January 2023

MEMS 411: T-Shirt Strip Dispenser

Connor Eames

Colter Nunn

Jack Ward

Jay Wiebe

Washington University in St. Louis
JAMES MCKELVEY SCHOOL OF ENGINEERING

Mechanical Engineering Design Project
MEMS 411, Fall 2022

T-Shirt Strip Dispenser

For this design project, we worked with Dr. Mary Ruppert-Stroescu from the Sam Fox School of Design and Visual Arts to create a device that dispenses t-shirt strips. Dr. Ruppert-Stroescu has a patented process where strips of cloth are laid down on a sticky backing paper and sewn together to be made into new clothing. Our goal was to streamline the strip-laying process, making it less tedious and time consuming. Our design had to be ergonomic so that the device was comfortable to use. It also had to be lightweight to avoid the user experiencing wrist or hand fatigue after using the device for a long period of time. Lastly, the device had to be simple to use as Dr. Ruppert-Stroescu often works with non-native English speakers. This language barrier makes it difficult to teach proper use of more complicated devices and mechanisms. Our device is made up of 4 main components: the handle/backing plate, the spool, the roller, and the ball bearing. Each one of these components is essential in order for our device to work properly.

Eames, Connor
Nunn, Colter
Ward, Jack
Wiebe, Jay

Contents

List of Figures

List of Tables

1 Introduction

For our design project, we will be working with Dr. Mary Ruppert-Stroescu from the Sam Fox School of Design and Visual Arts to create a t-shirt dispensing device. Dr. Ruppert-Stroescu up-cycles old t-shirts, cutting them into long and thin strips that are laid out on quilting paper, stitched together, and turned into fashionable clothing. Currently, the time-consuming process of laying each strip is done entirely by hand, limiting her production capabilities. The goal of this design project is to come up with a mechanism capable of expediting this process, allowing Dr. Ruppert-Stroescu to increase throughput and scale her operation. By designing a dispensing device that can roll out each strip, seamlessly cut the material, and be repositioned to lay the next strip, this process can be dramatically improved upon.

2 Problem Understanding

2.1 Existing Devices

Below we will introduce several existing devices that utilize similar features and principles to a t-shirt strip dispensing device.

2.1.1 Existing Device #1: Duck Brand Foam Handle Tape Dispenser

Figure 1: Duck Brand Foam Handle Tape Dispenser (Source: Duck Brand)

Description: The Duck Brand Foam Handle Tape Dispenser is a tape dispenser that allows the user to tape cardboard boxes easily by dragging the black roller along the box to lay the tape on it which places the tape flat if pressed firmly against the box. When the user is finished taping, there is a sharp blade that will cut the tape. There is also a long plastic piece used to aid in the cutting of the tape. Most aspects of this dispenser will relate to our design including the ability to hold a rolled material, the comfortable handheld grip, the ability to cut the material when finished, and the manipulation of the rolled material in order to press it flat against a surface.

Website Link: https://www.duckbrand.com/products/moving-storage/tape-dispensers/clear-188-in-x-546-yd

Video Link: https://www.youtube.com/watch?v=ahiYt7aRsYs

2.1.2 Existing Device #2: Nichiban Push-Cut Tape Cutter

Figure 2: Nichiban Push-Cut Tape Cutter (Source: Yoseka Stationary)

Description: The Nichiban Push-Cut Tape Cutter is a device that allows the user to dispense tape and then cut it. The top button pushes the tape out a set distance, then the lever at the bottom cuts the tape. The device easily opens up so that the user can change or replace the tape. The cutter mechanism and the ease of changing the material are two components that could be useful for our design.

Link: https://yosekastationery.com/products/nichiban-push-cut-tape-cutter

2.1.3 Existing Device #3: BIC Wite-Out EZ Correct Correction Tape Roller

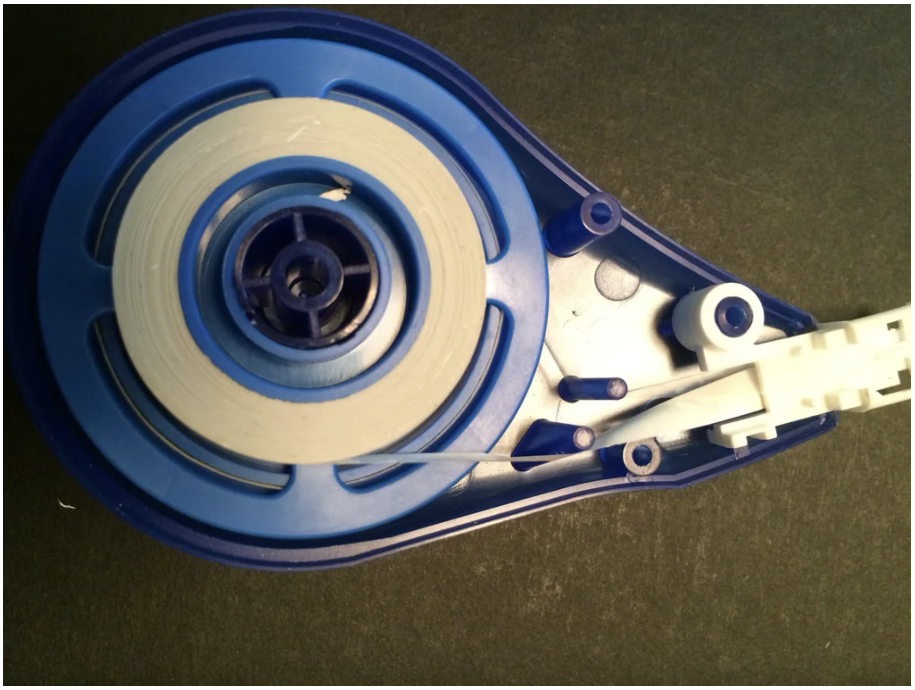


Figure 3: BIC Wite-Out EZ Correct Correction Tape Roller (Source: Instructables Craft)

Description: The BIC Wite-Out EZ Correct Correction Tape Roller is a device used to lay strips of white correction tape over errors in written documents. This mechanism accomplishes a similar goal to a t-shirt strip dispenser, taking a spool of easily-deformed strip material and laying it perfectly flush and straight along a flat surface. The device features a cutting mechanism to control the length of each strip, and the system of rollers provides adequate tension for laying without causing deformation. The case can be opened to replace spools of correction tape material and to fix any jams or misalignment. All of these features could be useful in the design of our t-shirt strip dispenser.

Link: https://www.instructables.com/Fix-Your-Bic-Wite-Out-Correction-Tape-Feed/

2.2 Patents

The following patents provide valuable design insight into similar products to our proposed t-shirt strip roller. Each patent pertains to one of the existing devices mentioned above, and gives a closer look at each mechanism's construction and function.

2.2.1 Patent 1

Patent Name: Shipping and Packing Tape Dispenser and Mount
Patent Number: US 8,037,917 B2

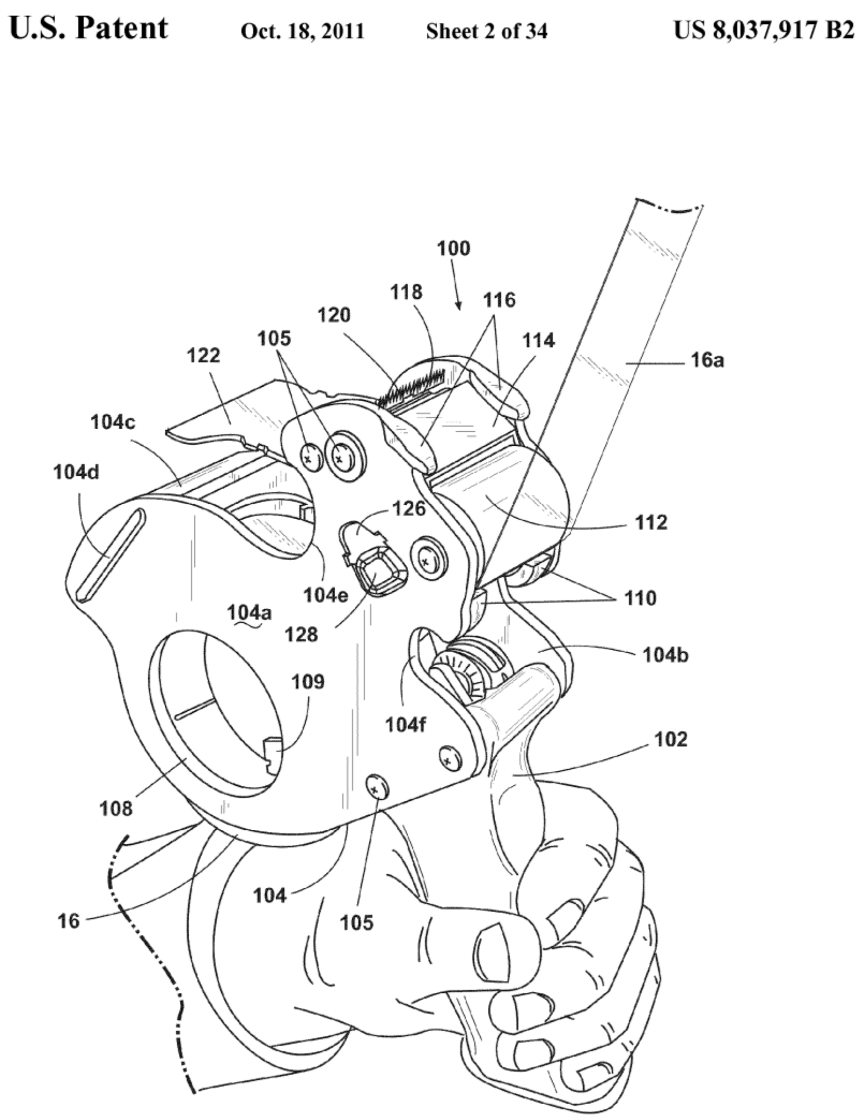


Fig. 2

Figure 4: Patent images for packing tape dispenser

Description: This patent for a packing tape dispenser consists of a ergonomic handle, a body to hold a roll of tape, and a serrated blade to cut the tape. It also has a cylindrical roller and a press plate that is used to flatten the tape as it is placed down. While this mechanism is used for tape rather than cloth, it is still fairly similar to what we hope to design.

2.2.2 Patent 2

Patent Name: Correction tape re-tensioning mechanism and correction tape dispenser comprising same
Patent Number: US8746313B2

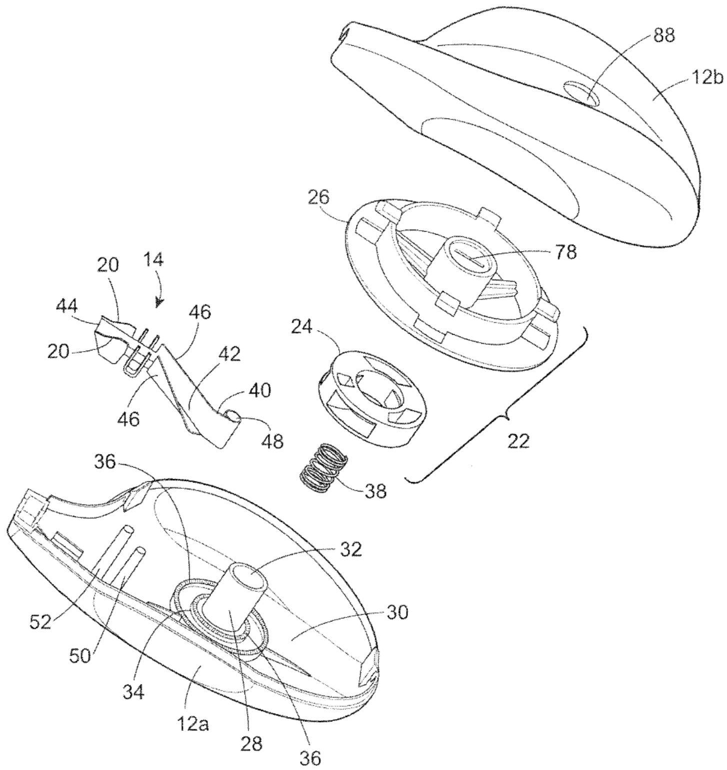


FIG. 2

Figure 5: Patent images for correction tape re-tensioning mechanism

Description: This patent shows all parts making up the re-tensioning system within a correction tape dispenser, similar to the BIC Wite-Out EZ Correct Correction Tape Roller pictured earlier. This system is critical to the function of the device as it keeps the strip of correction tape in tension, even after it is cut. This ensures strips can be dispensed repeatably and there is no need to re-align or re-thread the tape. Finding a way to implement a similar feature in our t-shirt dispensing device is important to ensure maximum efficiency, allowing the user to immediately lay a new strip of material after cutting the previous strip.

2.3 Codes & Standards

The following codes and standards provide standardized procedures and information relevant to the design of our device.

2.3.1 Code/Standard 1

Code/Standard Name: Standard Test Method for Stretch Properties of Textile Fabrics - CRE Method
Code/Standard Number: Standard ASTM D6614/D6614M-20
Description: Standard ASTM D6614/D6614M-20 defines a test method capable of determining the amount of elongation and change in area when low-stretch fabrics are extended a specified distance

and held for a specified period of time. As Dr. Ruppert-Stroescu showed during our customer interview, the cloth strips can easily be permanently deformed when placed in excessive tension, leaving gaps between laid out strips. It is critical that our device provides enough tension to lay the cloth strips straight and flat, but this must occur without causing any permanent deformation to ensure the strips overlap properly. This standard will allow us to obtain baseline stretch properties for the cloth strips being used and ensure the forces applied by our device will not cause any permanent deformation.

2.3.2 Code/Standard 2

Code/Standard Name: Standard Tables of Body Measurements for Mature Men, ages 35 and older, Sizes Thirty-Four to Fifty-Two (34 to 52) Short, Regular, and Tall
Code/Standard Number: ASTM D6240/D6240M-12(2021)e1
Description: Standard ASTM D6240/D6240M-12(2021)e1 provides tables of relevant adult male body dimensions to aid in the design of properly-fitting clothing. These dimensions are important for the design of our device as it will allow us to determine the necessary maximum footprint and aid in the programming of any automated processes. While much of the device's focus is on improving the strip laying process itself, the end product must meet or exceed these target dimensions to ensure each resulting piece can actually be incorporated into a properly-fitting item of clothing. *Note: The standard for women's sizes (ASTM D5585-21) will also be investigated and accounted for. These standards are listed together to eliminate repetitiveness within this document.*

2.4 User Needs

To determine device requirements and design specifications, a customer interview was conducted with Dr. Ruppert-Stroescu. Afterwards, we compiled a list of what we thought to be the most important user needs, then ranked them on a scale from 1-5 (with 1 being the least important and 5 being the most important).

2.4.1 Customer Interview

Interviewee: Dr. Mary Ruppert-Stroescu
Location: Bixby 14, Washington University in St. Louis, Danforth Campus
Date: September 9^{th}, 2022
Setting: We went to Dr. Ruppert-Stroescu's workspace, where she walked us through her current fabrication process. She demonstrated how old t-shirts are cut into one long strip, which is then laid in a series of rows on quilting paper. She then talked us through her next steps and showed us what the final products look like. She allowed us to investigate the materials and tools currently used during the process, and we followed up by asking relevant questions. The whole interview took ∼50 min.

Interview Notes:
What is the intended use of the device?

- This device is intended to lay strips of textile material on quilting paper so they can be stitched together and turned into clothing.

Interview Notes:
What challenges are commonly seen in the current laying process?

- Laying the strips by hand is a time-consuming process that limits throughput.

– Strips can be easily deformed by applying too much tension, causing them to shrink in width and leading to the presence of gaps.

– Without sufficient tension, strips can bunch up or crease during the laying process, leading to defects in the fabric pattern.

– It can be difficult to align strips such that they overlap properly, leading to uneven spacing.

Interview Notes:
What goals does the ideal device accomplish?

– Expedites the strip-laying process, allowing for increased throughput.

– Limits the amount of manual labor required, reducing wear and tear on Dr. Ruppert-Stroescu.

– Consistently lays strips flat and straight without causing any permanent deformation.

– Ensures even spacing and overlap between strips.

2.4.2 Interpreted User Needs

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	Device is lightweight	4
2	Maintain proper tension	5
3	Lays strips flat	4
4	Properly overlaps cloth strips	3
5	Device can hold one full spool of cloth	4
6	Easily cuts cloth	3
7	Device fits comfortably in hand	5
8	Device is easy/quick to use	5

2.5 Design Metrics

Below is a chart containing the design specifications that are necessary to follow as the design is created.

Table 2: Target Specifications

Metric Number	**Associated Needs**	**Metric**	**Units**	**Acceptable**	**Ideal**
1	1	Total weight	lb	5	3
2	5	Total volume	in^3	< 150	< 100
3	8	Time to load/unload fabric	sec	< 60	< 30
4	6	Time to cut fabric	sec	< 5	< 3
5	4	Width of strip the device can work with	in	< 0.75	< 0.80
6	3	Lays strips meeting dimensional requirements from Patent Number US8746313B2	in	< 40	< 50
7	2	Applies tension compliant with Patent Number US 8,037,917 B2	in	< 0.0625	0

2.6 Project Management

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

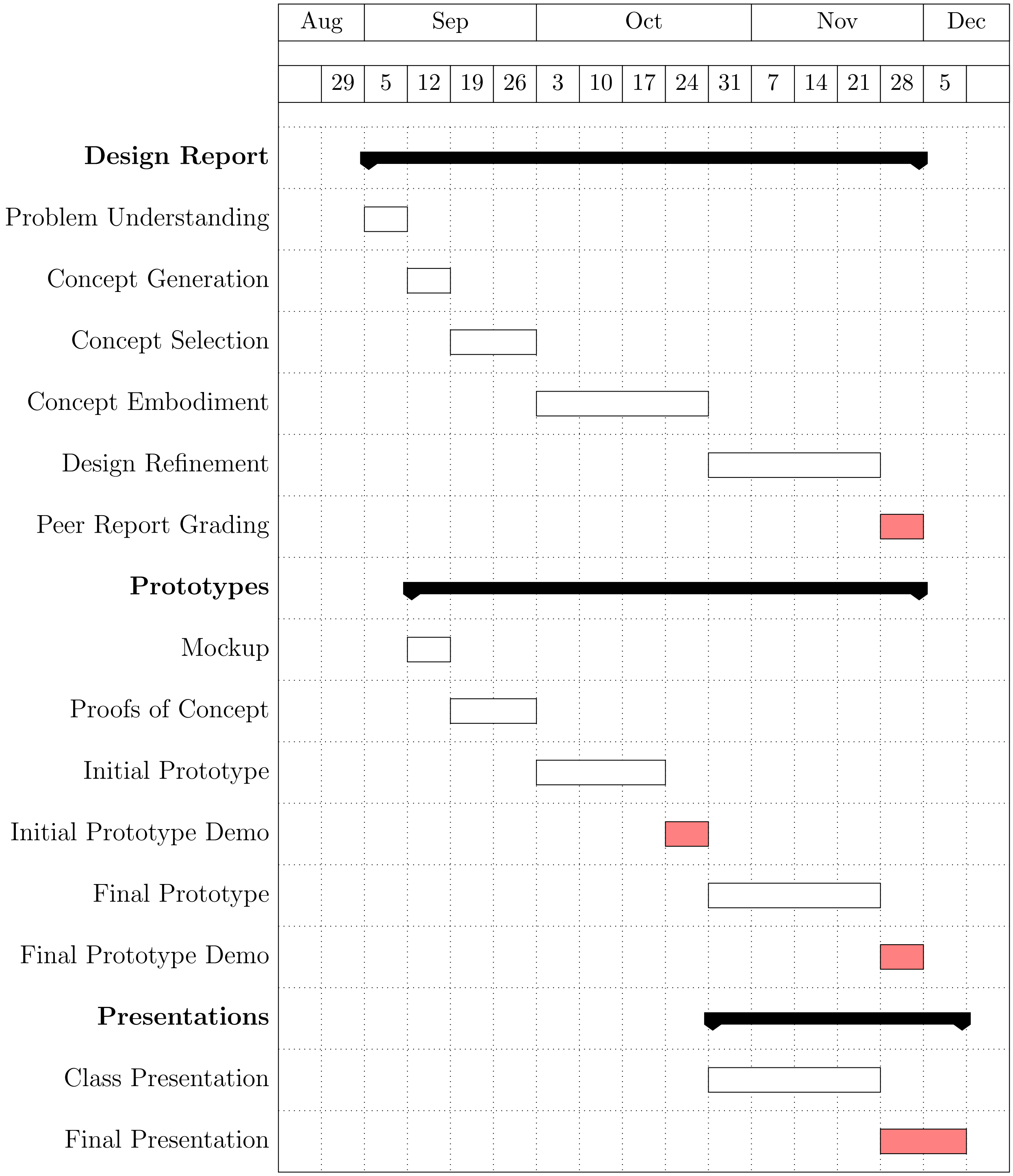


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

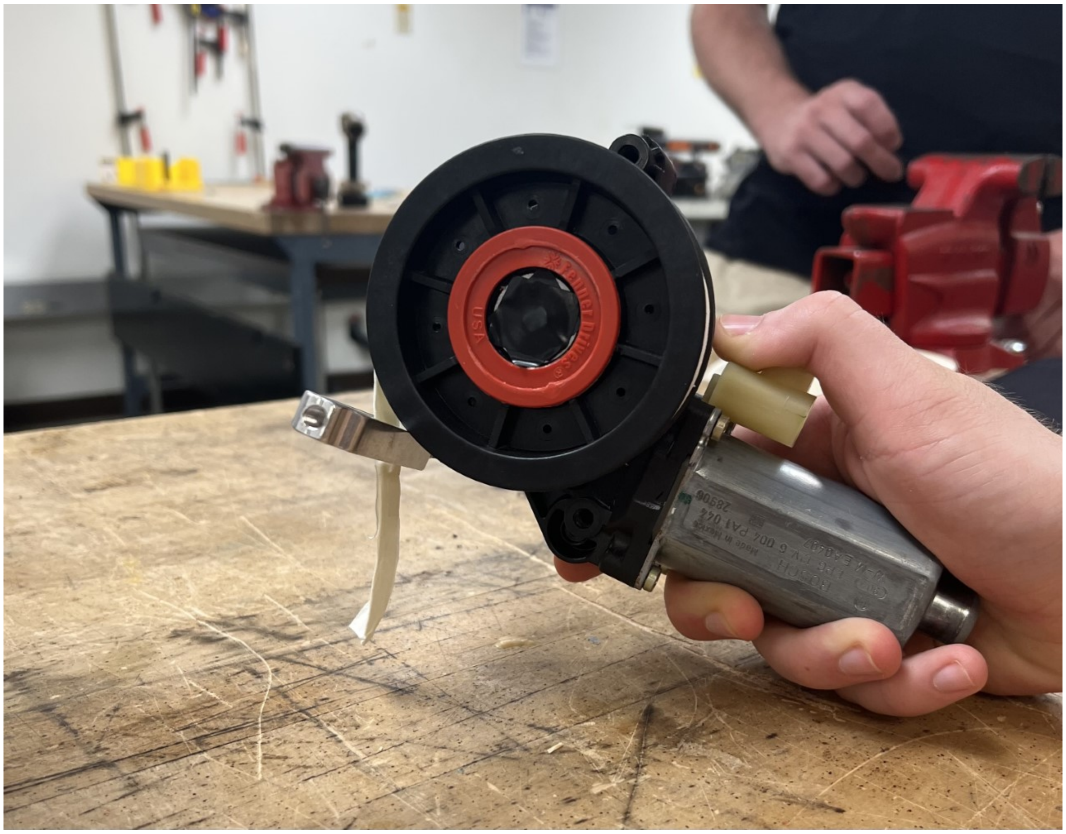


Figure 7: Side view of mockup prototype

Figure 8: Top view of mockup prototype

Figure 9: Other side view of mockup prototype

Creating our mockup gave us some valuable insight on ideas that could work in our design. We folded tape onto itself to simulate t-shirt fabric and found that the black and red spool did a great job of holding the fabric, so we'll try to replicate that in our spool design. The metal handle worked well enough, but it was a bit heavy and uncomfortable to hold. In our final design, we will use a lighter and more ergonomic handle. Finally, the metal slot that we put the fabric through was good for holding the tape and laying it flat on the table. However, we found that it was difficult to maintain proper tension on the tape so we will need to find a method to do so, possibly by using a cylindrical roller or a second slot.

3.2 Functional Decomposition

Below is our function chart, which states the overall function of our product and list the necessary subfunctions with some examples.

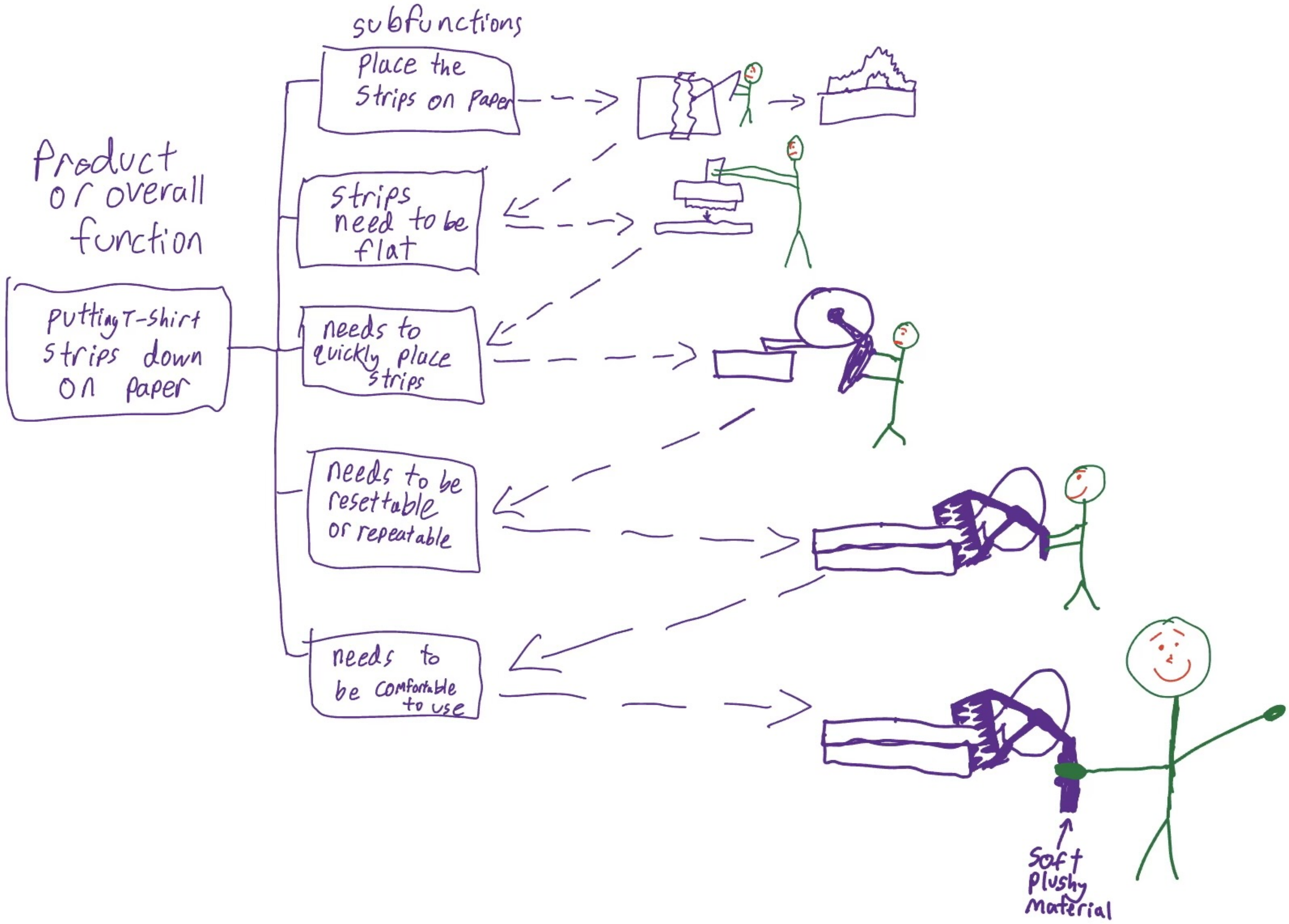


Figure 10: Function tree for the t-shirt strip dispenser

3.3 Morphological Chart

Below is our morphological chart, which contains three specific ideas for each subfunction of our product.

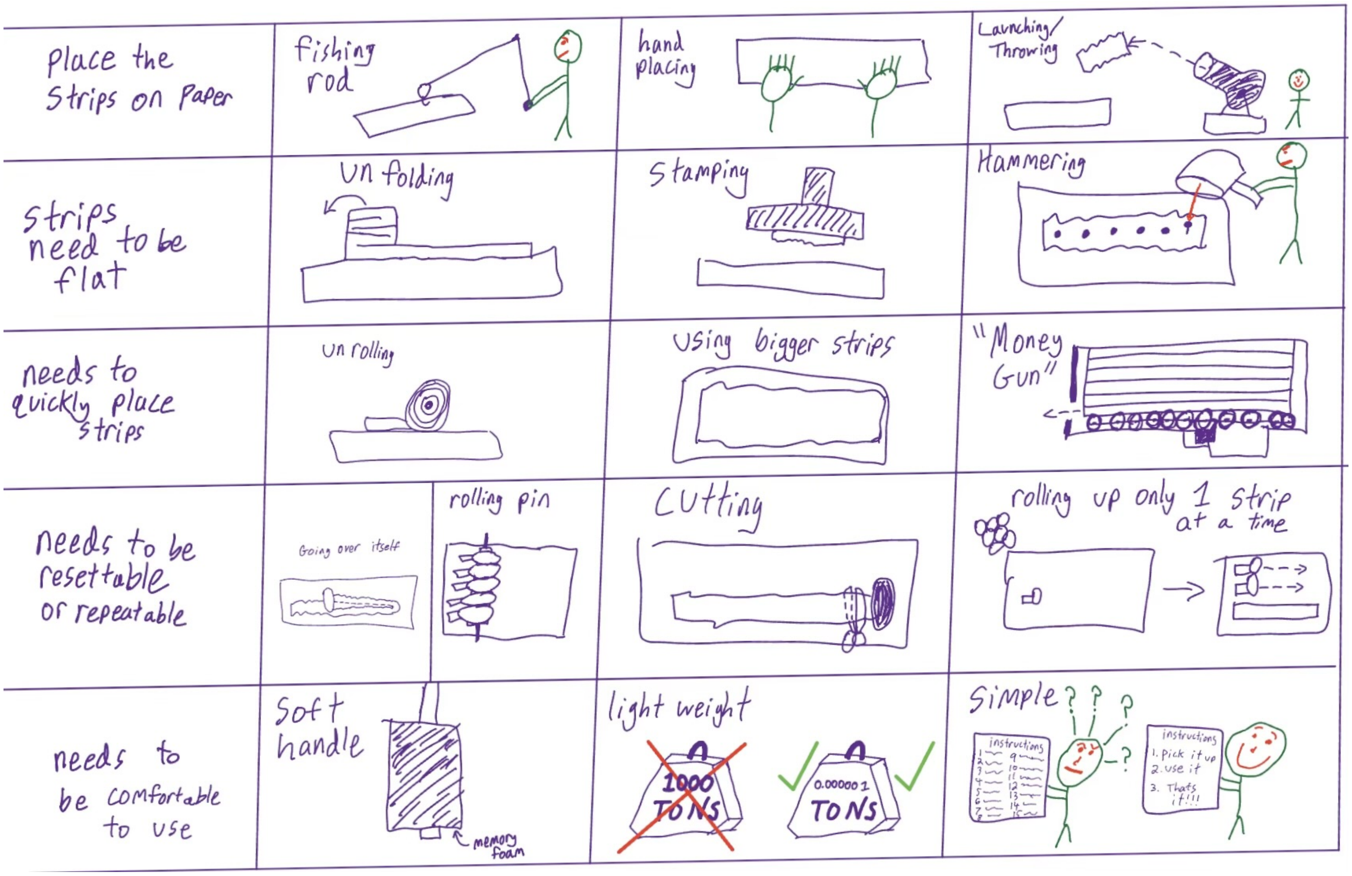


Figure 11: Morphological chart for the t-shirt strip dispenser

3.4 Alternative Design Concepts

3.4.1 Concept #1: The Packing Tape Roller

(by Jack Ward)

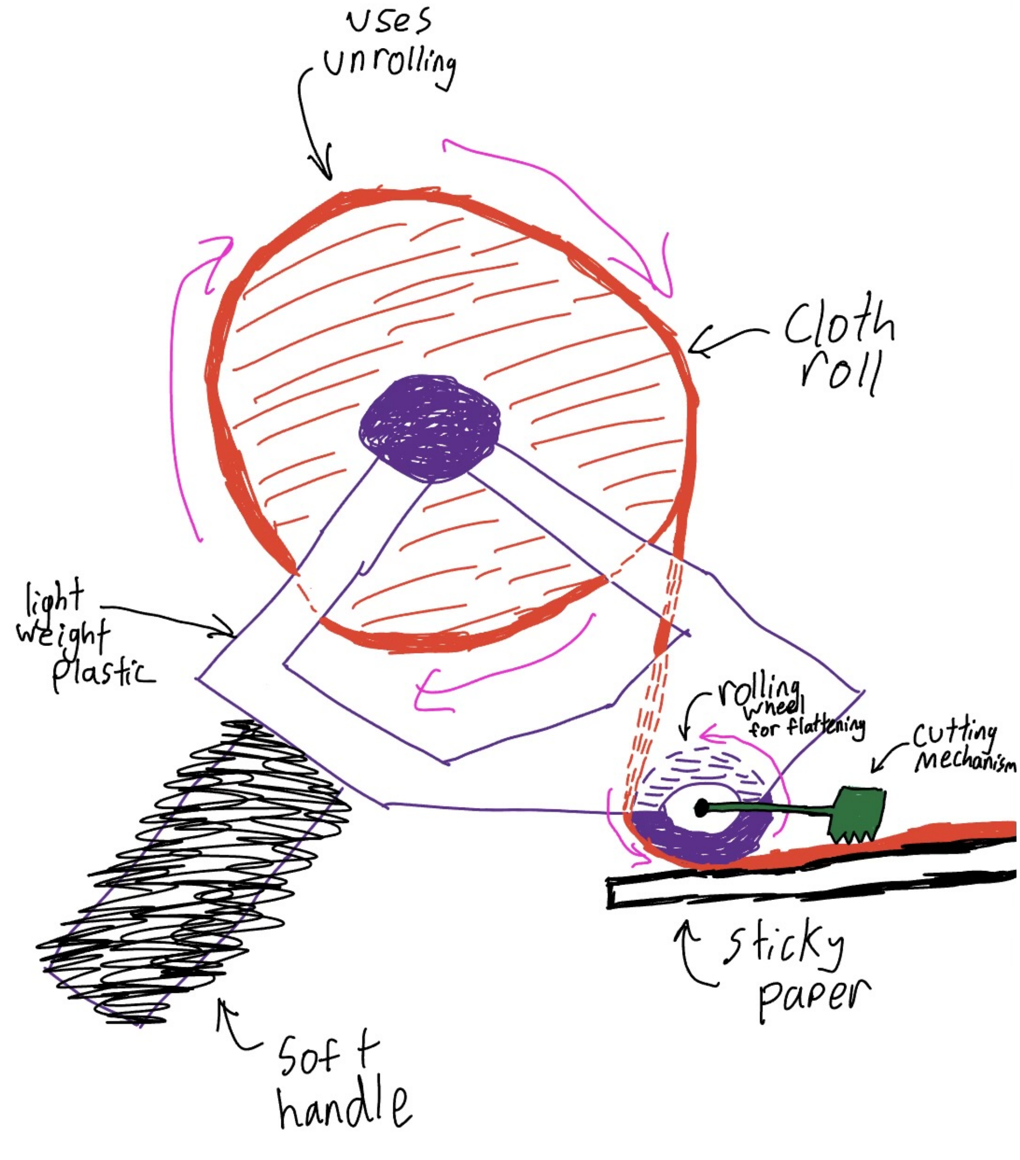


Figure 12: Sketch of the Packing Tape Roller concept

Description: A cloth roll which contains one strip of cloth will be placed on an extruded circular part to keep it in place, but allow it to spin in a circle. The cloth from the roll will be manipulated around another roller at the bottom which is used to ensure that the cloth is flat on the desired surface and that the cloth does not bunch up when in contact with the surface. There is also a cutting mechanism used to cut the end of the placed cloth when the user wants to move to a new strip. There is also a soft handle and the whole device is made out of lightweight plastic to ensure it is comfortable to use.

3.4.2 Concept #2: The Textile Laying Cart

(by Colter Nunn)

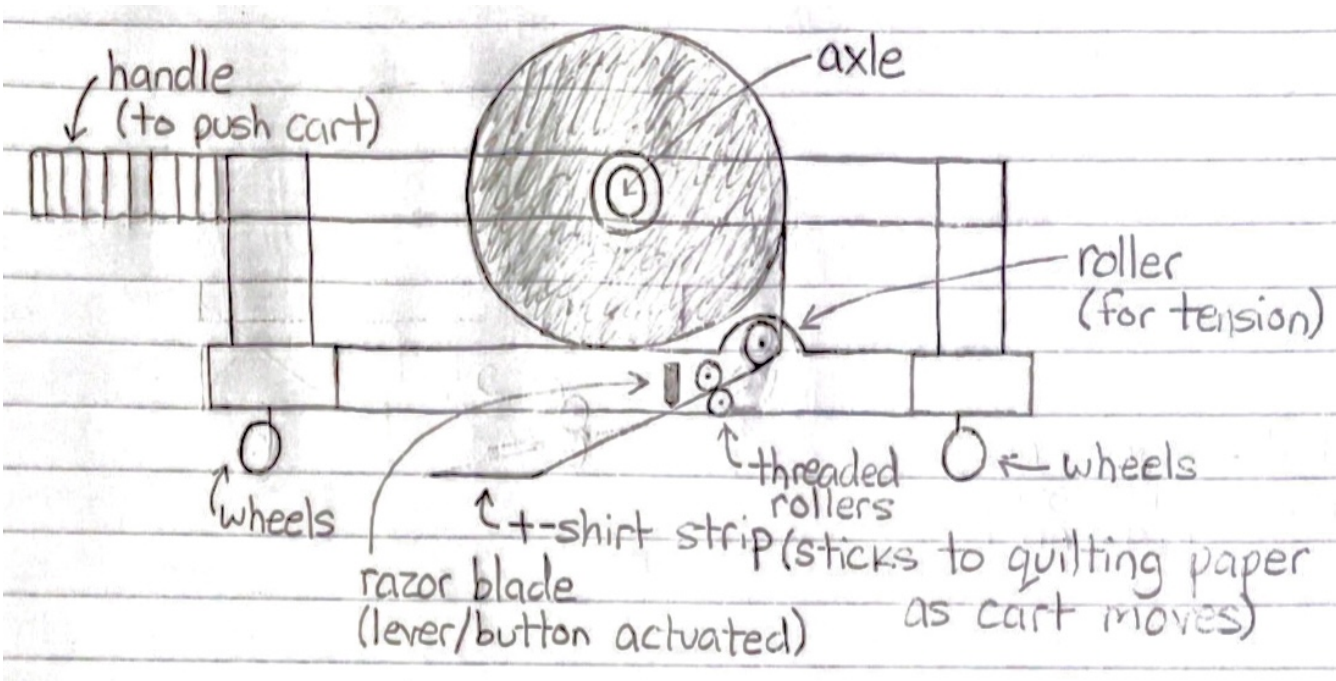


Figure 13: Sketch of the Textile Laying Cart concept

Description: A wooden cart frame holds the spool of material on an axle. As the user pushes the wheeled cart using the ergonomic handle, the t-shirt strip sticks to the quilting paper beneath and the spool begins to unravel. The larger individual roller is used to keep the material in tension during the rolling process, while the pair of smaller threaded rollers ensure a singular strip of material is dispensed at a time. The razor blade can be actuated using a lever and cuts the t-shirt strip, allowing the device to be re-positioned and a new strip to be started.

3.4.3 Concept #3: The Case Dispenser

(by Connor Eames)

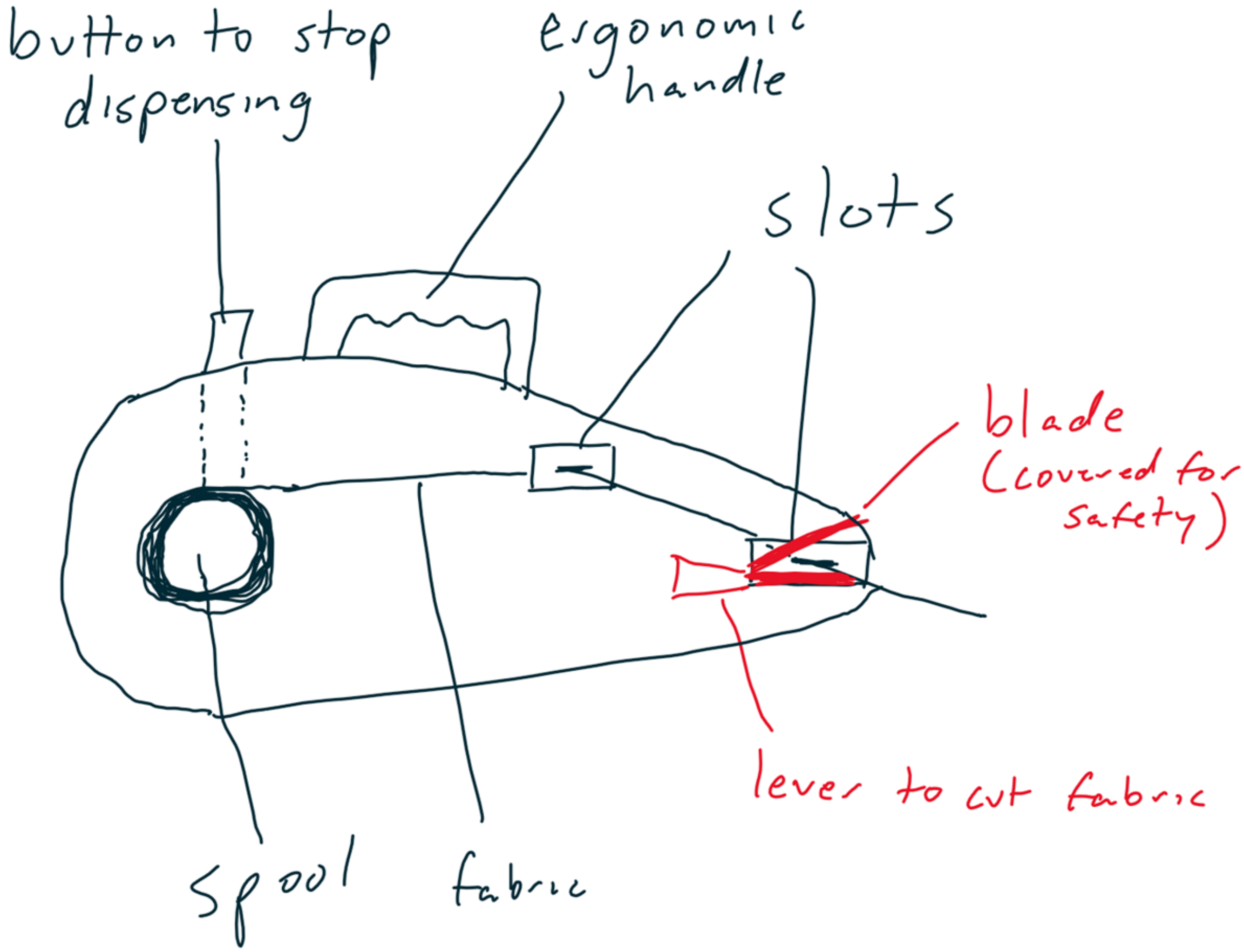


Figure 14: Sketch of the Case Dispenser concept

Description: This sketch shows a cross-sectional view of the third concept. A plastic spool holds the fabric, which is fed through two slots. The first slot serves to maintain the proper tension on the fabric, and the second slot is where the fabric is dispensed. Two blades are placed at the dispensing location and there is a lever that lowers the top blade, allowing the fabric to be cut. All of the previously listed components are held in a plastic case that can open up for reloading. There is a comfortable handle at the top of the case as well as a button that can push down on the spool, stopping the fabric from dispensing.

3.4.4 Concept #4: The Wheel

(by Jay Wiebe)

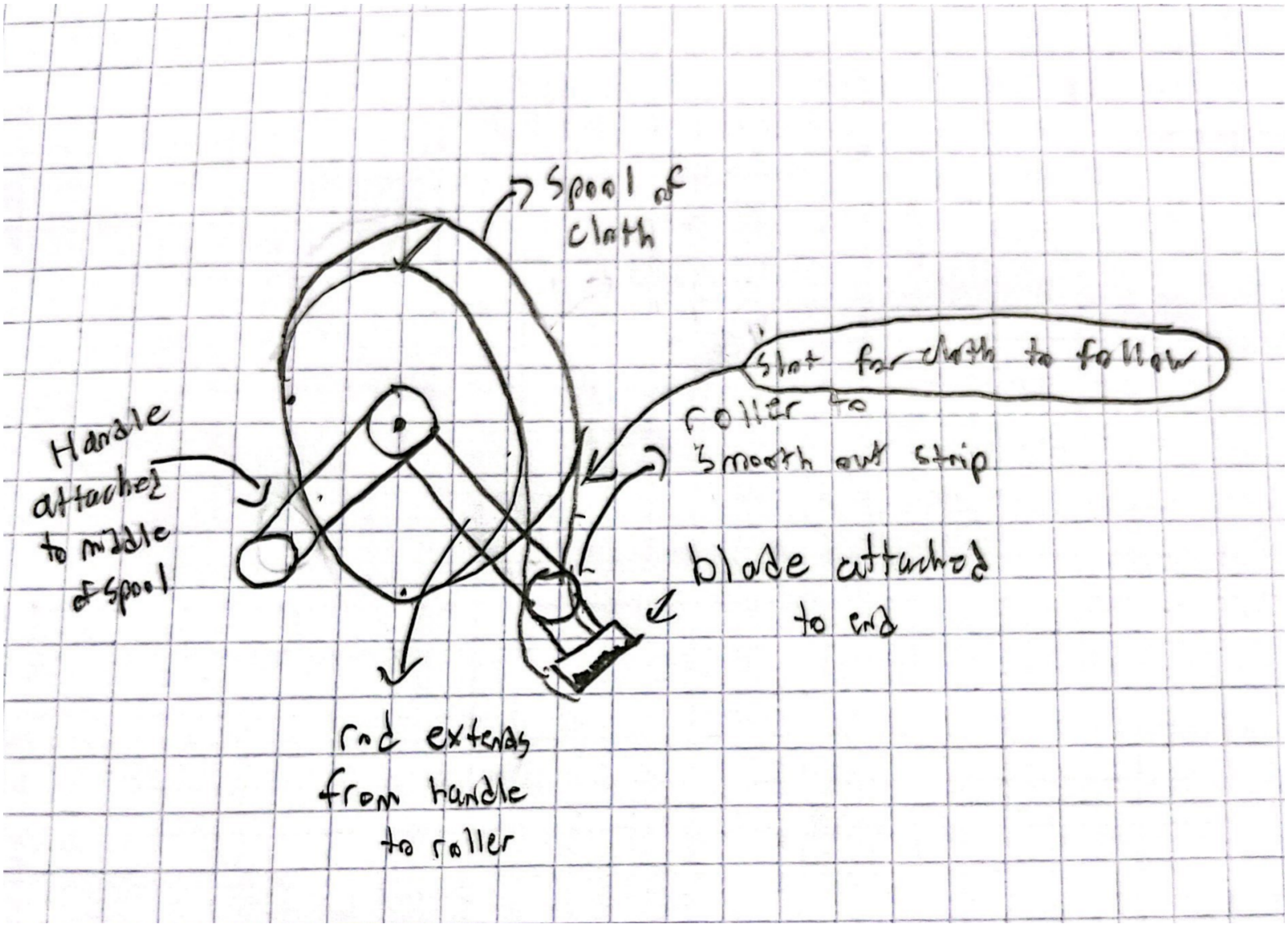


Figure 15: Sketch of the Wheel concept

Description: This sketch shows the middle of the spool sliding onto the end of the handle. The handle is placed at the center of the spool. At the end of the spool will be a roller that can help ensure that the cloth is rolled out of the spool evenly. There is a blade attached to the end of the device so that you can easily cut the cloth once the strip of cloth has been rolled out.

4 Concept Selection

4.1 Selection Criteria

Below is our analytic hierarchy process table used to determine scoring matrix weights. The 5 most important criterion for our device were chosen and compared to each other, allowing us to generate a percent value signifying their relative importance.

	Quick/Easy to use	Lightweight	Resettable/Repeatable	Lays strips flat	Maintains proper tension	Row Total	Weight Value	Weight (%)
Quick/Easy to use	1.00	0.33	3.00	0.33	1.00	5.67	0.16	15.65
Lightweight	3.00	1.00	1.00	1.00	0.33	6.33	0.17	17.50
Resettable/Repeatable	0.33	1.00	1.00	0.33	0.20	2.87	0.08	7.92
Lays strips flat	3.00	1.00	3.00	1.00	0.33	8.33	0.23	23.02
Maintains proper tension	1.00	3.00	5.00	3.00	1.00	13.00	0.36	35.91
					Column Total:	**36.20**	**1.00**	**100.00**

Figure 16: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

Below is the weighted scoring matrix used to compare alternative design concepts. The weights generated in our analytic hierarchy process table were entered and each concept was rated for all criterion on a scale from 1 to 5. This enabled us to generate a total score for each concept and rank them based on their ability to meet the desired criteria.

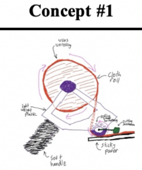
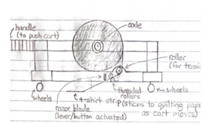
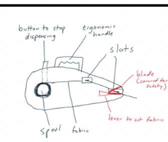
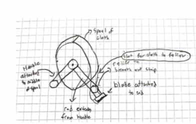
Alternative Design Concepts		**Concept #1**		**Concept #2**		**Concept #3**		**Concept #4**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Quick/Easy to use	15.65	5	0.78	4	0.63	4	0.63	4	0.63
Lightweight	17.50	4	0.70	3	0.52	5	0.87	3	0.52
Resettable/Repeatable	7.92	5	0.40	5	0.40	4	0.32	4	0.32
Lays Strips Flat	23.02	5	1.15	5	1.15	4	0.92	5	1.15
Maintains Proper Tension	35.91	4	1.44	4	1.44	4	1.44	4	1.44
	Total score	**4.466**		**4.134**		**4.175**		**4.055**	
	Rank	**1**		**3**		**2**		**4**	

Figure 17: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

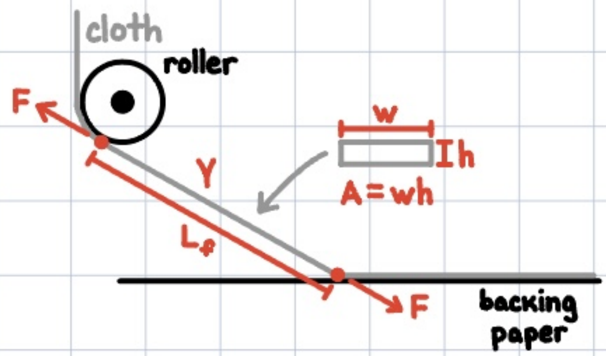
4.3 Evaluation Results

After investigating the results of our concept evaluation we decided to go with Concept #1, which is modeled after a packing tape dispenser. This concept scored the highest out of the four designs in the weighted scoring matrix, suggesting it is the best choice for meeting the desired criterion. In addition to the highest total score, Concept #1 was one of two concepts (in addition to Concept #3) that scored fours and fives for all criterion, indicating this design is well-rounded and can allow us to meet each individual need identified. Between these two, Concept #1 scored higher on the second and third highest weighted criterion, while being in a tie for the highest weighted criterion. Overall, the packing tape dispenser concept will best meet our needs as it is lightweight, easy to use, and can maintain proper tension in the cloth. This concept gives us confidence that we will be able to succeed in creating a product that will dramatically improve the efficiency of Dr. Ruppert-Stroescu's strip-laying process.

4.4 Engineering Models/Relationships

In this section, we show three engineering models that may be useful in our design process. They each include a diagram with relevant variables and equations in addition to a brief description of their importance to our device.

Model: Strip Deformation



As discussed in our customer interview, it is critical that our device provides proper tension to the cloth strips without permanently deforming them. To analyze deformation and strain of the material, a number of parameter values can be collected or found experimentally. The length of the strip in tension, tension applied, cross-sectional area, and Young's modulus of the material can be combined as shown to determine the change in length.

$$\underbrace{L_f - L_0}_{\Delta L} = \frac{1}{Y}\frac{F}{A}L_0 \qquad A = wh$$

where:

L_f = deformed length of strip

L_0 = initial length of strip

Y = Young's modulus of cloth

F = tensile force applied to strip

A = cross-sectional area of strip

w = width of strip

h = height of strip

given: Y F L_f $A(wh)$

find: L_0

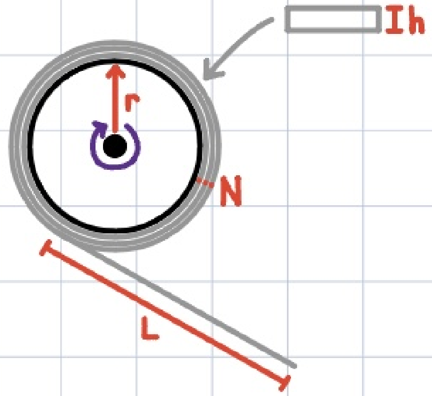
Determining this change in length will provide a value for the initial length of the strip (prior to any deformation). While this value may seem unimportant, it can be used to calculate strain with the following relation.

$$\text{strain} = \frac{\overbrace{L_f - L_0}^{\Delta L}}{L_0}$$

This strain value can then be plugged into additional equations to analyze additional considerations such as lateral deformation.

Figure 18: Engineering model for analyzing strip deformation

Model: Strip Length



One important consideration of our device (particularly for any automated features) is the length of the cloth strip being dispensed. If we assume the height of the strips themselves is negligible, the length of strip dispensed per rotation is simply equal to the circumference of the spool.

$L = 2\pi r$ where:
L = length of strip dispensed
r = radius of spool

given: r find: L

However, as seen during the customer interview, the thickness of the cloth strips is not necessarily negligible. Therefore, the initial radius can be more accurately represented by multiplying the number of strip revolutions initially on the spool times the strip height, and adding that value to the spool radius.

$r_0 = Nh + r$ where:
r_0 = initial radius
N = number of strip revolutions on spool
h = height of strip
r = radius of spool

given: N h r find: r_0

It is worth noting that as the cloth is unspooled, this radius is constantly changing. For each rotation, the value of N decreases by 1, decreasing the radius by a value of h. Writing this function into software such as MATLAB would allow a new radius value to be calculated each time, giving the most accurate length values possible.

Figure 19: Engineering model for calculating the strip length dispensed

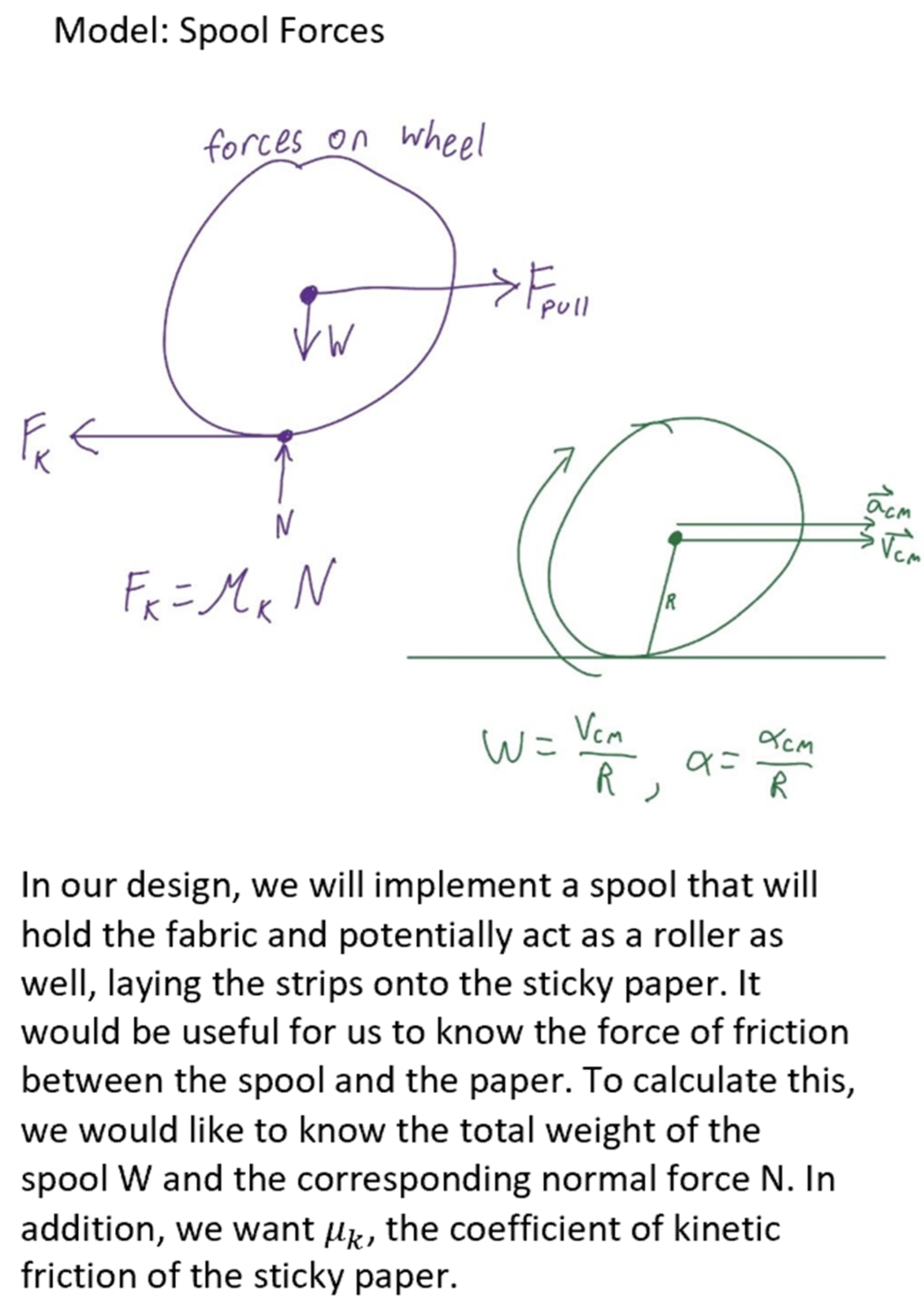


Figure 20: Engineering model for calculating the force of friction on the backing paper

5 Concept Embodiment

5.1 Initial Embodiment

The drawings below show a CAD embodiment of our initial prototype. They include basic overall dimensions as well as a bill of materials (BOM) for the assembly.

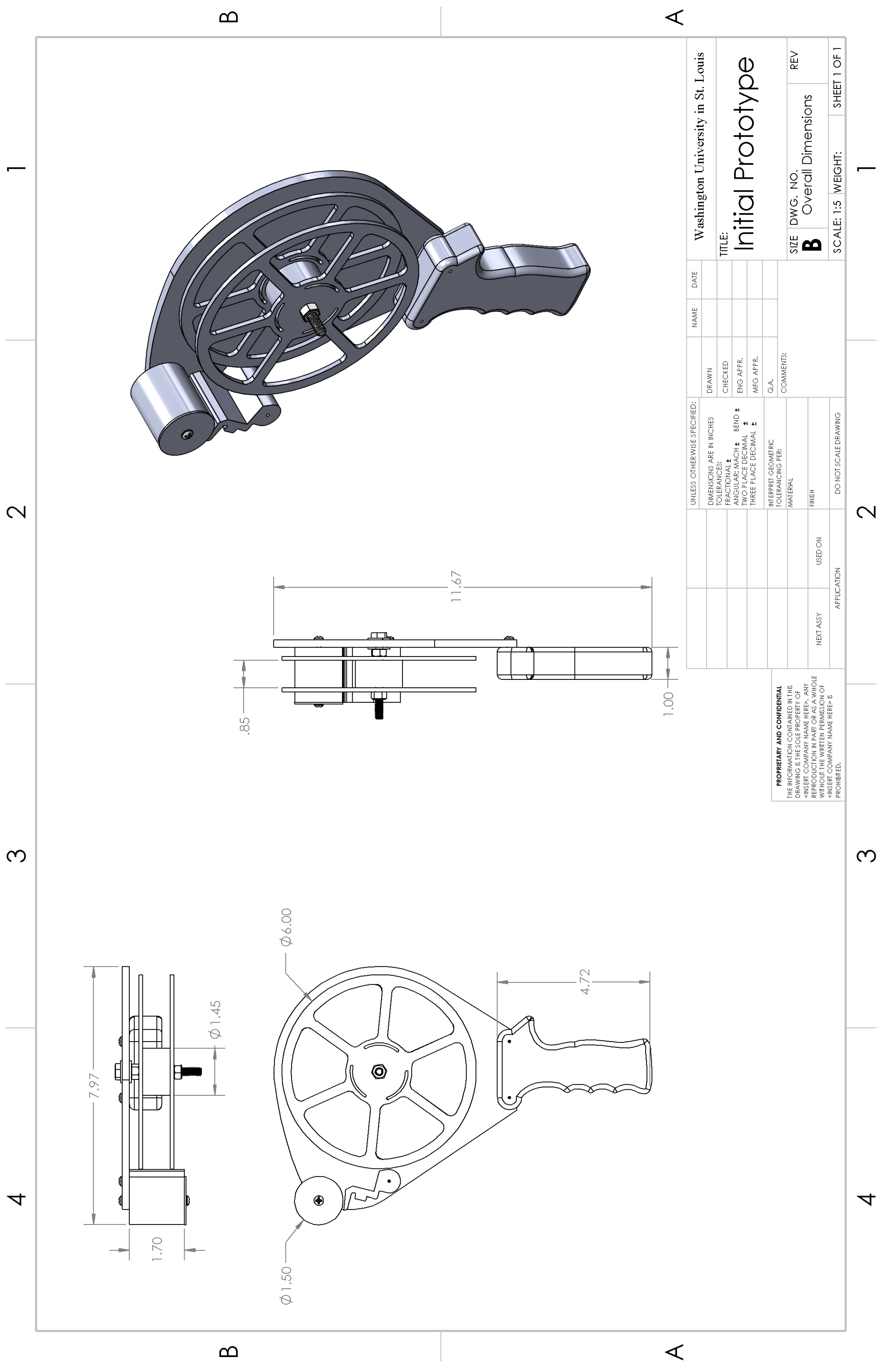


Figure 21: Projected views with overall dimensions

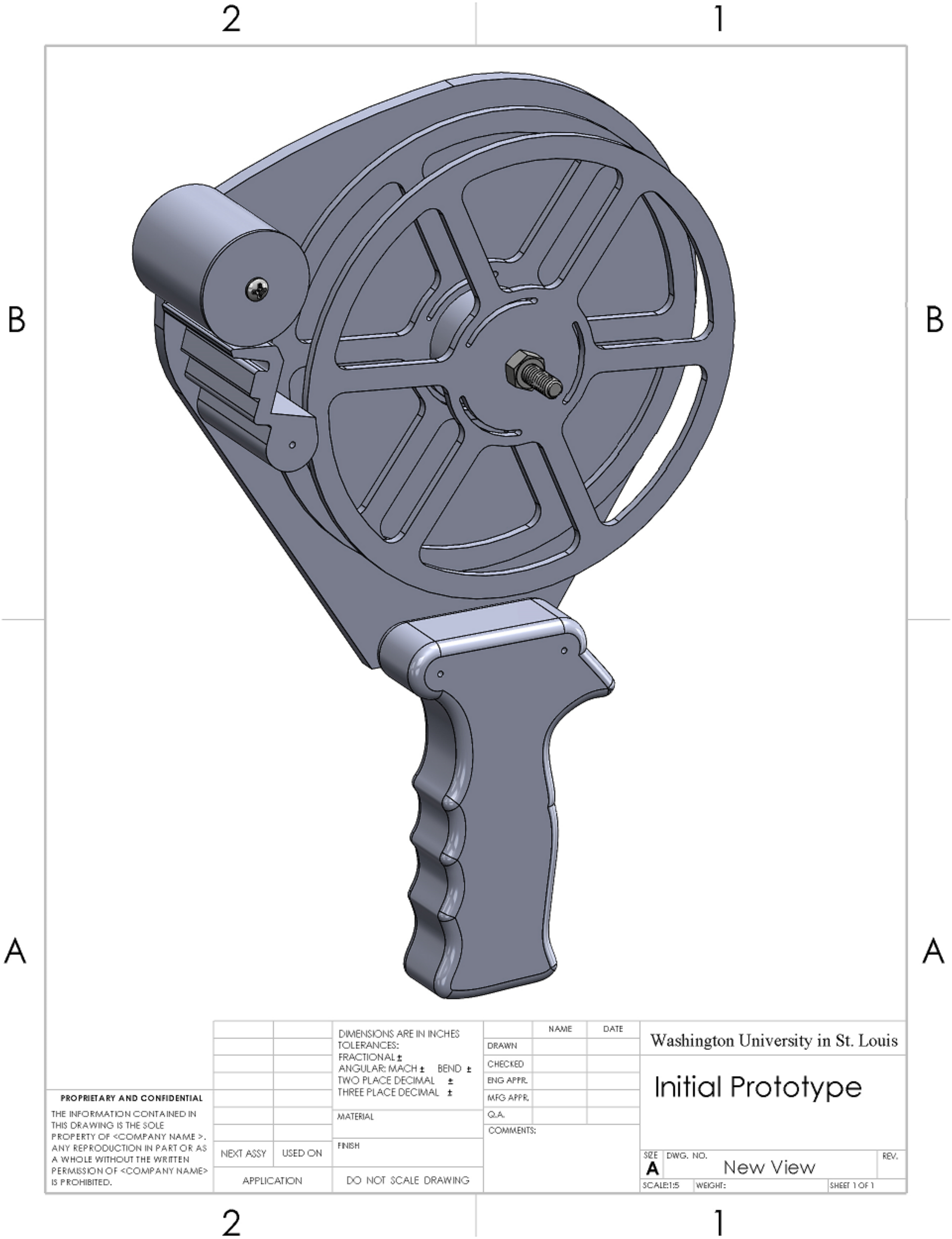
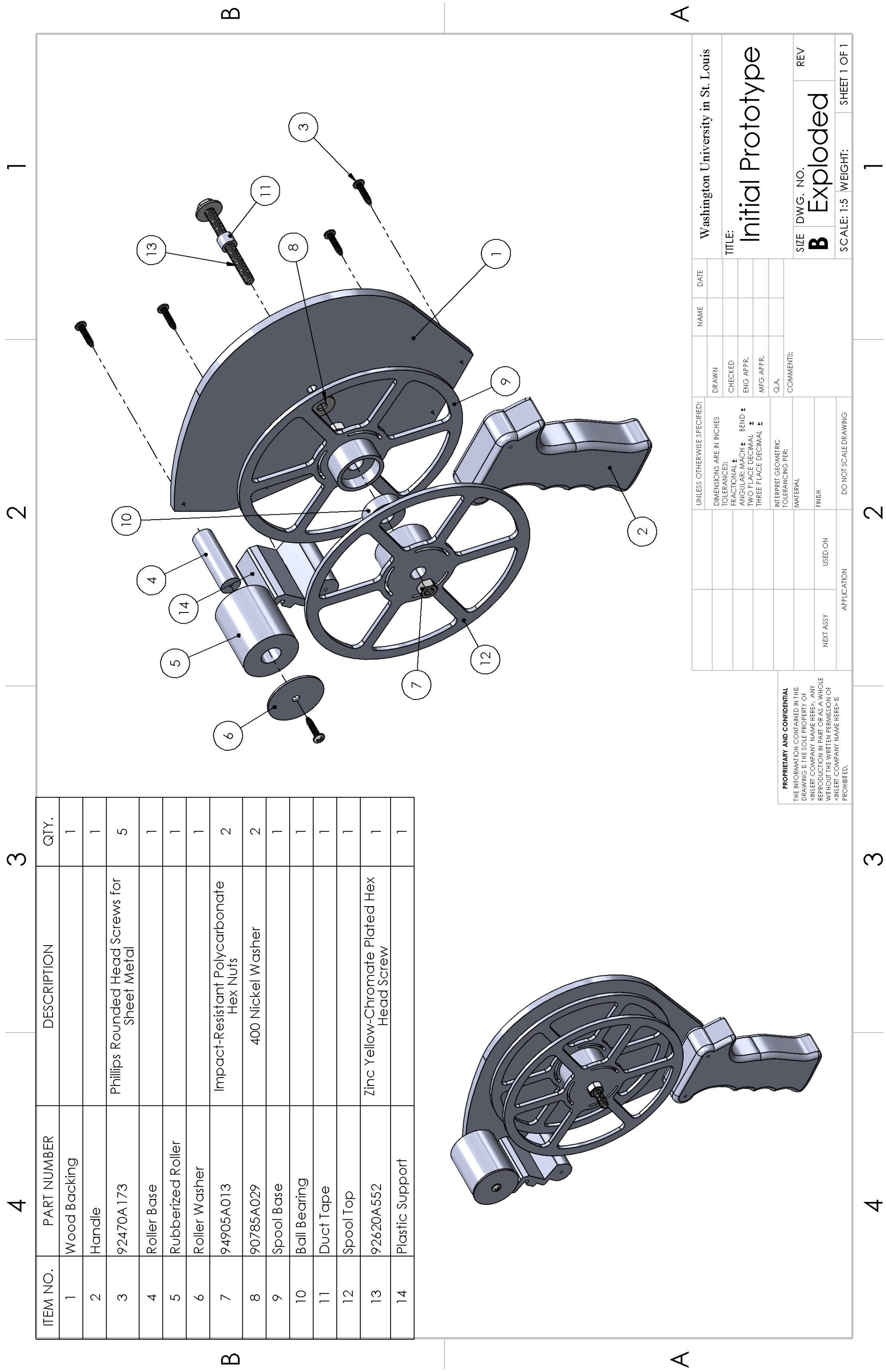


Figure 22: Large isometric view



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Wood Backing		1
2	Handle		1
3	92470A173	Phillips Rounded Head Screws for Sheet Metal	5
4	Roller Base		1
5	Rubberized Roller		1
6	Roller Washer		1
7	94905A013	Impact-Resistant Polycarbonate Hex Nuts	2
8	90785A029	400 Nickel Washer	2
9	Spool Base		1
10	Ball Bearing		1
11	Duct Tape		1
12	Spool Top		1
13	92620A552	Zinc Yellow-Chromate Plated Hex Head Screw	1
14	Plastic Support		1

Figure 23: Exploded view with a bill of materials

To determine how well our prototype could meet our needs and help our customer, we established 3 prototype performance goals. We wanted to be able to replace the spool of fabric with a new one in under 30 seconds (Goal 1), be able to lay 5 2-foot strips of cloth in under 1 minute (Goal 2), and ensure that 4 of the 5 strips laid down were properly adhered to the backing paper (Goal 3). We were able to replace the spool in under 30 seconds, but we were not able to lay out the 5 strips in under 1 minute. The strips that were laid down were also not properly overlapping and did not meet the requirements of the third prototype performance goal.

5.2 Proofs-of-Concept

Our proof-of-concept prototype and related testing provided us with valuable information that we incorporated into our initial prototype. First, the spool used on the proof-of-concept prototype had too narrow of a channel to hold the cloth strips and nowhere to secure the end of the material. To overcome this, we designed an improved spool in SolidWorks that was wide enough for the cloth strips and included small slots that the end of the material could be tied around. Additionally, the metal handle we used for our proof-of-concept prototype was quite heavy, making the device uncomfortable to hold for long periods of time. This emphasized the importance of minimizing the weight of our device components and led to us using a hollowed-out plastic handle on our initial prototype. Overall, the proof-of-concept stage gave us the opportunity to iron out kinks in our design and optimize crude components to best meet our needs.

5.3 Design Changes

The concept we selected in Section 4 was based on a packing tape roller. Our initial prototype largely resembles the selected concept, however a handful of minor improvements were made along the way. First, we added a guide piece below the roller to ensure the cloth strip remains flat and in contact with the rubberized surface. This allows proper strip tension to be maintained and ensures the strips being laid do not have any creases or kinks. In addition, we observed that the cloth would often fall off of the roller each time a strip was cut. This guide piece reduces the need for the device to be manually reset each time a new strip is cut, simplifying and expediting the strip-laying process. Another design change we made involved the removal of the cutting mechanism from our initial prototype. Originally, we intended to feature a mechanism that could simplify the cutting process for the user. However, we realized in the early stages of testing that the cloth was too difficult to consistently cut without deforming. Tailor scissors were found to be the only device capable of producing a consistent and straight cut, and attaching them to the device is impractical given their size and weight. Therefore, it was determined that our device could be better optimized in other areas.

6 Design Refinement

6.1 Model-Based Design Decisions

Engineering models and relationships were applied to specific key parts of our prototype in order to help us make design decisions. These models include simplifying the spool geometry and analyzing the moment of inertia to determine the optimal spool material, estimating the radius of the rolled cloth to find an appropriate spool radius, and analyzing the friction between the roller and the cloth to determine the best material to use for the roller.

1. A new engineering model for determining the moment of inertia of a solid cylinder was created.

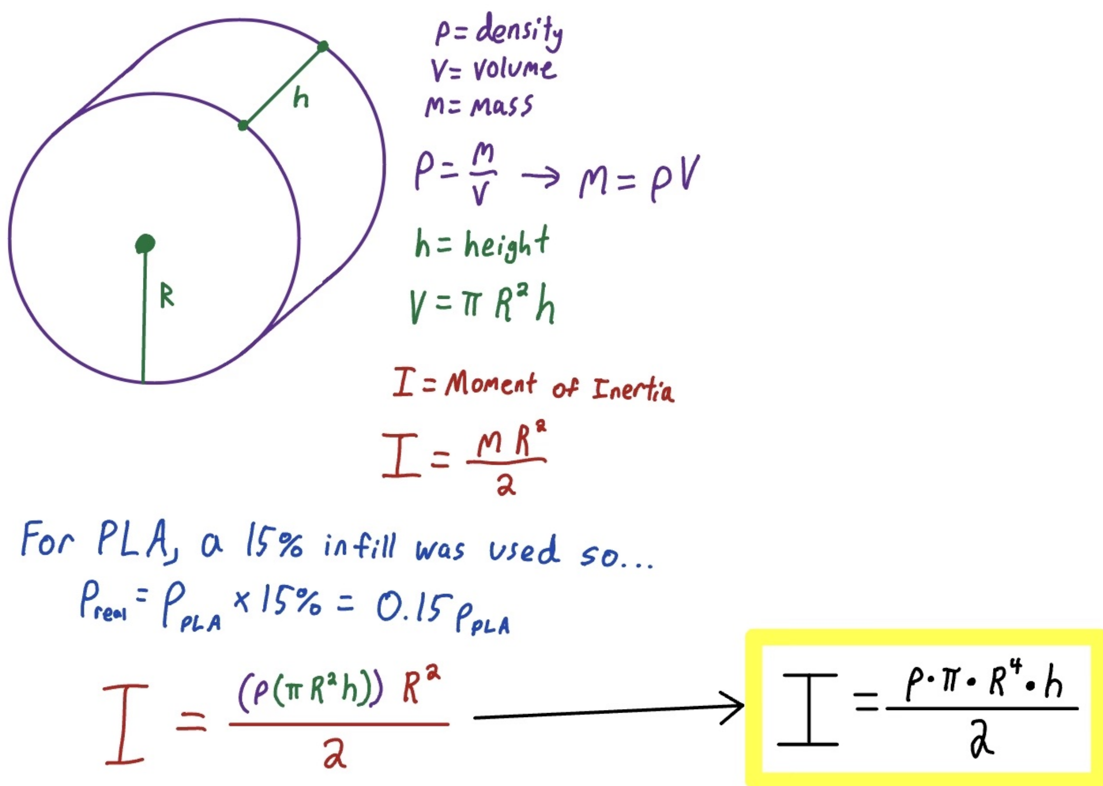


Figure 24: Engineering model and relevant equations for calculating moments of inertia

The engineering model for moment of inertia of spool, shown in Figure 24, is used to determine what material we should use for the spool. The goal is to minimize the moment of inertia, that way it is easier to spin the spool and avoid adding too much tension to the strip of cloth, causing it to warp. We wanted to find whether maple wood or PLA makes the moment of inertia smaller, therefore making our spool easier to spin. We were considering using maple wood because it is very commonly used in wood shops and has a density of around 625 kg/m^3. We were considering PLA because it was easily accessible and has a density of 1240 kg/m^3.

In order to calculate the moment of inertia, we modelled the spool as a solid cylinder. The equation for finding the moment of inertia through its center is $I = (mr^2)/2$, where m and r is the mass and radius of the cylinder respectively (our specific radius was 3in or 0.0762m and our height was 0.85in or 0.0216m). In order to find the mass, we used $m = \rho V$ where ρ is the density of the material and V is the volume. The volume can be found by, $V = \pi r^2 h$ where h is the height or depth of the cylinder. We reduced these equations to find that the moment of inertia is $I = (\rho \pi r^4 h)/2$ as shown in Figure 24. For maple wood, plugging in the density (625 kg/m^3), the radius (0.0762m), and the height (0.0216m) and using the moment of inertia equation, the moment of inertia for maple wood comes out to be 7.15*10$^-$4 kg*m^2. For PLA, the print showed that it was only a 15 percent infill, so we ony used 15% of the density, 1240kg/m^3 * 0.15 = 186 kg/m^3. Plugging in the density

(186 kg/m^3), the radius (0.0762m), and the height (0.0216m) and using the moment of inertia equation, the moment of inertia for PLA comes out to be 2.13*10^-4 kg*m^2. After calculating each moment of inertia, we found that the value for PLA is much lower than the maple wood. Therefore, we decided that it would be best to go with creating the spool out of PLA.

2. We used the engineering model of strip length, shown in Figure 19, to determine how large to make our CAD spool. We started with a radius [r] (the radius of the inner cylinder under the cloth) of 1.45 inches. We then approximated the number of times the cloth went around the spool [N] as roughly 80 times. The height of the strips [h] was based off of the standard thickness of t-shirts which is 0.015 inches. We wanted to get the total radius [R] in order to make the spool big enough to hold the cloth so we plugged those into the formula R = Nh + r to get R = 2.65 inches. We ended up making our spool radius 3 inches (diameter of 6 inches) to ensure that the cloth would never be wider than the spool.

3. The engineering model of spool forces in Figure 20 is useful for picking out what roller is best for our intended purpose. We wanted the roller to be made of a material that would have a high coefficient of static friction when interacting with cloth so that the roller doesn't slip as it is laying down the cloth. The higher the static friction coefficient, the less the user has to push down on the device (creating the normal force N shown in Figure 20) to get the cloth to stay connected with the roller. This would allow the rubber to stick to the cloth so the cloth does not slip out from under the roller and cause a fold. We ended up choosing rubber, which has a high coefficient of static friction of around 1.15 (when interacting with rubber). One limitation of our model is that since there wasn't a published value for the coefficient of static friction between rubber and cloth, we instead used the value for rubber on rubber. However, we believe this is a valid assumption because rubber has higher coefficients of friction when in contact with a large variety of materials compared to the alternative choices for the roller material (such as plastic or acrylic) when in contact with those same materials.

6.2 Design for Safety

Every device can fail in numerous ways, and often times these failures can cause harm to the user. It is our responsibility as engineers to examine ways in which our device can fail in an effort to minimize risk. Below, five potential risks associated with our device are described along with their severity and probability of occurring. Steps we have taken to mitigate these risks are also outlined.

6.2.1 Risk #1: Dropped Device

Description: Device falls on the user's hand/fingers/arm, causing minor injury
Severity: Marginal
Probability: Likely
Mitigating Steps: Ergonomic handle with good grip, lightweight device to minimize potential harm

6.2.2 Risk #2: Fingers Jammed while Replacing Spool

Description: The user's fingers get caught in the gap between the wood backing and the spool when the spool is being replaced
Severity: Marginal
Probability: Occasional
Mitigating Steps: Guard/casing shielding gap between wood backing and spool

6.2.3 Risk #3: Hand/Wrist Cramps

Description: The user experiences painful contractions in the muscles used to grasp the handle and use the device
Severity: Critical
Probability: Occasional
Mitigating Steps: Ergonomic contoured handle, lightweight device, appropriate handle angle to ensure the arm is not in an unnatural position

6.2.4 Risk #4: Fingers Caught in Roller

Description: The user's fingers get jammed between the roller and plastic support when re-threading cloth
Severity: Marginal
Probability: Occasional
Mitigating Steps: Plastic support offset from roller, narrow gap between components (wide enough for cloth but too narrow for any portion of a finger)

6.2.5 Risk #5: Splinters from Wood Backing

Description: The user gets a splinter in their finger/hand from the wooden backing
Severity: Marginal
Probability: Seldom
Mitigating Steps: Wood backing is sanded and a finish is applied, vastly decreasing the probability of splinters occurring

These risks were added to a heat map, categorizing overall hazard based on the severity and probability of each risk occurring. The resulting heat map is shown in Figure 25 below.

Severity of risk	Probability that something will go wrong				
Category	**Frequent** Likely to occur immediately or in a short period of time; expected to occur frequently	**Likely** Quite likely to occur in time	**Occasional** May occur in time	**Seldom** Not likely to occur but possible	**Unlikely** Unlikely to occur
Catastrophic					
Critical			Hand/Wrist Cramps		
Marginal		Dropped Device	Fingers Jammed while Replacing Spool Fingers Caught in Roller	Splinters from Wood Backing	
Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial					

Figure 25: Risk assessment heat map

Based on the heat map, the potential for hand/wrist cramps was determined to be highest priority risk. This risk had the highest severity and is expected to occur occasionally, landing it within the orange region of the heat map (representing the second highest level of concern). Three other risks landed within the yellow region of the heat map, representing the third highest level of concern. These are the potential for a dropped device, fingers getting jammed while replacing the spool, and fingers getting caught in the roller. Because our device is lightweight and doesn't have any moving parts, these risks are all seen as marginal to the user (and would likely cause minimal discomfort). A dropped device is of slightly higher concern than the other two risks due to its higher probability of occurring. Splinters from the wood backing are viewed as the least concerning risk, falling in the green region of the heat map. This is primarily due to their seldom probability of occurring. While splinters may cause marginal discomfort to the user, the wood has been sanded and sealed, making this risk the least likely to occur. Combined with a relatively low severity, this risk is the least concerning of those identified.

6.3 Design for Manufacturing

Number of parts (excluding threaded fasteners): 10

Number of parts (including threaded fasteners): 20

Theoretically Necessary Components: Backing Plate/Handle, Spool, Ball Bearing, Roller

The first theoretically necessary component is a backing plate/handle. In our design the two components are made of different materials and are therefore separate parts, but they could easily be made of the same material and combined into a singular component. The backing plate is necessary to hold the other components in place, while the handle allows the user to easily hold and manipulate the device.

The second theoretically necessary component is a spool used to store and dispense the cloth material. The long strips of cloth material must be stored compactly, and wrapping them around a spool is the most effective way to do so. The circular nature of the spool allows the material to be unraveled easily, simplifying the dispensing process. This component must be a separate piece due to the fact it must rotate during the dispensing process.

The third theoretically necessary component is a ball bearing, which allows the spool to rotate freely while keeping the rest of the device stationary. This component serves as an interface between the spool and the axle protruding from the backing plate, reducing friction and minimizing the force required to dispense cloth. Because this component must interface with two separate parts, one rotating and one stationary, it must be a separate component.

The final theoretically necessary component is a roller. This roller is used to maintain proper tension in the cloth as it is being dispensed, ensuring that strips are laid flat without being deformed. The roller must rotate in a different direction and at a different rate than the spool as the cloth is dispensed, therefore it must be a separate component.

To get our design closer to the minimum number of components, certain parts could be combined or simplified. As discussed above, in our design the handle is separate from the backing plate, while the two could easily be combined by 3D printing a backing plate with a pre-attached handle. Additionally, we use a plastic cylinder as an axle for the roller, which could also be printed directly onto the backing plate/handle assembly. These minor adjustments would help us get much closer to the minimum number of components.

6.4 Design for Usability

When creating our design, conditions that could limit the usability of the device were taken into account. These factors include a vision impairment (such as red-green color blindness or presbyopia), a hearing impairment (such as presbycutia), a physical impairment (such as arthritis, muscle weakness, or limb immobilization), and a control impairment (such as those caused by distraction, excessive fatigue, intoxication, or medication side effects).

1. Vision Impairment: Someone with a vision impairment probably would not have major trouble using the device. The only colors on the device are purely aesthetic and have no meaning so someone with color blindness may not be able to appreciate the visual artistic choices, but should have no problem using the device. Someone with presbyopia or myopia might have a bit of trouble using the device due to their inability to see the cloth very clearly and would likely struggle making the cloth perfectly even, but would still be able to use the device as intended with a bit more time and

focus.

2. Hearing Impairment: Since the device does not make any noise, people with hearing impairments would not impact their ability to use our device. The device makes little to no noise when used so even someone who was completely deaf would easily be able to accomplish all the goals we were given. Additionally, Dr. Ruppert-Stroescu indicated that she wanted the device to be able to be used by non-English speakers so, in the prototyping process, we wanted to make sure that the device was fairly self-explanatory to use for people who did not understand English or couldn't hear it.

3. Physical Impairment: The most important factor that was taken into account was making the device usable for people with physical impairments. When talking to Dr. Ruppert-Stroescu, she indicated that she wanted the device to be used by all types of people. Some of these people might be older and not be in peak physical shape. To account for this, we added a small roller to guide the cloth for the user and an ergonomic universal handle to allow the user to feel more comfortable using the device. An improvement we could make would be to add a motor on the roller system to allow the user to simply guide the device and not have to use any force to push the device forward and across the page. If given enough time, the device could be modified to be able to roll many layers of cloth across the page at once. This would decrease the amount of distance the user would have to push the device and lessen the effort required to use the device.

4. Control Impairment: Ideally, the device would be able to be used by someone who had a control impairment (like if they were distracted). To keep the strips evenly spaced (a crucial goal of the device), a lot of concentration is required and it would be nearly impossible to accomplish this task when distracted. However, the device uses a piece under the roller so the user does not have to concentrate on keeping the cloth flat as it goes into the roll. While this does not make the device second nature to people, it allows the user to concentrate more on other goals such as keeping the cloth straight as they roll. An improvement we could make would be to add a motor on the roller system to allow the user to simply guide the device and not have to focus on pushing the device across the page.

7 Final Prototype

7.1 Description

Our final prototype can be seen in Fig. 26 below:

Figure 26: Final prototype

There were four aspects of our final prototype. The handle & backing, spool, spool attachment mechanism, and roller & support. The handle is a hollow plastic piece that is screwed into the lightweight wooden backing. The spool is 3D printed with PETG and consists of two components that overlap and contain the ball bearing inside. The spool has a slot that allows the user to slide the start of the fabric in while ravelling so it doesn't slip. The completed spool model can be seen below:

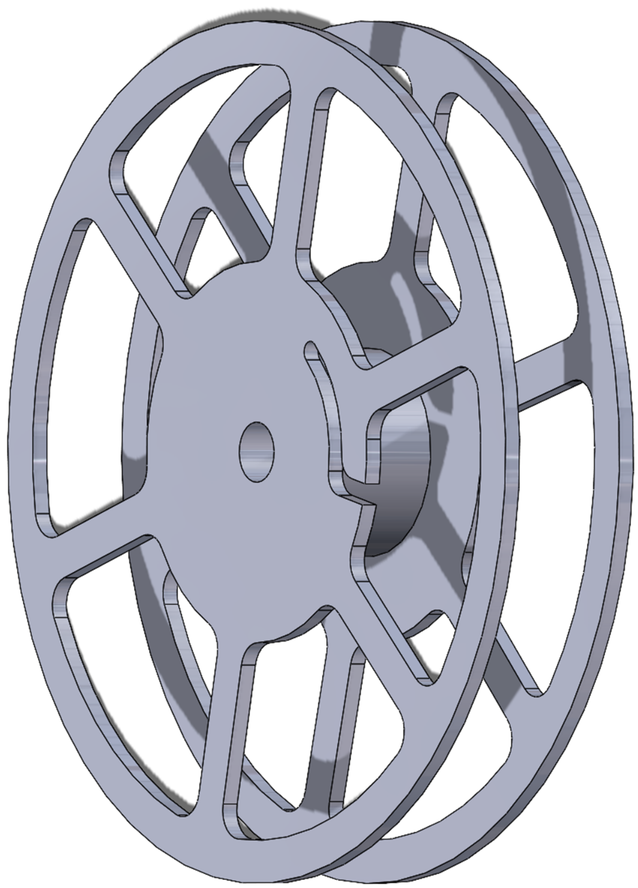


Figure 27: Spool model

The spool is attached to the wooden backing by an attachment mechanism. This mechanism consists of a screw, washers on the wood, a nut that serves a spacer between the wood and the spool, and a wing nut for easy removal of the spool. There is duct tape wrapped around the screw that is just the right diameter to engage the ball bearing and help the spool roll smoothly. Last, there is a black rubber roller and a plastic support. The roller is attached to the wooden base and lays the strips down. The support helps to flatten the fabric as it is fed under the roller. It protrudes out slightly further than the roller so that the user can easily slide the fabric in.

7.2 Prototype Performance Goals

In addition to meeting Dr. Ruppert-Stroescu's needs, the device was designed to accomplish a trio of performance goals. The first performance goal stipulated that the roll of cloth must be able to be replaced in under 30 seconds. We let Dr. Ruppert Stroescu attempt this goal herself and found she was able to replace the spool in 22 seconds, successfully accomplishing this goal. The second performance goal specified that the device needed to be able to lay 5 2-foot-long strips of fabric in under one minute. We were able to successfully lay the strips in just under 49 seconds, accomplishing this goal. The third and final performance goal required 4 of the 5 strips laid to be well-adhered to the backing paper and free of any warping or deformation. We found that all 5 of our strips were well-adhered and free of any warping or deformation, accomplishing this final goal. There were a few areas were the strips did not overlap properly, but that can be largely attributed to user error and the uneven width of the cloth strips we cut.

7.3 Conclusion

After working extensively with Dr. Ruppert-Stroescu on many prototype iterations, our group was able to produce a final device that met her needs and our own prototype performance goals. Dr. Ruppert-Stroescu was very pleased with the device's level of comfort and ease of use, noting how this tool can easily be incorporated into her current workflow. In addition, the performance testing for our final device was a resounding success, with all three goals being accomplished. This device is proof that working closely with your customer to understand their needs is a critical component of engineering design. Dr. Ruppert-Stroescu made it clear that the device did not need to be overly complicated, but simply needed to do the little things well. Our group was able to deliver on this promise, providing her with a practical tool that we hope she continues to use going forward.