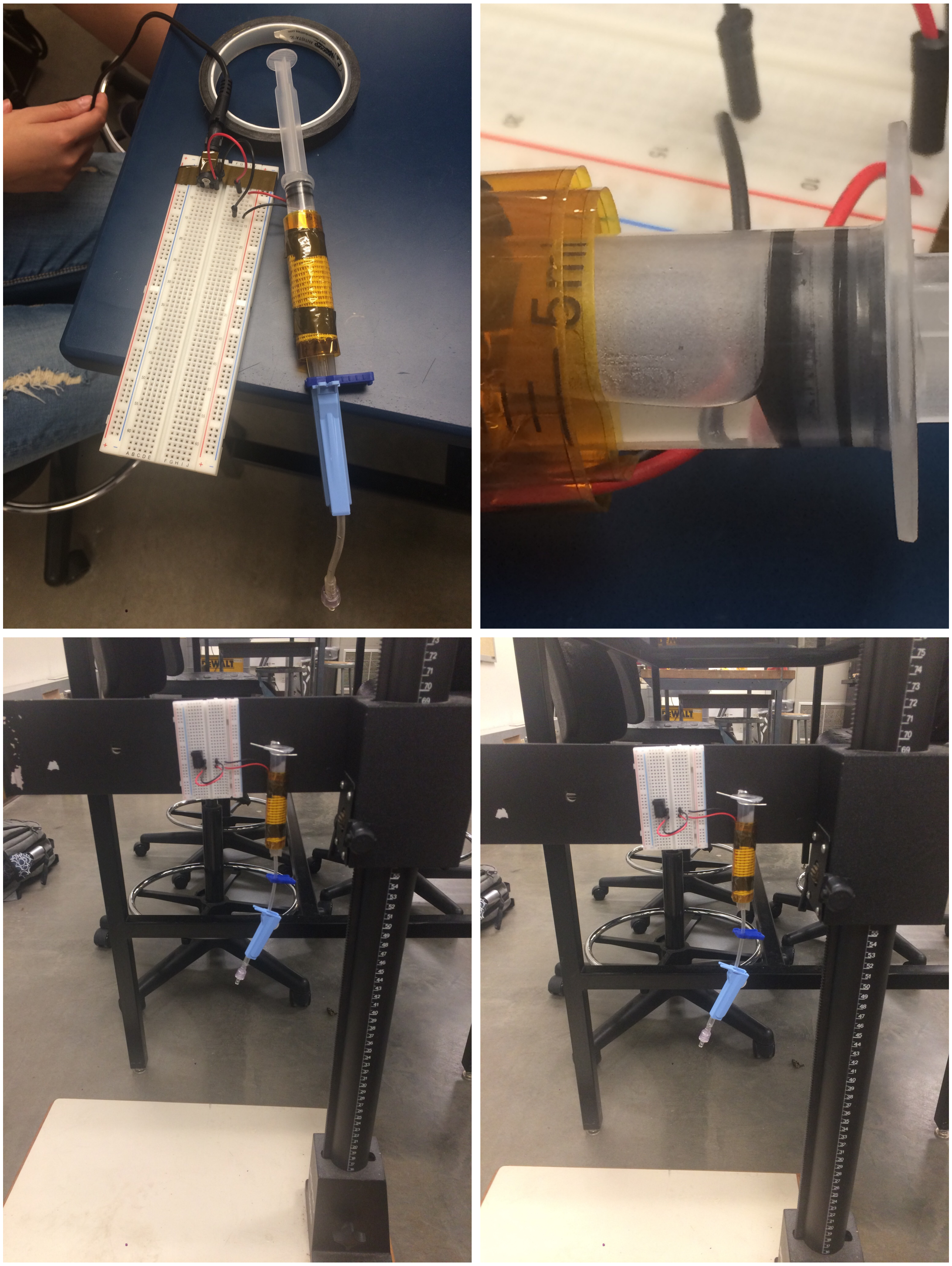


Figure 25: Images of proof of concept model

5.2.2 Influence on the Initial Prototype

Since we did not have chocolate available for this proof of concept, we tested out the heating mechanism by running water through it. We found that the heating pad effectively heated the water, but knew that it would probably take longer to completely melt a piece of chocolate and that the chocolate would be more viscous than the water. With this, we decided that for our initial prototype, we would want to use larger diameter tubing, and considered the possibility of using more than one heating pad and adding insulation around them. We also decided that for the initial prototype we would want the chocolate to melt in a heated basin made of metal with a high thermal conductivity.

5.2.3 Initial Prototype Changes

Our initial prototype and selected concept had a few minor differences. In our selected concept, for example, we had the heated basin directly connected to the flexible tubing. However, in creating our proof of concept and ordering our parts, we decided to use a funnel to connect the two. This way, we could have a gradual change in area from the basin to the tube while avoiding the difficulties and error that could come with shaping one end of the copper basin. After researching common food safe materials used in pots and pans, we decided the funnel would be stainless steel due to its high thermal conductivity. To ensure that the heat stays inside the basin, we also decided to add insulation tape around the heating pad.

Since our priority was getting the chocolate to melt and flow at consistent rates, we were a bit constrained for time and did not make complicated design choices for the dropper stand. While our original concept included a hand crank rank and pinion to adjust the height of the dropper, we ultimately decided to use a clamping mechanism instead. This still allowed for the user to adjust the dropper at any height on the stand, but now required the user to hold the entire arm to avoid tipping. However, this was not a major concern since the arm and dropper were light.

The last and smallest difference between our original concept design and initial prototype was the lid. While the lid was originally designed to be connected to the heated basin by a hinge, we chose not to connect it at all. By removing the hinge aspect, the user could freely insert chocolate to the basin from any angle, without the worry that the lid may snap off. After inserting the chocolate, the lid could now simply be placed on the basin and still provide the same insulation as the original lid would have.

6 Working Prototypes

6.1 Overview

After proofs-of-concept demo, two major changes were made to the design, along with some minor changes. We made a smaller and lighter stand, changed the IV kit into a copper tube, funnel and a 3D-printed roller clamp. We also added a 3D-printed lid and insulation tapes to prevent heat losing and protect users.

6.2 Initial Prototype

Since the base in the proofs-of-concept was too large and inconvenient to carry, we made a smaller base with the same mechanical theorem. A 30cm x 20cm wooden platform was cut and a hole was drilled at the left center to insert support arms. Two PVC pipes were cut into 40cm and 20cm to be used as the support arms. Two holes, whose diameter were the same as the diameter of the pipes, were drilled on a 10cm x 5cm x 5cm wooden block, so that the pipes can be inserted. A side hole was also drilled on the wooden block, so that a 1/4”-20 head bolt can be screwed in to fasten the position of the block. In this case if we loose the bolt, the height of the wooden block could be adjusted, which satisfy our performance goal.

A copper tube, connected to a funnel, was cut into 10cm. Two layers of heating pad was attached around it, so that the chocolate could melt faster. In order to prevent hurting when touching the hot heating pad, we added insulation tapes outside the heating pad. Since the wires of heating pad were short, we attached the breadboard on the support arm and stabilized it with electrical tape. A 3D-printed lid was added to the copper tube. One end of the 3D printed fork was glued into the support arm, and the other end of that fork was used to hold the copper tube.

A soft plastic tube with a nozzle was connected to the end of the funnel. It was also inserted to a 3D-printed roller clamp.By controlling the position of the gear of this roller clamp, we could adjust the drop rate or stop the dropping completely. The initial prototype is shown below.

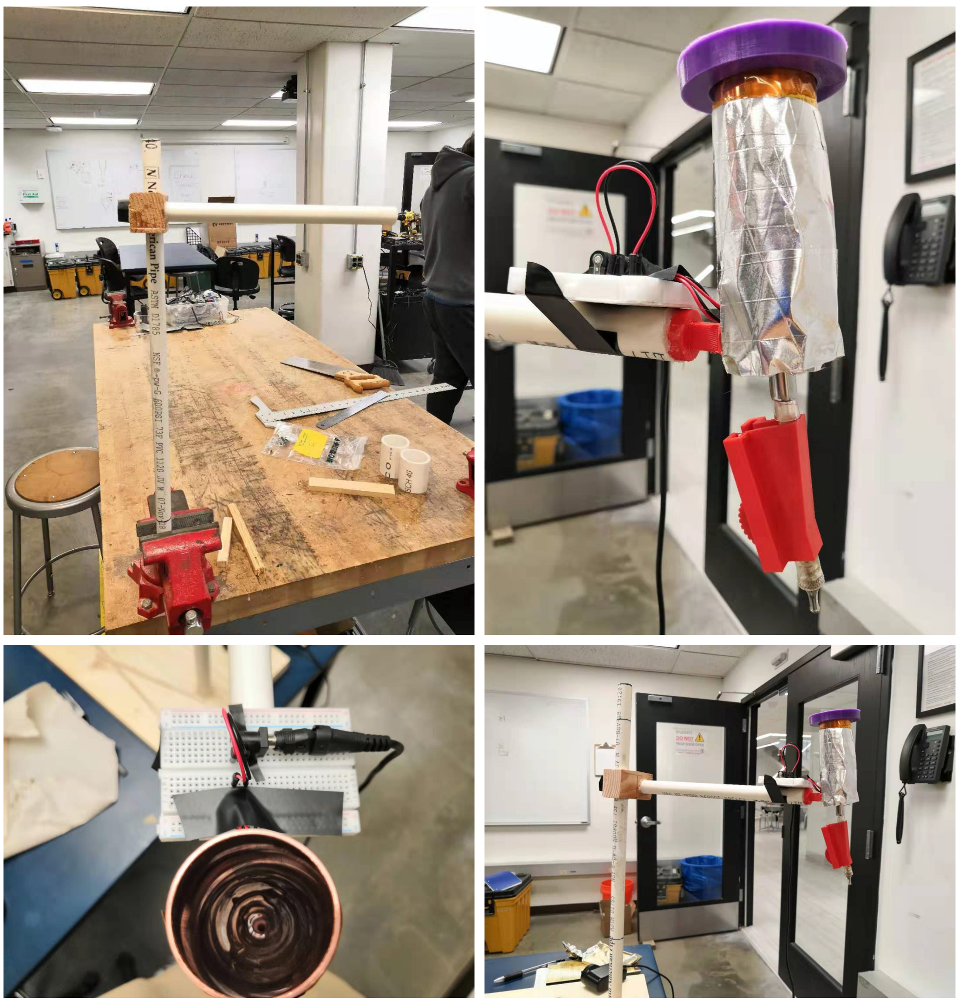


Figure 26: Images of initial prototype

6.3 Final Prototype

While all of our performance goals were met in the initial prototype demo, there is always room for improvement in any design. Our final prototype is shown below.

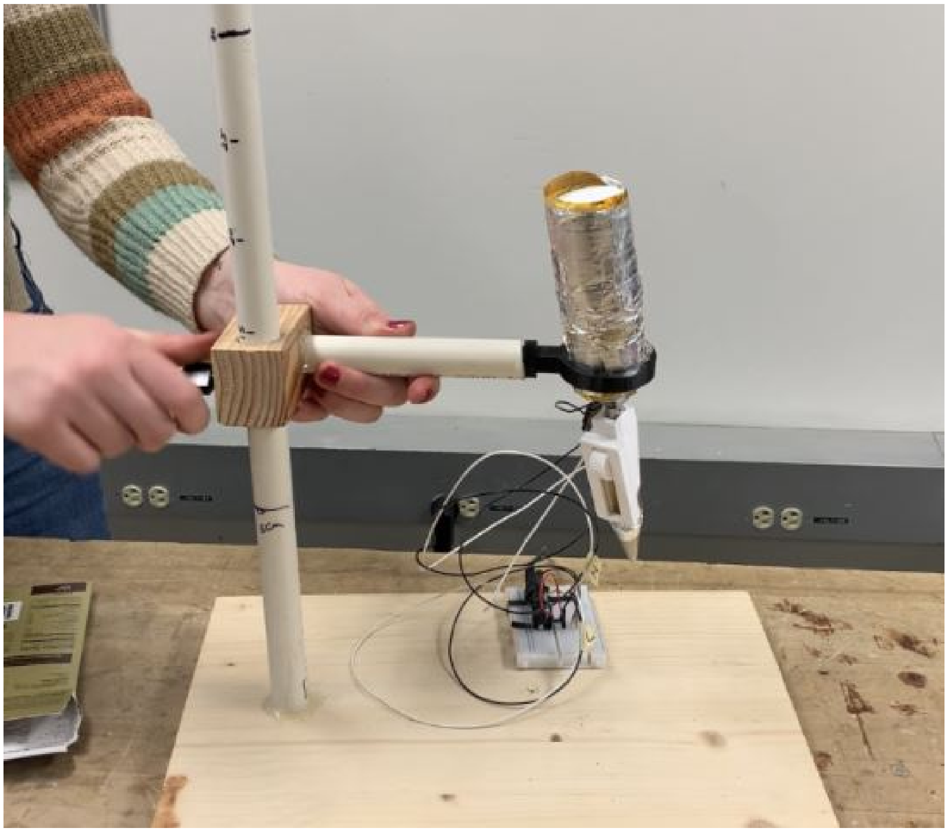


Figure 27: Image of final prototype

One problem that we ran into during the initial demo was that there was some clogging in the nozzle caused by the chocolate cooling and solidifying. To improve this, we chose to lower one of the two heating pads so that both the copper basin and stainless steel funnel would remain heated.

A second adjustment made from the initial to final prototype is that we switched the size of the tubing and the nozzle. Increasing the size of the tubing allowed for a better fit into the funnel and easier assembly overall. With this, increasing the size of the nozzle allowed for a better fit into the new tubing and roller clamp. Additionally, the increased diameter of the nozzle gave a larger area for the chocolate to flow out of, thus minimizing clogs and creating faster, more reasonable flow rates.

A third design challenge that we faced was that the breadboard was not stable on the arm of the stand, so we attached longer wires to the breadboard. With this, we were able to place the breadboard flat on the base of our stand and still adjust the height of the device within its full range. The fourth design challenge that we came across was that there was some shaking in the nozzle as droplets came out. Since the group doing the base plate of the printer will be the ones controlling the movement to create the 3D images, we wanted to make sure that our dropper device is stable. To do so, an extension was added onto the roller clamp that would easily attach to the end of the funnel. This extension can be seen in the CAD sketches of the roller clamp in Fig. 28, especially at the left side of the top and side views. Fig 29 shows the evolution of the roller clamp across all iterations. First the extension was made, then the overall size was increased as we chose to increase the tubing size.

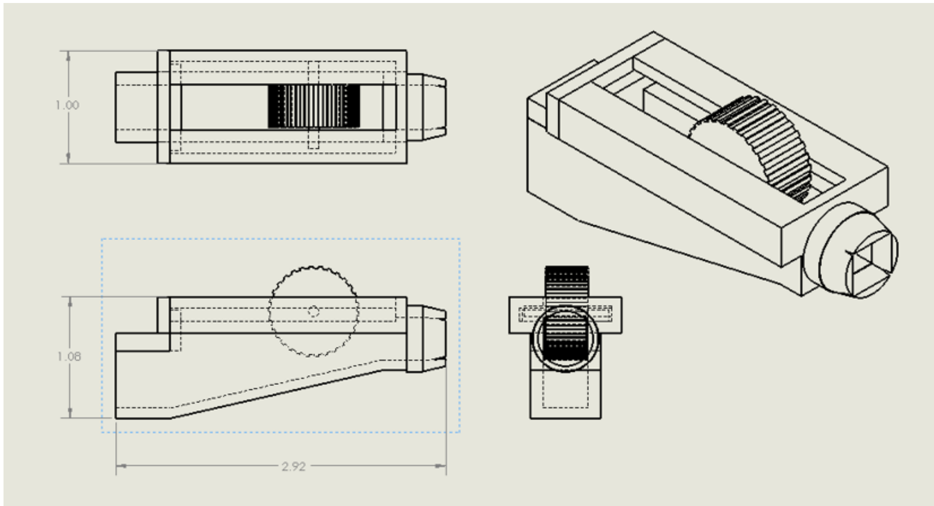


Figure 28: CAD sketches of final prototype roller clamp

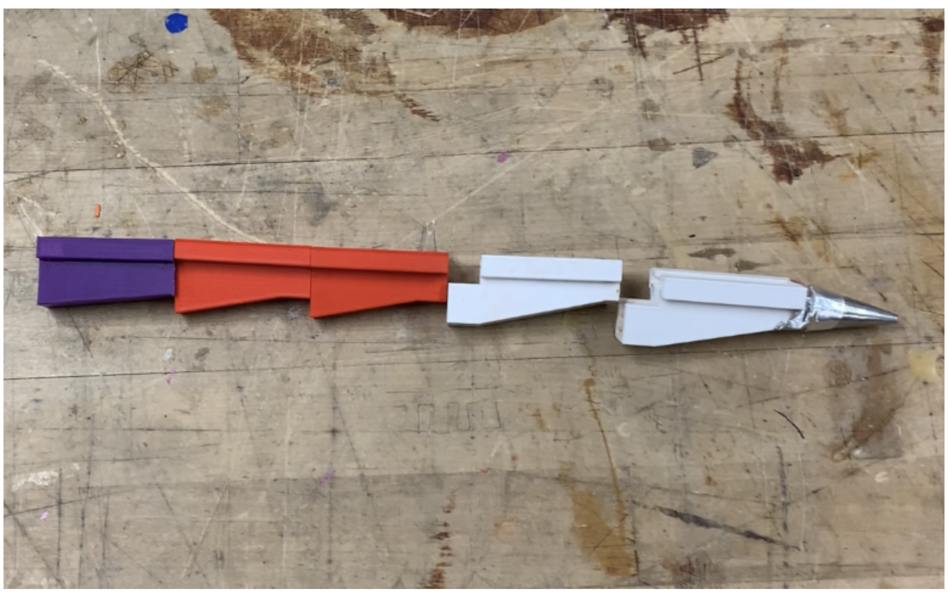


Figure 29: Roller clamp evolution

7 Design Refinement

7.1 FEM Stress/Deflection Analysis

The model for the arm consisted of the 4-inch-long PVC pipe and hooped PLA extruder holder that was 3 inches in length. The PVC pipe was modeled as a cylindrical tube 4 inches in length and with a 0.75 inner diameter and 1.05 inch outer diameter. The extruder holder was 3 inches in length and contained a hoop with a 0.75 inch outer and 2 inner diameter which connected to the base of the holder. The base of the holder had a 2.5 inch extension which fit into the PVC tube. The two pieces were modeled together in a SolidWorks assembly to test for deflection and stress.

The assembly was fixed at end of the PVC tube that did not intersect with the extruder holder and was free at every other point. On the real-life mechanism, the PVC portion of the arm was clamped to vertical part of the frame—another PVC pipe anchored by a wooden base—but due to the rigidness and stability of the frame this fixed boundary condition was appropriate for the model. An external force load of 2.5 N was applied normal to and evenly distributed about the outer circumference of the hoop of the extruder holder. The applied force was based on the calculated weight of the extruder parts plus the estimated maximum weight of chocolate that would be contained in the heating basin of the extruder. In real life, the force distribution of the weight of the extruder on the extruder holder could be more concentrated in certain areas, but due to the symmetry of the parts this assumption sufficed for the model.

Finally, the material properties of the model were manually inputted into SolidWorks. Properties included the density, elastic modulus, shear modulus, tensile strength and compressive strength for both PLA and PVC. Values for these properties were found online. [11][12]

An interference error in SolidWorks appeared for the original assembly when trying to create a mesh for the system, so the portion of the extruder holder that extended into the PVC pipe was deleted for the model before creating a new mesh. The settings of the mesh were set to solid, standard and high quality.

The modeled system is depicted in Fig. 30 through 33 below, where Fig. 30 and 31 show the model prior to testing and Fig. 32 and 33 show the von Mises stress and deflection distributions, respectively. The latter two figures show only the side view of the system, as symmetry was assumed.

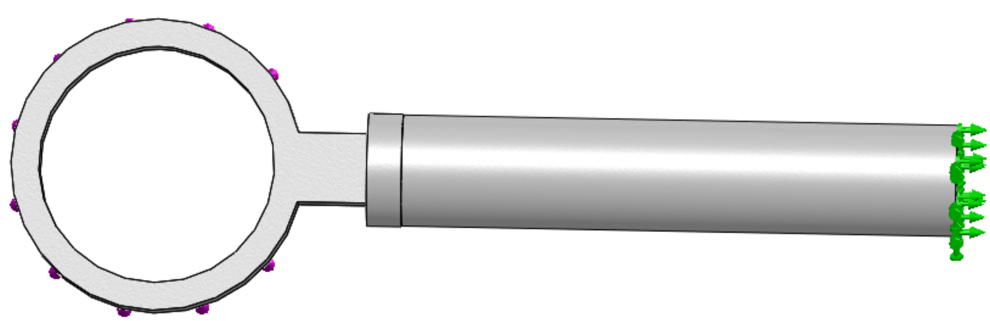


Figure 30: Top view of the model of the arm

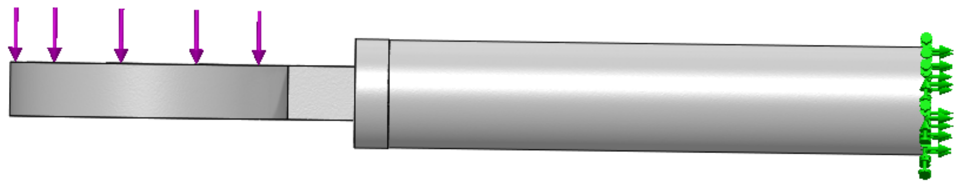


Figure 31: Side view of the model of the arm

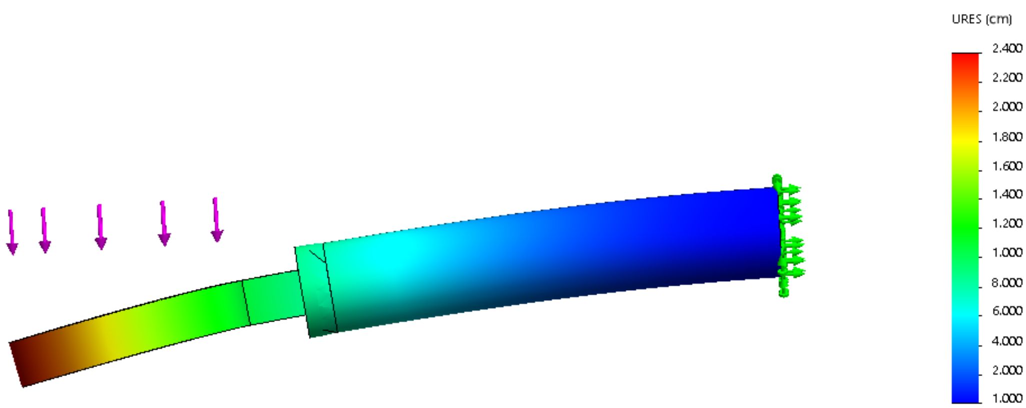


Figure 32: Deflection distribution of the arm

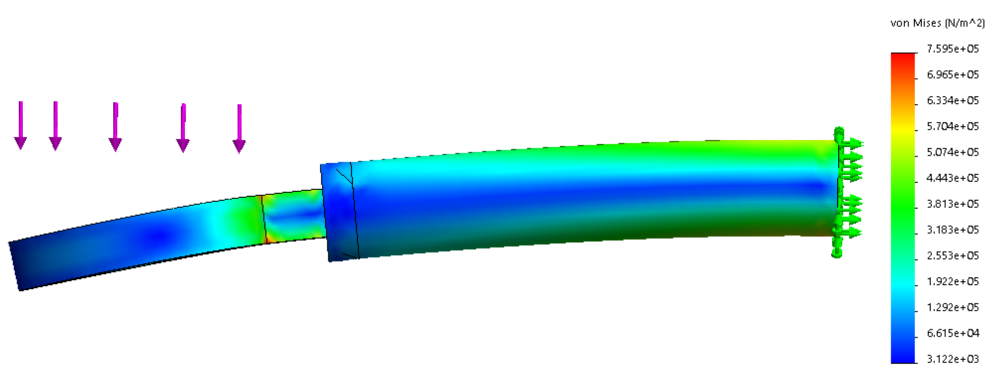


Figure 33: Von Mises distribution of the arm

Since both materials were brittle and failure would be expected to be a fracture, the Modified Mohr theory was used to calculate the factor of safety for the arm. The factor of safety ($F.O.S.$) was calculated from the equation below:

$$F.O.S. = \frac{S_U T}{\sigma_{1st}} = \frac{S_U C}{\sigma_{2nd}} \tag{14}$$

Where S_{UT} is the ultimate tensile strength, S_{UC} is the ultimate compression strength, and σ_{1st} and σ_{2nd} are the first and second principle stresses, respectively. The smaller of the two values was taken to be the $F.O.S.$ Plugging in the values of the compression and tensile ultimate stresses of PLA and the first and second principle stresses obtained through the SolidWorks simulation,

$$F.O.S. = \frac{46.8MPa}{0.84MPa} = \frac{17.9MPa}{0.49MPa} \tag{15}$$

the $F.O.S$ was found to be 36.5 MPa. The ultimate strengths of PLA were used as the stress-analysis indicated the highest concentration of stress in the extruder-holder. The $F.O.S.$ was extremely high and thus it was assumed that the arm would not break in use. This analysis had later been confirmed by repeated testing of the real-life device.

Based on the model, a maximum deflection of 2.4 cm would be expected. This amount would not have any major repercussions for the functionality of the device, as the extruder would still remain upright and the drops would still fall normal to the base plate. There were labels on the vertical part of the frame that indicate what height the extruder is dropping from. To correct for deflection, the measurements for the label were taken from the top of the base plate to the tip of the extruder.

7.2 Design for Safety

When designing any product, safety of the consumer should always be considered, whether that may be from a component failure or user error. As a result, we identified five potential risks associated with the chocolate printer dropper.

7.2.1 Risk #1: Sticking a Hand into the Chocolate Heating Basin

Description: Someone removes the cap and puts their finger into the melting chocolate. The heater is still on when inserting a new piece of chocolate. This could cause minor burns and pain to the user.
Severity: Marginal
Probability: Likely
Mitigating Steps: Add a warning message on the cap

7.2.2 Risk #2: Touching the Heating Pad

Description: Someone grabs the device while it is hot, causing pain and some potential burning.
Severity: Marginal
Probability: Likely
Mitigating Steps: Add insulation around the heating pad

7.2.3 Risk #3: Choking on Small Parts

Description: Someone removes a component of the device, sticks it in their mouth, and accidentally chokes on the part.

Severity: Catastrophic
Probability: Seldom
Mitigating Steps: Add age restrictions

7.2.4 Risk #4: Loose Wiring

Description: The wiring connecting the breadboard and heating pad becomes loose.
Severity: Marginal
Probability: Seldom
Mitigating Steps: Careful soldering or crimping to ensure the wires are secure

7.2.5 Risk #5: Consumption of the Hot Chocolate

Description: Someone attempts to eat the chocolate before it gets cooled, leading to a burned tongue and pain.
Severity: Marginal
Probability: Occasional
Mitigating Steps: Give safety instructions. For example, "Allow chocolate to cool for 5 minutes before consumption."

7.2.6 Heat Map and Risk Prioritization

After identifying hazards of our device, we created a heat map using the severity and probability of each to prioritize each risk. Risks with more precedent are in red, moderate risks are orange and yellow, and unlikely or un-concerning risks are in green.

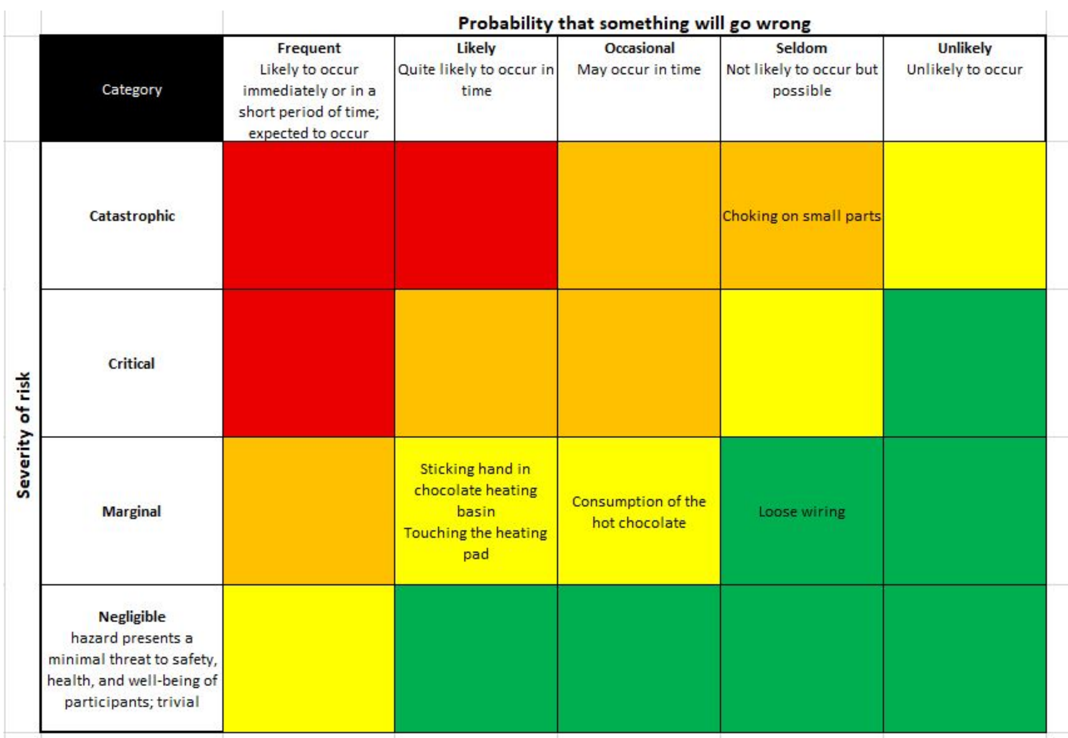


Figure 34: Risk Assessment Heat Map

Based on this heat map, we did not have any red risks, which meant that there were not any risks that both posed very large threats and could easily happen. However, while the risk of choking on small parts would not likely occur, it could produce a catastrophic outcome. For this reason, choking on small parts was highlighted orange in the heat map and became our highest priority. To combat this, we could add an age restriction to the device, which should be simple since the intended user will be college-aged. The risks that would be next highest in priority were the yellow ones that could cause minor pains and burns. Someone could burn themselves by placing their hand in the chocolate heating basin or touching the heating pad while it is hot. Both of these are likely to occur, but would not be very severe. To mitigate the yellow risks, we would add a cautionary note on the cap of the basin, add insulation tape on the outside of the device as a protective layer from the skin, and suggest that the user wait before eating the chocolate or cleaning the device to allow for proper cooling. The final, lowest priority risk was loose wiring, which could cause the heating pad to disconnect from the breadboard and not warm up. To prevent this from happening, we would make sure our crimping is done carefully, the wires are long enough for the device to move up the arm, and the wires are secure in the breadboard.

7.3 Design for Manufacturing

7.3.1 Draft Analysis

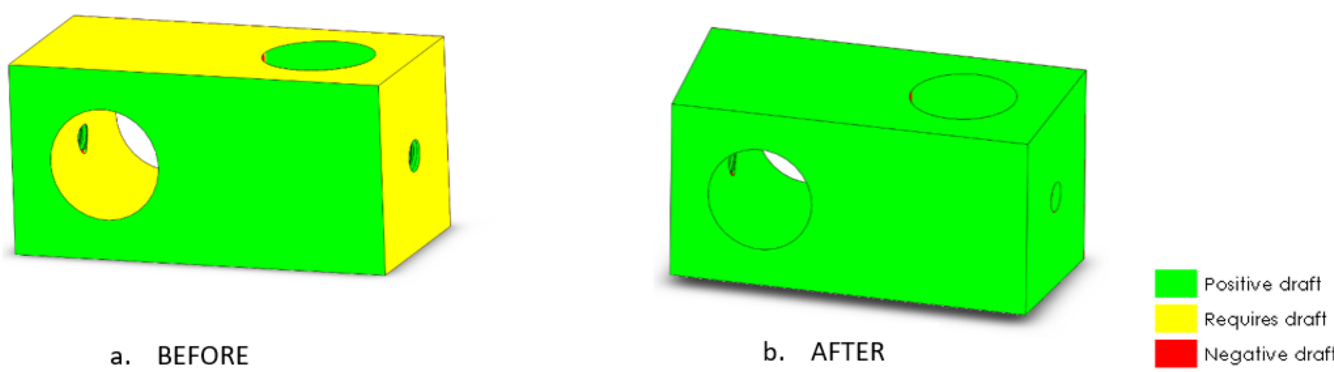


Figure 35: Images of the clamp mount used for draft analysis in SolidWorks, a) Draft analysis of original clamp, b) Draft analysis after adding 3 degrees to the required faces.

A draft analysis was performed on the clamp due to its simple geometry. Images of the draft analysis before and after drafting the clamp are shown in Fig. 35. Initially, all walls except the front wall required a draft. Thus, a draft angle of 3 degrees was added to each of the walls so that the wall thickness would be minimally affected. After the drafting process, all walls and holes had a positive draft and no other faces required drafts.

7.3.2 DFM Analysis

A DFM analysis was applied on the gear of the rolling clamp in the 3D chocolate printer. The following page contains the results for an analysis run for a mill/drill only and an injection molding manufacturing method.

Mill/Drill only

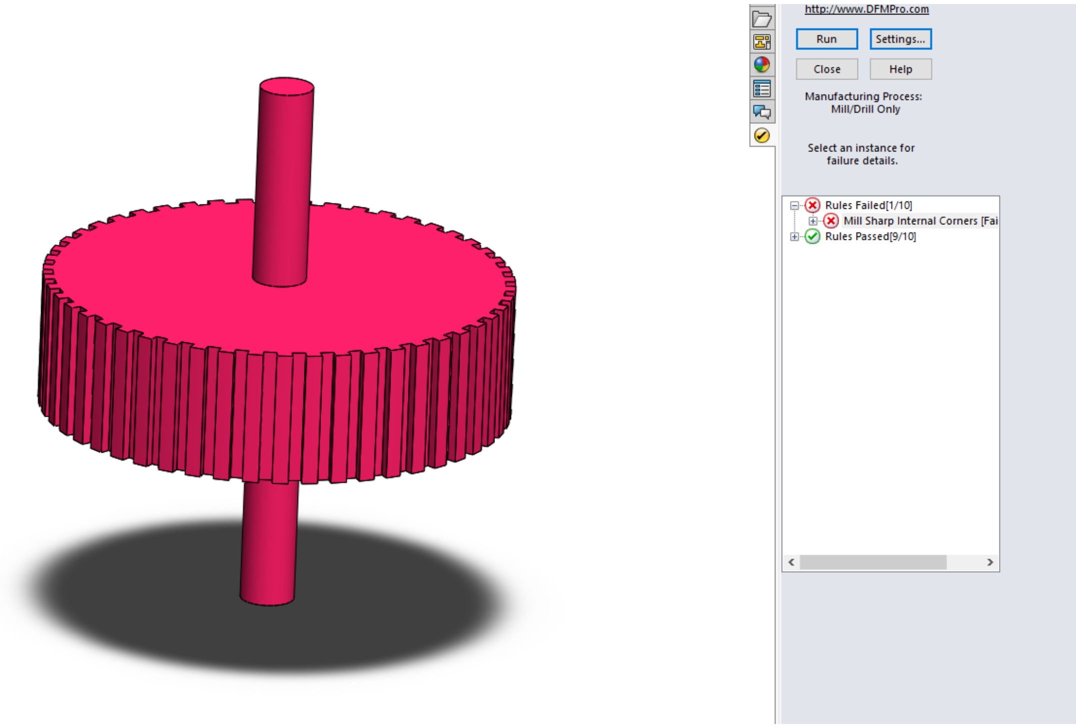


Figure 36: Issues present for a mill/drill-only manufacturing process

Using a manufacturing process of mill/drill only, there were ten rules that needed to be followed. For the gear, only one rule failed, as shown in Fig. 36. Sharp internal corners were difficult to achieve with milling, and thus these sharp corners should be radiused.

Injection Molding

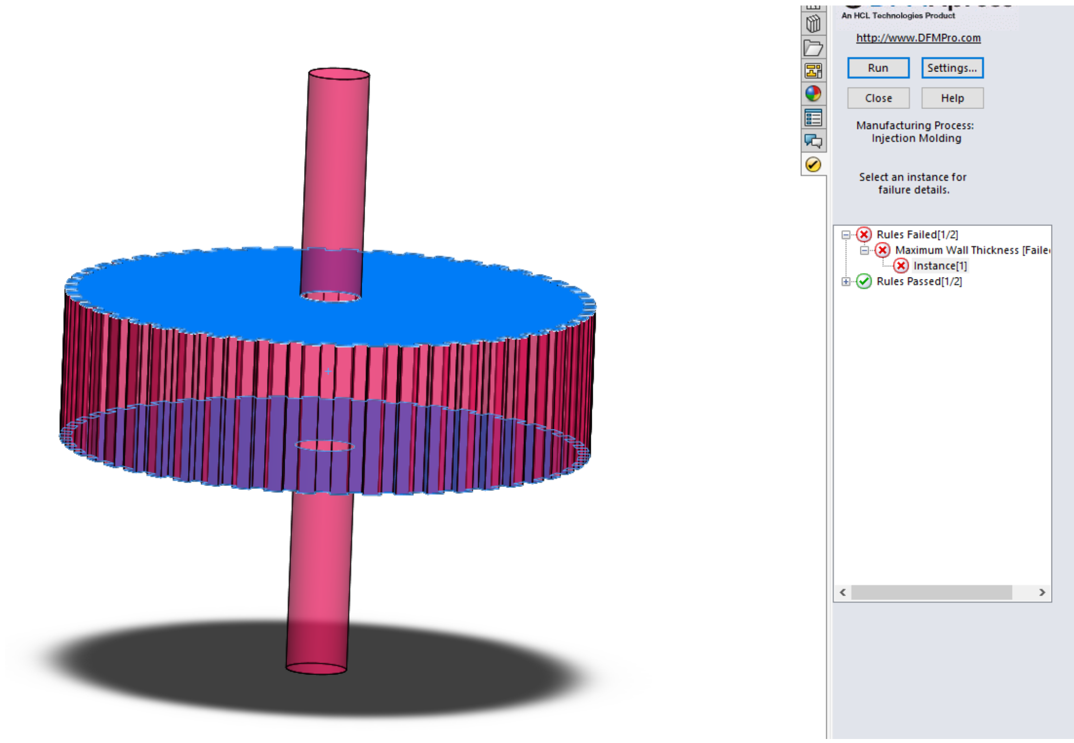


Figure 37: Issues present for an injection modeling manufacturing process

Using a manufacturing process of injection modeling, there were two rules that needed to be followed. The gear did not satisfy the rule related to the maximum wall thickness. The expected wall thickness was less than 0.12 in, but the gear had a wall thickness of 0.2 in, which could lead to cooling problems and defects. Therefore, the wall thickness should be redesigned in order to use injection modeling.

7.4 Design for Usability

7.4.1 Vision Impairment

Vision impairment would be an issue for users of our device. Since the wires in the original heating pad were too short to connect to the breadboard, we connected these short wires with longer wires using the crimping method. The short wires could be disconnected to the longer ones for easier cleaning of the container. However, the positive and negative wires were colored red and black, which could be difficult for color blind users to differentiate. Thus, this would create a problem for those users to connect the wires. To mitigate this, we could label the positive and negative wires, and make the signs large enough for people with presbyopia to see.

7.4.2 Hearing Impairment

Hearing impairment would have no influence on the usability of our device, because no part of the device relied on auditory signals for the user and no part could make any sound during use. Therefore, we did not need to worry about the usability of our device for people with hearing impairment.

7.4.3 Physical Impairment

Physical impairment would create several problems for users of our device. While a primary goal of our device was ease of cleaning, the container and nozzle would need to be disassembled. Since the openings of these parts were small and the tube needed to be compressed to be inserted into the funnel, it would be difficult for users with arthritis or a limb immobilization to assemble the device. Additionally, the height of the dropper was controlled by a clamp with a head bold, which would be difficult to loosen and fasten with only one available arm.

7.4.4 Control Impairment

Control impairment would have an influence on the usability of our device. Since the device needed to be pre-heated for about 10 minutes and continue heating for 5 more minutes to melt chocolate, distracted users could lose their focus. Additionally, the inner wall of the container became hot to touch in use, so users with ADHD (attention deficit hyperactivity disorder) could hurt themselves if they inserted their fingers into the container. Thus, a caution label should be added on the cap and wall of the container.

8 Discussion

8.1 Project Development and Evolution

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

- Yes, the initial project description stated that a chocolate dropper would be created that would both melt and distribute chocolate at adjustable and controllable rates. The final project result consisted of a heating basin that effectively melted added chocolate and a rollerclamp that could control the droplet rate of various frequencies.

Was the project more or less difficult than expected?

- The project was more difficult as expected and less in others. For instance, it was initially thought that creating a mechanism to control the drop rate would be the most difficult, but the discovery that a rollerclamp that utilizes gravity could be effectively used (as opposed to constructing a motor-operated plunger as originally thought) made the task less difficult. However, other issues arose that were not initially taken into account for the scope of difficulty of the project, such as vibration of the extruder and solidifying of the chocolate in the nozzle.

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

- The part of the design process that we should have spent more time on was drawing and perhaps even CAD modeling of our project at before stage of development. There were some items that we had difficulty fitting together in the assembly (such as the nozzle to the device) that we may have been able to make design adjustments for an easier and more stable assembly. There did not seem to be an area of focus in the design process that required less time than what our group put into it. Adequate research helped inform our decisions in choosing parts that would be imperative to the functioning of our device, and most time spent on the project was dedicated to making much-needed design requirements in order to meet the three benchmarks set for the project.

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

– Creating a frame with an adjustable arm height was significantly easier than expected. Some of our earliest design concepts consisted of using a rack-and-pinion or spring clips. Ultimately, we designed a sliding clamp that was made of just wood with drilled holes and a screw for tightening. This held the arm securely and was easy to adjust to any height on the leg of the frame.

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

– In hindsight, a ball valve might have been more effective at controlling the drop rate of the chocolate, as it does not push excess chocolate out as it closes, so the change in drop rate occurs much faster. In addition, the support for the extruder could have been refined for more stable placement of the parts to decrease vibration.

8.2 Design Resources

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

– Codes and standards involving safety regarding food handling equipment were deemed most relevant for this project because its intended user would be working with hot or contaminated food that they may later consume. The most direct impact the codes and standards had on the final design was the addition of insulating tape around the heating basin to protect the user from coming into contact with a hot heating pad.

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

– The biggest unknown early in the design process was how well a heating pad could melt chocolate, especially when not in direct contact with it. We continued with our design concept to wrap a heating pad around a metal tube to melt the chocolate inside, which ultimately proved to be effective and thus stifled any fears that were had about not being able to melt the chocolate.

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

– An analysis of the cooling rate of chocolate, particularly as it passes through the rubber tubing, would have been helpful in determining how far the chocolate could travel from the heating basin before solidifying. This could have informed design decisions around the length of the extruder extending from the heating basin.

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

– The second time around, we would explore more existing parts for us to use in our device, especially more durable and machined materials that would make the device more precise and have a longer lifespan.

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

– With more time and money, the frame could be swapped out with metal bars and a metal stand for more durability and less deflection. Also, a more intricately designed arm could be made to better support the extruder, and finally a new rollerclamp could be designed to have a fixture for the nozzle to attach to.

8.3 Team Organization

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

- Combined, the team possessed skills in and leadership traits that made for the success of the project, such as being detail-oriented, forward-thinking, big-picture, focused, precise, and flexible. Though there were not any specific skills that we collectively lacked that would be essential to the success of the project, a more robust background in design and build from each member could have granted us a larger idea of what features we could add to the device.

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

- Though there are not specific projects that come to mind, each member of the group agreed that this design experience was enjoyable and offered a good opportunity to combine classroom knowledge of engineering principles with creativity and design skills. We would be curious to practice the design process under longer time constraints and with more stakes in the real world.

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