Final Report
FeverDots

A Senior Project
presented to
The Faculty of the Biomedical Engineering Department
California Polytechnic State University, San Luis Obispo

For Sponsors
Caroline Jurado and Margaret Shaw, Wellhouse Enterprises, LLC

In Partial Fulfillment
of the Requirements for the Degree
Bachelor of Science

by
Rita Grigorian
Kameryn Laureano
Heidi Silk

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Statement of Disclaimer

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Executive Summary

FeverDots are wearable temperature sensitive stickers that change color from black to pink at 99°F when placed on the temple or forehead. The objective of this project was to develop an efficient manufacturing method for FeverDots, and manufacture a device along with it. To create the FeverDots manufacturing device, the full design process was executed. The team went through a thorough ideation phase before ultimately defining and specifying the scope of the project.

The key customer requirements of this device include that it is lightweight, portable, durable, simple to assemble, easy to use, and able to generate uniform ink and force distribution. One additional requirement from the sponsors was feedback from human use of FeverDots. The key requirements were analyzed and translated into quantifiable engineering specifications. The lightweight and portable requirement is quantified by a 30lb maximum weight measurement. Durability was also quantified by a maximum total length of cracking in the wood set at 10 inches. A maximum number of 10 steps to go through a full cycle of stamping was set to quantify simple assembly. Ease of use was quantified with a spec of 27 ± 4N required to start the motion of the device. Finally, the device's ability to generate uniform ink and force distribution was quantified with a 0.015 ± 0.002 g/in^2 measurement for dry weight of ink and a minimum of 85% of the sticker paper receiving a uniform application of force per cycle.

An initial conceptual model was developed to test out the initial mechanical ideas; as these ideas were further defined and developed, the final design was selected. The transition from conceptual to final design occurred with a central focus on obtaining equal force and ink distribution. Four total iterations of the prototype were created throughout the life of the project, including the initial and final prototypes. The various iterations were made to fine-tune the ink stamping mechanism and the interactions between assembly pieces.

The team conducted 7 different tests to analyze if it met the specified metrics outlined above. These tests were for: weight and portability, durability, simple assembly, dry weight specification for ink, ink distribution, force uniformity, and minimum force. The purpose of the Weight and Portability test was to identify if the device was not excessively heavy. Next, the Durability test was designed to assess if the parts would be able to remain assembled during stamping, and the Simple Assembly test analyzed if the device requires too many operational steps for use. Also, the Dry Weight Specification of Ink Test allowed the team to observe if the device could apply the correct amount of ink onto the substrate, while the Ink Distribution Test evaluated how well the ink spread across the substrate. Similarly, the Force Uniformity Test noted how force was applied throughout the lid of the device. Lastly, the Minimum Force Test determined if the force threshold to move the device was feasible. To gain data on the human use of FeverDots, a human use study was conducted; survey results were analyzed and presented to our sponsors.

The device achieved uniform force as it met the specification of 85% during the force uniformity test. Additionally, it met the specifications for simple assembly and easy to use as the number of operational

steps include only 9 and that it showed to only require a range of 23 N to 31 N to be able to move the lid, respectively. It also passed the portability test as its weight was only 12.2 lbs.

However, it failed the customer requirement of generating uniform ink application. This was revealed as it was unable to meet the specifications of 0.015 g/in^2 for the dry weight of the ink and 85% of the sticker paper area covered with ink. Lastly, it also failed the durability test as the total crack length summed to over 10 inches.

Statement of Work

Additional contents from the Statement of Work are located in the Appendix.

Introduction

FeverDots stickers are a product developed by Wellhouse Enterprises, LLC, intended to indicate if an individual has a fever (body temperature of 99°F or higher) when adhered to the forehead in a room temperature setting. The FeverDots Senior Project team planned to develop a more accurate and uniform manufacturing process to apply the thermochromic (temperature-sensitive) ink to the substrate for these FeverDots stickers. Additionally, a human-use study was conducted with participants from BMED Senior Design class to assess usability and comfort of the FeverDots stickers.

Background

FeverDots is a product developed by Wellhouse Enterprises. It can be used by any consumer who needs to continuously monitor for elevated body temperature. Its thermochromic ink will change from a black to a pink color once it senses that the body temperature is at or above the threshold of 99℉. Currently, this product is made with thermochromic ink and an adhesive paper, and is designed to be worn for a maximum of 24 hours.

Previously, Wellhouse Enterprises looked to hire an off-site flexographic printer professional to apply the ink to the substrate. This was unsuccessful as the number of passes required to get the desired amount of ink would have been inefficient. The next method of rolling the ink on with a paint roller was successful in applying the ink to the substrate to obtain a functioning product. However, this method was still cumbersome and inefficient; the entire process involved manual labor. This included flood coating the ink by painting it onto the substrate and using a Cricut machine to cut out the individual stickers. After some time, Wellhouse Enterprises contacted Cal Poly and had a previous senior project team generate a manufacturing tool to quickly apply the ink in a uniform process. Unfortunately, the tool - which utilized a rolling method to apply the ink onto the substrate - became impractical; it was slightly difficult to use and rolled the ink in an inconsistent layer.

The initial plan of the current FeverDots Senior Project team involved using a stamping mechanism to exert a uniform pressure to the substrate and ink. This was supported by a conjoint analysis of four potential manufacturing processes including: manual operation, 100 stickers per cycle, stamp/clamp ink application mechanism; manual operation, 250 stickers per cycle, rolling ink application mechanism; automated operation, 100 stickers per cycle, rolling ink application mechanism; and automated operation, 250 stickers per cycle, stamp/clamp ink application mechanism.

Objectives

The final goals of this project included the production of a relatively light-weight, portable device and manufacturing method that can print the maximum number of FeverDots with uniform ink thickness per each cycle of use. Initial steps included understanding the problem the sponsors have with their current method and analyzing them in order to find solutions. The final product was created with the intentions of being easy to use, transport, and assemble if pieces ever happen to detach, as well as being durable enough to last and properly function for around three years.

The final product is indicated for manual press printing of FeverDots stickers such that an 8”x8” square sheet of sticker paper is filled with a uniform layer of ink per pressing cycle. It will be used in a home setting by the small business owners of Wellhouse Enterprises, Caroline Jurado and Margaret Shaw. Ink dispense of the device should be very precise in applying a uniform layer of ink on each sheet of sticker paper from which different shapes will be cut out using a Cricut machine after the ink has dried.

Customer requirements were converted into engineering specifications after careful review of client wants and needs. The most important requirements in the eyes of the customer were the uniformity of applied ink thickness and convenience of use. These requirements were converted into engineering specifications with quantifiable units. Ink application was narrowed to precise values of 0.05 ml/in^2 (volume of wet ink), or 0.015 g/in^2 (weight of dry ink). Specifications in the ease of use include an ideal application force of 27 N to initially move the device. Portability is quantified by specifying a maximum weight of 30 lb for the final product, in an attempt to make it easy to handle and transport when necessary.

Network Diagram

Microsoft Project was used to develop a Network Diagram and associated Gantt Chart. The list of tasks making up the Network Diagram is located below, in Table 1. The full Network Diagram is shown in Figure 1, with the critical path highlighted. The task numbers in Table 1 correspond to the task numbers in the bubbles in Figure 1. The task list includes the task number, task name, and duration. The tasks in bold have related subtasks, located directly following the bold task. To distribute responsibilities, the following titles were assigned: Rita - lead developer, Kameryn - lead researcher, and Heidi - lead designer.

Table 1. Task Sheet, Correlating to Network Diagram

Task No.	**Task Name**	**# Days**
2	IFU	6
3	Budget	6
4	House of Quality	6
7	Analyze Previous Year's Materials, Pro-Con	8
8	Research Competitor Methods and Products	10
5	Statement of Work	7
6	Status Update Memo 1	2
9	Pugh Charts	2
10	Conceptual Model	4
11	Conceptual Design Review	3
12	Status Update Memo 2	3
13	Compare Methods	8
14	Status Update Memo 3	3
48	Initial Machine Shop Visits	3
1	CAD of Design	5
43	Create Testing Protocol for Prototype	5
42	Create Manufacturing Plan	5
46	Critical Design Review	3
49	Select and Order Hardware for Prototype	5?
50	Create Protocol/Survey for Human Study of FeverDots	7
15	Winter Status Update Memo 1	2
17	**Create Functional Prototype**	8?
18	**Machine Base**	1
19	Cut Wood Pieces to Correct Size	1
20	Glue Wood Pieces Together	1
21	Drill Holes into Wood	1
22	**Machine Lid**	1
23	Cut Wood Pieces to Correct Size	1
24	Drill Wood Pieces Together	1
25	Drill Holes into Wood	1
26	Machine Foam	1?

30	**Machine Handle**	3
31	Cut Stock to Right Length	1
32	Drill Holes	1
33	Shape Rod	1
27	**Machine Ink Well**	1
28	Cut out Pieces	1
29	Glue Pieces Together	1
34	Assemble Prototype	1
35	Create Functional Prototype Video	1
16	Winter Status Update Memo 2	2
44	Perform Human Use Study	25
36	Functional Prototype Demo/Test Plan	3
37	Make any Changes to Final Manufacturing Process	7?
52	**Perform Testing**	20?
55	Test Weight of Device	1?
56	**Dry Weight of Ink Test**	3
57	Press Ink onto Paper	1
58	Analyze Results	1
59	**Ink Distribution Test**	3
60	Press Ink onto Paper	1
61	Take Images and Analyze on ImageJ	1
76	**Force Uniformity Test**	1
77	Apply Droplets And Press Ink	1
78	Analyze Droplet Area Using ImageJ	1
66	**Dry Weight of Ink Test**	3
67	Press Ink onto Paper	1
68	Analyze Results	1
69	**Ink Distribution Test**	3
70	Press Ink onto Paper	1
71	Take Images and Analyze on ImageJ	1
79	**Force Uniformity Test**	1
80	Apply Droplets And Press Ink	1
81	Analyze Droplet Area Using ImageJ	1

72	**Minimum Force Test**	1
73	Measure Force to Move Handle	1
75	Analyze Data	1
62	**Minimum Force Test**	1
63	Measure Force to Move Handle	1
65	Analyze Data	1
53	Measure Crack Lengths	1
54	Count Steps of Assembly	1
47	Manufacture Final Design	18
38	Winter Status Update Memo 3	2
39	Winter Status Update Memo 4	2
40	Winter Status Update Memo 5	2
51	Analyze Data from Human Use Study	7?
41	Winter Status Update Memo 6	2
45	Final Design Review	3

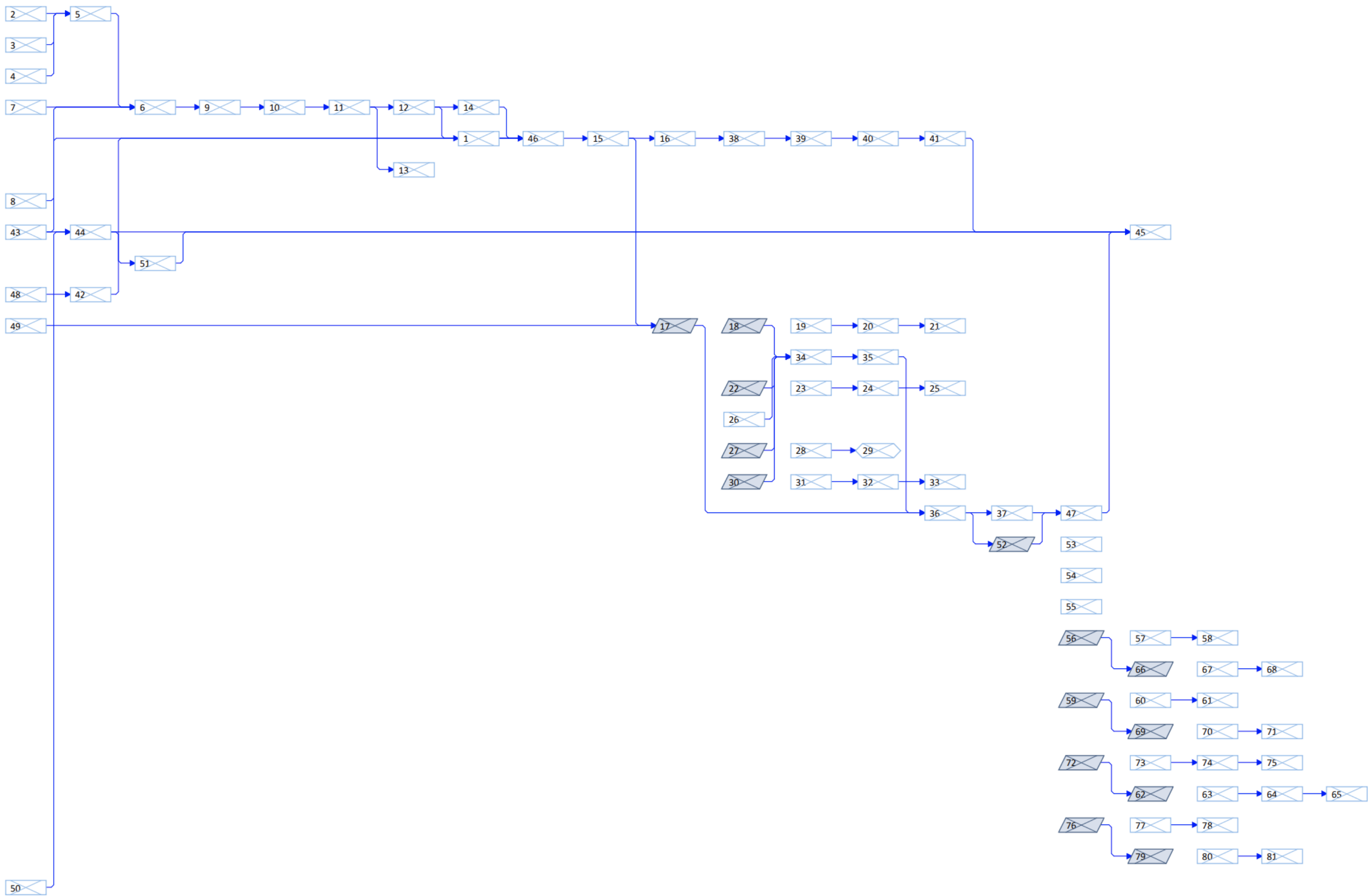


Figure 1. Network Diagram.

Indications for Use

The final device is indicated for manual press printing of FeverDots such that an 8”x8” square sheet of sticker paper is filled with a uniform layer of ink per one pressing cycle. It would be used in a home setting by the small business owners of Wellhouse Enterprises, Caroline Jurado and Margaret Shaw. Ink dispense of the device should be very precise in applying a uniform layer of ink on each sheet of sticker paper; different shapes will be cut out using a Cricut machine after the ink has dried.

Budget

The FeverDots team had a total budget of $700: $200 from state funds and $500 from the Hannah Forbes grant. An itemized spending budget is depicted in Table 2. The table depicts the amount spent for each item as well as what account the funds were taken out of. Additionally, it shows the amount the team had planned to spend, and the amount that was actually spent. The total that was spent was $662.31.

Table 2. Budget.

Number	Item Description	Product Number	Purpose	Associated Task
1	Wooden Dowels	N/A	Conceptual Model	Model Dowels for Alignment
2	Scotch Tape	N/A	Conceptual Model	Model Hinges
3	5 mL Pipettes	N/A	Conceptual Model	Depositing Ink
4	8.5" x 11" Matte White Sticker Paper	OL177WX	Testing	Ink Testing
5	PT Hem Fir Wood	N/A	Functional Protoype	Base and Lid of the Device
6	Compression Spring 0.5" Long	9657K278	Functional Prototype	Force Distribution
7	Nylon Black Spacers	90176A154	Functional Prototype	Prevent Wear
8	Nylon Off-White Spacers	94639A760	Functional Prototype	Prevent Wear
9	Aluminum Washer93286A044		Functional Prototype	Prevent Wear
10	6 ft. 1-1/2" Diameter Aluminum Rod	8974K18	Functional Prototype	Handle
11	1/4" Thick Polyurethane Foam Sheet	86375K122	Functional Prototype	Ink Sponge
12	1/2" Thick Cast Acrylic	8560K265	Functional Prototype	Ink Well
13	Black Steel Socket Head Screw	90044A129	Functional Prototype	Handle Attachment to Base
14	2 ft. 3/16" Diameter Aluminum Rod	8974K212	Functional Prototype	Handle Attachment to Lid
15	Acrylic Glue	N/A	Functional Prototype	Binding Acrylic Well
16	Support Hinges & Mounting Screws	N/A	Functional Prototype	Force Distribution
17	Stainless Steel Hex Drive Flat Head Screw	92210A249	Functional Prototype	Wood Attachment
18	MDF Sheet 3/4" Thick	2726N13	Functional Prototype	Paper Area
19	MDF Sheet 1/2" Thick	2726N12	Functional Prototype	Ink Well Alignment
20	1/2" Thick Polyurethane Foam Sheet	8614K83	Functional Prototype	Ink Sponge
21	6 ft. 1" Diameter Steel Round Tube	7767T39	Functional Prototype	Handle
22	2 Liter Black Acrylic Paint	N/A	Testing	Thermochromic Ink Substitute
23	8" x 8" Sticker Paper Roll (325 Sheets)	RL4127XW	Testing	Sticker Paper Substrate
24	1/8" Thick Clear Acrylic Sheet	8560K239	Final Prototype	Ink Sponge Enclosure
25	Stainless Steel Paper Towel Holder	N/A	Final Prototype	Sticker Paper Holder
26	3/4" Thick 2' x 4' MDF	N/A	Final Protoype	Paper Area
27	Stainless Steel Sheet Metal	N/A	Final Prototype	Lid Reinforcement
28	Phillips Head Wood Screws	N/A	Final Prototype	Attachment of Sheet Metal

	Planned						Actual			
Number	Unit	Quantity	Cost/Unit	Total Cost	Notes		Quantity	Cost/Unit	Total Cost	Notes
1	4	1	$ 0.43	$ 1.73	Michaels		1	$ 0.43	$ 1.73	State Funds
2	1	1	$ 3.90	$ 3.90	Michaels		1	$ 3.90	$ 3.90	State Funds
3	200	1	$ 0.06	$ 12.12	Amazon		1	$ 0.06	$ 12.12	State Funds
4	25	1	$ 0.61	$ 15.26	Online Label		1	$ 0.61	$ 15.26	State Funds
5	1	1	$ 31.98	$ 31.98	Home Depot		1	$ 35.09	$ 35.09	Hannah Forbes
6	6	1	$ 1.12	$ 6.71	McMaster-Carr		1	$ 1.67	$ 10.01	Hannah Forbes
7	25	1	$ 0.13	$ 3.32	McMaster-Carr		1	$ 0.26	$ 6.62	Hannah Forbes
8	25	1	$ 0.57	$ 14.30	McMaster-Carr		1	$ 0.70	$ 17.60	Hannah Forbes
9	5	1	$ 1.32	$ 6.59	McMaster-Carr		1	$ 1.98	$ 9.89	Hannah Forbes
10	1	1	$ 90.92	$ 90.92	McMaster-Carr		1	$ 94.22	$ 112.62	Hannah Forbes
11	1	1	$ 12.54	$ 12.54	McMaster-Carr		1	$ 15.84	$ 15.84	Hannah Forbes
12	1	1	$ 33.98	$ 33.98	McMaster-Carr		1	$ 37.28	$ 37.28	Hannah Forbes
13	10	1	$ 0.82	$ 8.16	McMaster-Carr		1	$ 1.15	$ 11.46	Hannah Forbes
14	1	1	$ 3.02	$ 3.02	McMaster-Carr		1	$ 6.32	$ 6.32	Hannah Forbes
15	1	1	$ 12.78	$ 12.78	Amazon		1	$ 13.90	$ 13.90	Hannah Forbes
16	4	1	$ 3.27	$ 13.09	Amazon		1	$ 2.89	$ 11.54	Hannah Forbes
17	50	1	$ 0.24	$ 12.17	McMaster-Carr		1	$ 0.42	$ 21.09	Hannah Forbes
18	1	1	$ 7.21	$ 7.21	McMaster-Carr		1	$ 16.13	$ 16.13	Hannah Forbes
19	1	1	$ 5.73	$ 5.73	McMaster-Carr		1	$ 14.65	$ 14.65	Hannah Forbes
20	1	1	$ 15.09	$ 15.09	McMaster-Carr		1	$ 24.01	$ 24.01	Hannah Forbes
21	1	1	$ 16.25	$ 16.25	McMaster-Carr		1	$ 42.67	$ 42.67	Hannah Forbes
22	1	1	$ 23.45	$ 23.45	Amazon		1	$ 25.50	$ 25.50	Hannah Forbes
23	325	1	$ 0.30	$ 95.95	Online Labels		1	$ 0.34	$ 110.90	State Funds
24	1	1	$ 9.70	$ 9.70	McMaster-Carr		1	$ 19.63	$ 19.63	Hannah Forbes
25	1	1	$ 14.95	$ 14.95	Amazon		1	$ 15.44	$ 15.44	Hannah Forbes
26	1	1	$ 25.50	$ 25.50	Home Depot		1	$ 27.11	$ 27.11	Hannah Forbes
27	1	1	$ 14.98	$ 14.98	Home Depot		1	$ 16.34	$ 16.34	Hannah Forbes
28	100	1	$ 0.06	$ 6.30	Home Depot		1	$ 0.08	$ 7.66	Hannah Forbes
			Total	**$ 517.68**				**Total**	**$ 662.31**	

Customer Requirements

The final goals of this project include the production of a relatively light-weight, portable device and manufacturing method that can print the maximum number of FeverDots with uniform ink thickness and uniform force applied across the sticker paper per each cycle of use. Initial steps include understanding the problem the sponsors have with the current product and analyzing them in order to find solutions. Another requirement the sponsors brought up was a collection of feedback from human use of FeverDots. A human use study and data analysis of the results was conducted and composed into a concise human use report and submitted to the sponsors. The final product was created with the intention of being easy to use, transport, and reassemble if pieces ever detach. The device was designed to be durable enough to last and properly function for three years.

Specification Development

Customer requirements were converted into engineering specifications after careful review of client wants and needs. It was found that the most important requirements in the eyes of the customer were the uniformity of applied ink thickness and convenience of use. These requirements were converted into engineering specifications with quantifiable units. Ink application was narrowed down to precise volumes of 0.05 ml/in^2. Portability is quantified by specifying a maximum 30 lb weight for the final product, in an attempt to make it easy to handle and carry. Simple assembly is quantified by a step count of maximum 10 steps for device operational process. It was established by our sponsors that any process that took over 10 steps would be excessive. Ease of use was quantified with a spec of 27 ± 4N required to start the motion of the device, which was set by taking into account the total weight of the device and researching realistic amounts of force that would be appropriate to easily set it in motion. Finally, the specification for the device's ability to generate uniform ink was converted to a dry weight of 0.015 ± 0.002 g/in^2 measurement for dry weight of ink, which was given to the team by the sponsors. This customer requirement was further quantified through having 85% of the sticker paper uniformity covered by ink. This specification was a minimum also set by our sponsors, from where we would work to increase the percentage of uniform ink coverage. An engineering specification of 85% was also set for the force uniformity specification. To fulfill this requirement, at least 85% of the sticker paper would have to be receiving a uniform amount of force application. This specification was developed as it would produce greater results than the methods previously used by the sponsors, while still producing the desired outcome and establishing a reliable and tolerable starting point to improve upon. The aforementioned specifications are shown in the table below.

Table 3. Customer Requirements and Engineering Specifications.

Requirement	Measurement	Specification
Lightweight/Portable	Pounds (lb)	30 lbs (maximum)
Durable	Inches (in)	10 in (maximum)
Simple Assembly	Number of steps	10 steps (maximum)
Easy to Use	Newtons (N)	27 ± 4 N
Uniform Ink Distribution	Grams per square inch (g/in^2)	0.015 ± 0.002 g/in^2
Uniform Ink Distribution	Percentage of Area (%)	85% (minimum)
Uniform Force Distribution	Area receiving uniform force (%)	85% (minimum)

Intellectual Property Assessment

Several U.S. patents and patent applications were examined to determine if an infringement on intellectual property was occurring. In patent 11,059,312, claim 18 discusses that the stamping tool will have a “removably attachable base” (2021), but the team chose to operate at risk as the base and lid are intended to be permanently affixed to one another. Next, patent 11,060,924 mentions using thermochromic ink for activatable quality labels (2021). However, the thermochromic ink used in this situation is used as a temperature indicator for fevers. Another claim from patent 11,135,832 explains how a flexographic inking system uses a “force mechanism to push the ink tray assembly” (2021). Because the final design did not include a rolling mechanism, the team did not infringe on the claims of this patent. For the majority of the claims that were analyzed, the team decided to operate at risk as the planned design does not seem to violate the current patent claims.

Conjoint Analysis

A conjoint analysis of four potential manufacturing processes was conducted. These four options were the following: manual operation, 100 stickers per cycle, stamp/clamp ink application mechanism; manual operation, 250 stickers per cycle, rolling ink application mechanism; automated operation, 100 stickers per cycle, rolling ink application mechanism; and automated operation, 250 stickers per cycle, stamp/clamp ink application mechanism. From analyzing the results of the conjoint survey taken by the BMED 455 class, the following factors are preferred: automatic operation, 250 stickers produced per cycle, and a rolling ink application mechanism. The factors had the following contributions to attractiveness: 43.84% (mode of operation), 35.61% (number of stickers per cycle), and 20.55% (ink application mechanism). This statistical analysis told the group that manual versus automatic device operation had the greatest impact on customer attractiveness, followed by the number of stickers per cycle. See Appendix for full statistical output and factors/levels.

Morphology

A morphology (Figure 2) was constructed to form a range of concepts for the desired functions of the designs and eventually led to designs of conceptual models. These functions were chosen to be substrate attachment, transferral of the ink, ink well placement, and connection between the device pieces. For attachment of the substrate, the following concept ideas were generated: 2 clamps, 4 clamps, and placement of the substrate on the roller. Raising the ink well to the substrate, painting the ink using a roller, using an automated sprayer to spray on the ink, and pressing the ink onto the substrate using a lever were the concepts produced for the function of ink transferral. The ink well was also thought to possibly be attached as part of the base or placed on top of the roller or stamp so that it could flow down onto the substrate. Also, another concept was to have the ink inserted inside the roller so that it could diffuse through. For the last function, multiple mechanisms for attachment were considered. One included using two hinges that are parallel laterally, and another concept included using 4 rods or dowel pins to align the top and bottom pieces. Furthermore, the next concept combined the two preceding concepts with 2 hinges and 2 dowel pins. The fourth concept for this function was to use collapsible hinges to connect a bottom and top piece.

Morphology						
Product:		Organization Name : FeverDots Senior Project Group				
Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Hold Substrate	2 clamps	4 clamps	On roller			
Transfer Ink	Raise well to substrate	Roll like paint roller	Spray ink onto substrate	Use lever Press ink onto substrate		
Hold Ink Well	Part of base	Ink well on top of roller/stamp	Ink well inside the roller/stamp			
Connect between device pieces	2 hinges	4 rods/ dowel pins	2 dowel pins & 2 hinges	Collapsible hinges		
Team member: Rita	Team member: Kameryn	Prepared by: FeverDots Senior Project Group (all 3 team members)				
Team member: Heidi Silk		Checked by:		Approved by:		
The Mechanical Design Process Copyright 2008, McGraw Hill				Designed by Professor David G. Ullman Form # 15.0		

Figure 2. Morphology.

Concept Evaluation

The following concept designs were drawn based on the ideas formed in the morphology section. Concepts and techniques were compared and evaluated to form the three sketches which utilize the rolling method and stamping methods as the most promising ideas for printing FeverDots.

Sketch #1

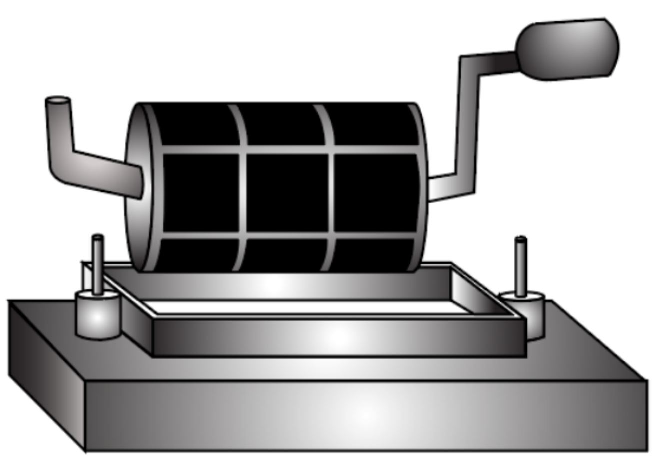


Figure 3. Conceptual Sketch 1.

This design was developed through consideration of the rolling method used in many printers. Ideally, the roller would have precisely lowered into the ink well so that the surface would have been submerged in the ink at a set depth. The substrate holding the sticker paper would have been wrapped around the surface of the roller, and the lever would have been used to roll the ink onto the sticker paper, which would then have been prepared to be removed from the device and cut into the desired sticker shapes.

Sketch #2

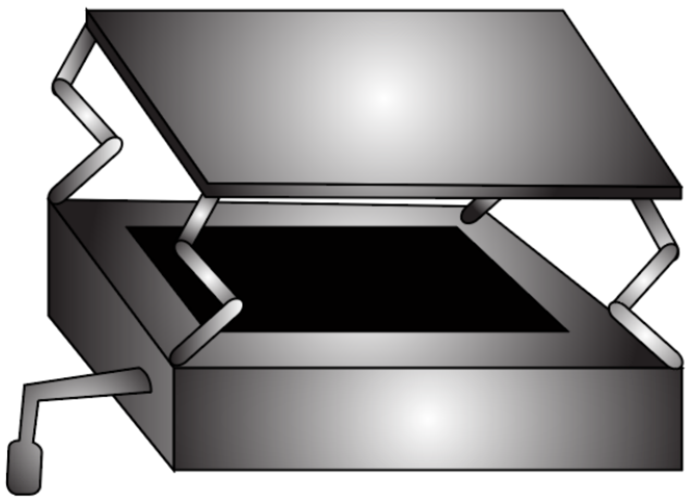


Figure 4. Conceptual Sketch 2.

The bottom segment of this design, the base, would have held the ink well and the thermochromic ink, as shown in the morphology. The bottom face of the top piece would have attached the substrate using clamps (not shown). The idea behind this design is that it was meant to lower the top of the device to the ink well to be able to apply the ink. Another idea for this design was to push down the substrate to the ink well while still using the collapsible hinges.

Sketch #3

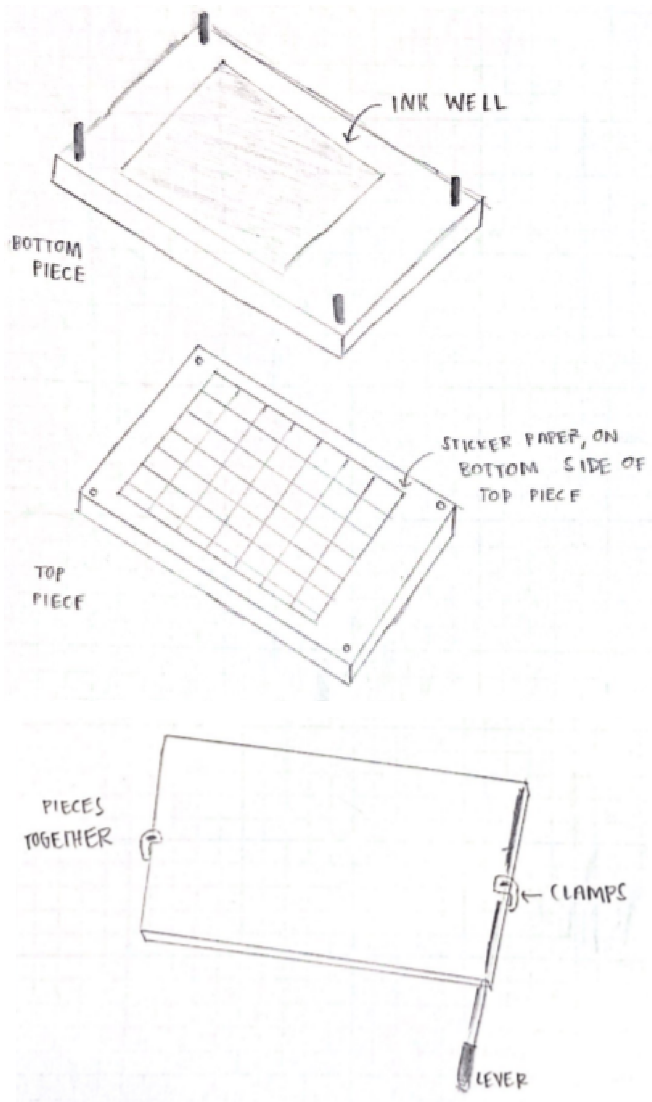


Figure 5. Conceptual Sketch 3.

This design incorporated the concepts of holding the substrate with 2 clamps, a lever to transfer ink onto the substrate, the ink well as part of the base, and 4 rods implemented to connect the top and bottom pieces. The main idea behind using clamps was that the clamps would have been tight enough to exert enough force for the ink to transfer; additionally, the clamps would have been attached for a calculated amount of time, then undone once the lever had sufficiently functioned in transferring the ink. Additionally, 4 rods connecting the pieces would have kept the two pieces aligned on all sides.

After each team member separately evaluated each conceptual sketch and compared them, the team collectively filled out three Pugh Charts, one for each conceptual sketch to come to an agreement. With the combined efforts of the team, the following Pugh Charts were formed.

Concept 1 as baseline

Sketch 1 as Baseline		Baseline	Sketch #2	Sketch #3
Manufacturability	30	Datum	0	1
Ease of Use	15	Datum	0	1
Control of Ink Deposit	35	Datum	1	1
Accuracy	20	Datum	1	0
		Total	2	3
		Weighted Total	55	80

Concept 2 as baseline

Sketch 2 as Baseline		Baseline	Sketch #1	Sketch #3
Manufacturability	30	Datum	0	0
Ease of Use	15	Datum	0	-1
Control of Ink Deposit	35	Datum	1	0
Accuracy	20	Datum	1	0
		Total	2	-1
		Weighted Total	55	-15

Concept 3 as baseline

Sketch 3 as Baseline		Baseline	Sketch #1	Sketch #2
Manufacturability	30	Datum	-1	0
Ease of Use	15	Datum	-1	1
Control of Ink Deposit	35	Datum	-1	0
Accuracy	20	Datum	0	0
		Total	-3	1
		Weighted Total	-80	15

Figure 6. Pugh Charts (group).

Front-Runner: Concept 2

The Pugh Chart analysis gave Concept 2 to be the front runner. In this design, the base would hold the ink well to place the thermochromic ink as shown in the morphology. The bottom part of the top piece of the product would attach the substrate using clamps (not shown). In terms of manufacturability, Concept 2 was ranked higher when compared to Concept 1 because of the difficulty of making Concept 1 feasible, and it was ranked similarly when compared to Concept 3 as a more straightforward mechanism. Additionally, Concept 2 was ranked similarly to Concept 1 regarding ease of use of the product because they both require applying the substrate, and then using a lever to apply the ink. However, Concept 2 ranked higher than Concept 3 in this category as Concept 3 adds extra steps with aligning the two pieces and may provide more difficulty when using. Also, Concept 2 was thought to have better control of ink deposit than Concept 1, as it appears harder to manage the application of ink using a rolling mechanism, but it was ranked the same as Concept 3 as they both involve vertical applications of ink. Lastly, Concept 2 was ranked higher than Concept 1 in accuracy and the same for Concept 3, since control of ink deposit and accuracy are related functions of the product. Moving forward, the team focused on keeping the manufacturability and ink control at the forefront of design and ideation.

Conceptual Model

To decide which factors to merge for the conceptual model, there was extensive analysis done from the morphology beyond the conceptual sketches. The initial concept for the conceptual model is shown in Figure 7. This merges the following functional concepts: substrate/sticker paper attached to top piece, pressing ink onto the paper using a lever, ink well as part of the base, and 2 hinges/2 dowel pins to attach the top and bottom pieces to one another. The model functioned similarly to a panini press, with the top piece coming down to compress the bottom piece (shown in Figure 8).

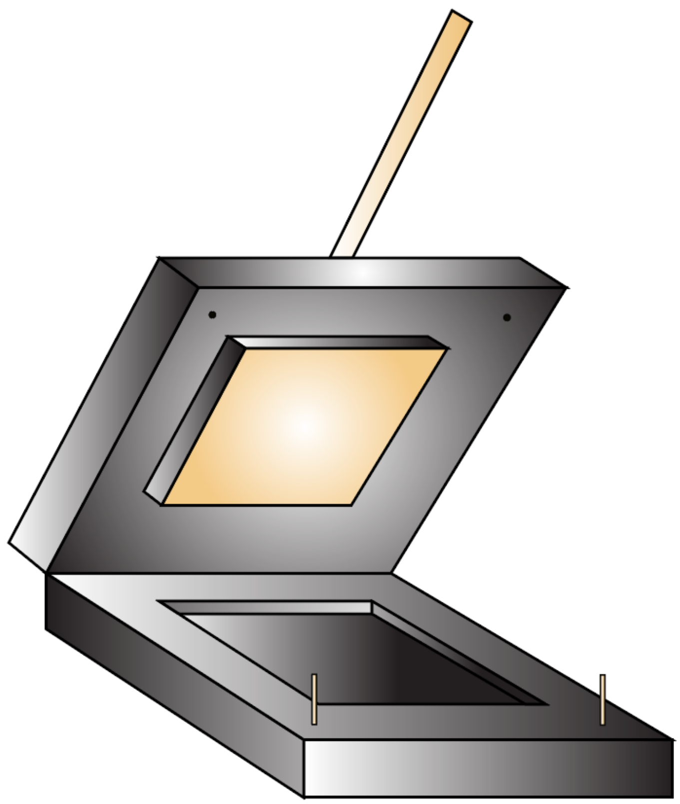


Figure 7. Sketch of Conceptual Model.

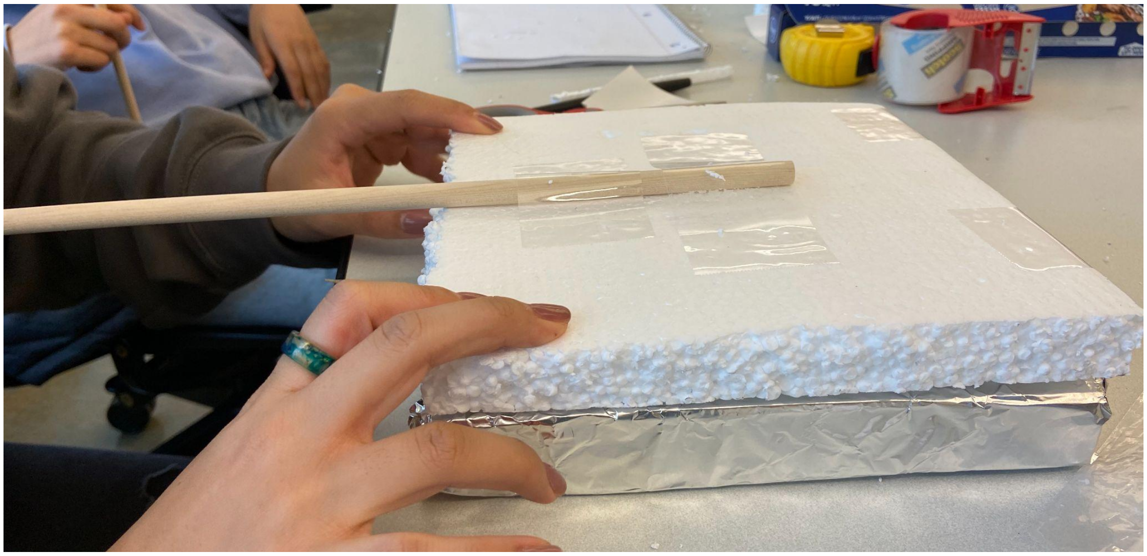


Figure 8. Functionality of Conceptual Model.

The conceptual model was created using styrofoam (top and bottom pieces), a wooden dowel (lever), two small wooden skewers (dowel pins), tinfoil (ink well), and packaging tape (hinges and securing the dowel onto the top piece) (see Figures 8 and 9). After cutting the styrofoam pieces to correct sizing, placing the tinfoil, and using tape to secure necessary pieces, thermochromic ink was added into the inkwell (see Figure 10). To determine the correct measurement, the specification of 0.05 mL/in^2 was used over the top square area of 37.5 in^2. This gave a measurement of ~2mL, but this initial amount was too small to evenly cover the inkwell. After gradually measuring and adding more ink, close to 6mL was added to ultimately have an adequate amount of coverage. The pieces were compressed together and the resulting ink distribution was initially not uniform, (see Figure 11). After smoothing out the ink that was on the sticker paper with a wooden dowel, the distribution was more uniform (see Figure 12).

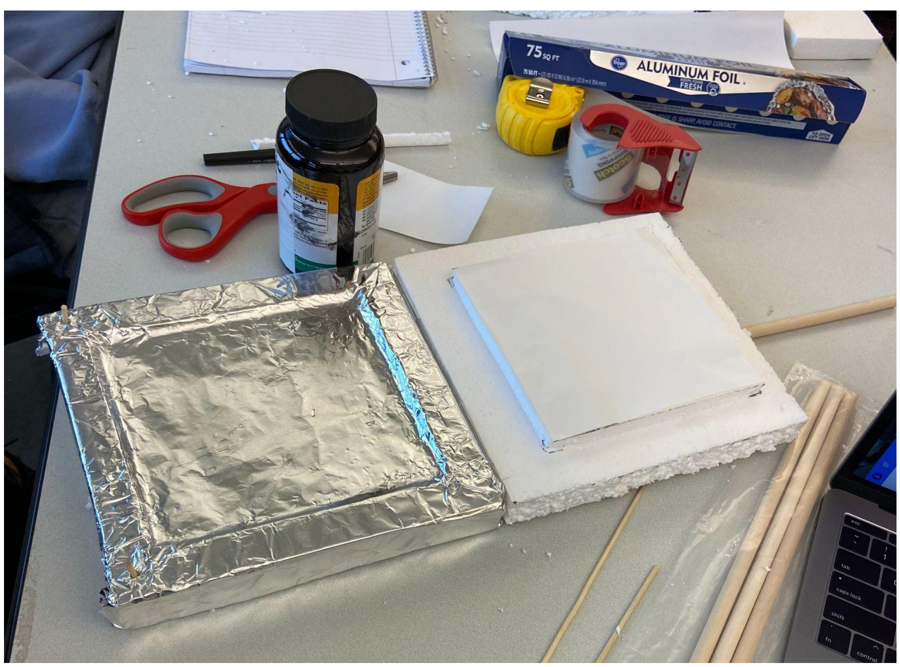


Figure 9. Parts Composing Conceptual Model.

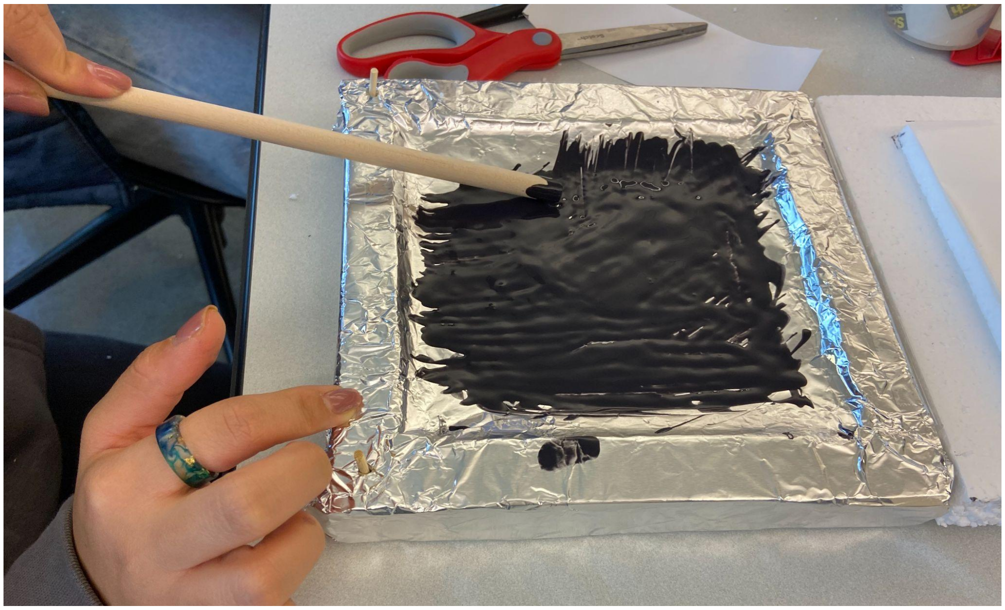


Figure 10. Ink Transfer to Ink Well.

Figure 11. Result of Initial Compression.

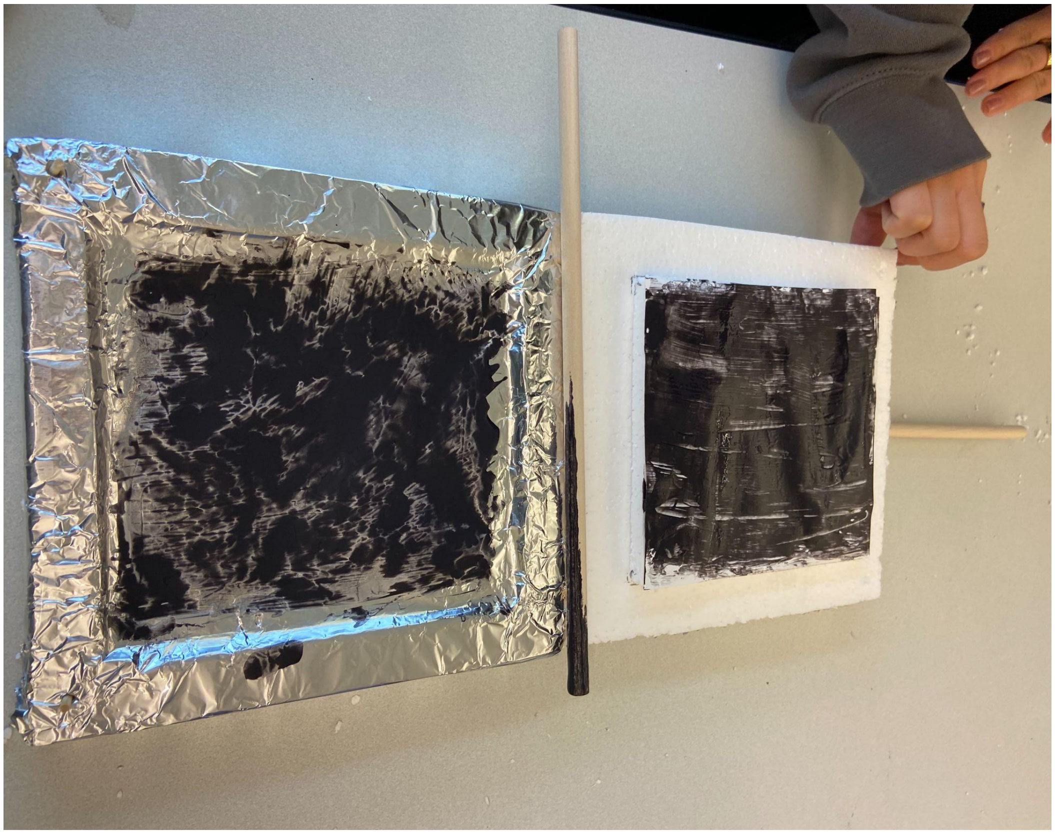


Figure 12. Ink on Conceptual Model, after Smoothing.

Analyzing this conceptual model gave many important lessons for the future development of this device. The difficulty of ink measurement and the fact that it was necessary to add more than the specification showed that ink measurement and estimation was going to be an obstacle in device testing and development. To help diminish this problem, 5mL micropipettes were ordered for future use. The inconsistencies in ink distribution taught that the ink may be too dark in some parts. At the time, this helped the team realize that this will be an important quantity to measure in further testing. The setup of the two pieces did work well, which taught that this was a practical functional concept to continue to develop. To improve future testing, a stronger specification was developed to measure ink distribution/thickness, rather than just observing it qualitatively.

Other future improvements from this model included developing a more reliable method and mechanism to hold the sticker paper reserve on the top piece, and ideally automating the paper movement process. Additionally, a set length was determined for how far the top piece needs to compress the bottom piece. Overall, this was a helpful model and gave in-depth insight for how to evaluate factors of the device and move forward in the development process.

Detailed Design

Following the initial analysis of the conceptual model, further analysis and development were done. One major concern that came out of the conceptual model analysis was the uneven distribution of force, which translates to an uneven distribution of ink. Through further analysis and ideation, the lever was switched to a long handle to span the entire width of the box; this handle coming down all at once allows for more even force distribution and thus more even ink distribution. This handle was designed out of steel, cut down and bent to fit the box. With this new handle, many additional changes followed. The base and lid were machined to make a 10”x10” wooden box. A square piece of steel sheet metal was screwed into the top of the lid, to reinforce the wood. The components for the ink well - both a basin and a piece of foam material (absorbent) sit into the base piece. The ink well is an 8.6”x8.6”x.5” piece of acrylic, with .25” thickness around. There was no coating applied to the acrylic pieces, taking advantage of the low water absorption rate (0.3-0.4% by weight) of acrylic. Inside this ink well piece is an 8”x8”x1” piece of foam, to absorb the ink. Another acrylic box was created to sit on top of the foam, as a cover for the ink well; this piece measures 9”x9”x.25”, with .125” depth and .25” all around. Additional fasteners (spacers and washers) were added to the bottom screws, for placement and alignment of the assembly pieces. Brackets were added to both sides, also aiding in the alignment and movement of the pieces. The aluminum rods at the front end of the device are located on both sides; these serve as a hard stop to mark maximum device movement. The assembly of the design is shown in Figure 13; this displays the components in their respective materials. Detailed drawings of the full design and the individual parts are located in the Appendix.

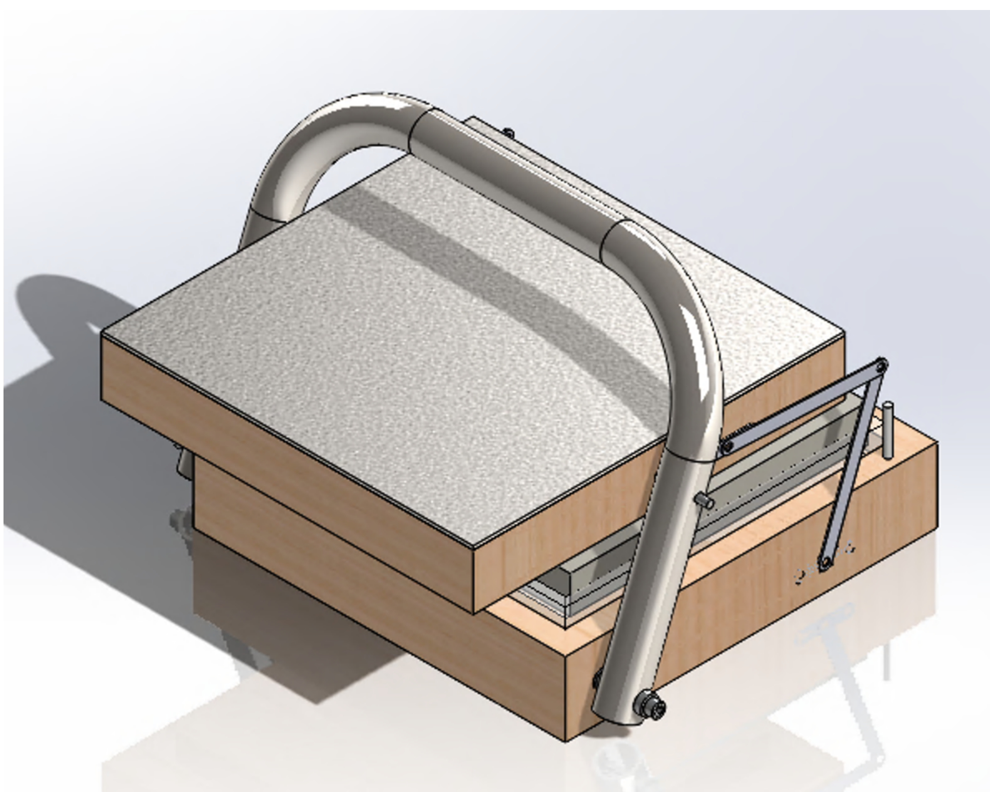


Figure 13. Isometric View of Full Assembly.

Figure 14, the Bill of Materials, lists the parts, quantities, materials, and vendor (if applicable). The following parts were manufactured: base (wood), lid (wood), handle (steel), ink well (acrylic), ink absorber (polyurethane foam), ink well cover (acrylic), and lid topper (steel). The following parts will be purchased: spacers, screws, washers, and rod (all from McMaster-Carr), as well as steel sheet metal and wood screws (Home Depot). The cost based on these components is located in the budget, Table 2. The detailed drawings for each component, and the full assembly drawing, are located in the Appendix.

Bill of Materials (BOM)

Date: 3/8/2022

Product: FeverDots Manufacturing Device

Item No.	Qty.	Part Name/Description	Part Number	Material	Source
1	1	Base	001	Wood	Home Depot
2	1	Lid	002	Wood	Home Depot
3	1	Handle (6' length)	7767T39	Steel	McMaster
4	2	Black-Oxide Alloy Steel Socket Head Screws	90044A129	Steel	McMaster
5	1	Ink Well	004	Acrylic	McMaster
6	1	Ink Foam Absorbent	8614K83	Polyurethane Foam	McMaster
7	1	Multipurpose 6061 Aluminum Rod, 3/16" Diameter	8974K212	Aluminum	McMaster
8	2	Nylon Unthreaded Spacers	90176A154	Nylon	McMaster
9	2	Bracket	N/A	Iron	Amazon
11	2	Aluminum Washer	93286A044	Aluminum	McMaster
12	1	Ink Well Cover	005	Acrylic	McMaster
13	1	Steel Top	006	Steel	Home Depot
14	4	Everbilt #8 x 1.25 in. Philips Flat Head Stainless Steel Wood Screws	N/A	Stainless Steel	Home Depot

Figure 14. Bill of Materials.

Prototype Manufacturing Plans

The manufacturing process associated with building the FeverDots printing device prototype consists of multiple steps, including machining material to create required parts, and finally the assembly of said parts. The following describes, in detail, the processes used to machine each part and assemble the final prototype.

Base and Lid

To build the base of the device, obtain a piece of 1.5" thick pressure treated (PT) fir wood. Use a table saw to cut the wood into two 10"x10" squares. Use a table saw to cut an 8"x8" square from 0.75" thick medium density fiberboard (MDF). Use a planer jointer and belt sander accordingly to ensure that all of these pieces are perfectly flat and have parallel surfaces.

Place the 8”x8” piece of MDF flat and centered on top of one of the 10”x10” pieces. Next, use a power drill to drill pilot holes through the four corners of the 8” x 8” piece of MDF. These are thru holes, located ½” from each edge of the piece. Use the power drill to drill 1.25” stainless steel flathead screws with a 0.19” diameter into all four holes to secure the wood pieces together. This piece will act as the lid of the device. Use a wooden drill press to drill two 7/32” diameter holes into two parallel sides of the lid (one hole on each). Each hole should be 1.5” deep, located in the middle (5” from each side and 0.75” from the top and bottom). Obtain a piece of stainless steel sheet stock and cut to 10”x10.” Drill four 5/16” diameter holes in the four corners of the steel piece; these should be 0.5” from each corner. Using a power drill, drill the steel piece into the wood, using #8-1.25” screws.

The remaining 10”x10” piece of wood from earlier is the base of the device. Using the 0.5” MDF, use the table saw to cut 4 rectangles - two measuring 8.7”x.65” and two measuring 10”x.65.” Place these rectangles on top of the 10”x10” piece, and glue on top using wood glue. Use a drill press to drill .25” diameter holes into two opposing sides of the lid. These holes should be 1” from the bottom of the piece (including the MDF) and 1” from the edge, 2” deep. Use a drill press to drill 3/16” diameter holes into the top face of the base, 1” from the edge and 0.5” deep.

Ink Well

To build the ink well, obtain a 12”x12” acrylic sheet with 0.5” thickness. Use a laser cutter to cut out one 8.6”x8.6” square, two 8.6”x0.25” rectangles, and two 8.1”x 0.25” rectangles. Once cut, place the two 8.6”x0.25” rectangles on two opposing edges of the 8.6”x8.6” square, as shown in Figure 15. Place the two 8.1”x0.25” rectangles on the remaining two edges of the square. Ultimately, the four rectangular pieces should be lying on top and framing the square, creating a well. Use acrylic glue to glue these pieces into place, sit overnight to let them dry. Once dry, an open celled 0.5” super cushioning polyurethane foam with adhesive on one side should be cut into an 8”x 8” square and stuck into the ink well. Two of these foam pieces should be layered for a total foam thickness of 1”.

To build the box that serves as a cover for the ink well, obtain a 12”x12” acrylic sheet with 0.125” thickness. Use a laser cutter to cut one 9”x9” square, two 9”x0.25” rectangles, and two 8.5”x0.25” rectangles. Once cut, place the two 9”x0.25” rectangles on two opposing sides of the 9”x9” square. Place the two 8.5”x0.25” rectangles on the remaining two edges of the square. Ultimately, the four rectangular pieces should be lying on top and framing the square, creating a well shape; this is a similar method as creating the ink well. Use acrylic glue or epoxy resin to glue these pieces into place, sit overnight to let them dry.

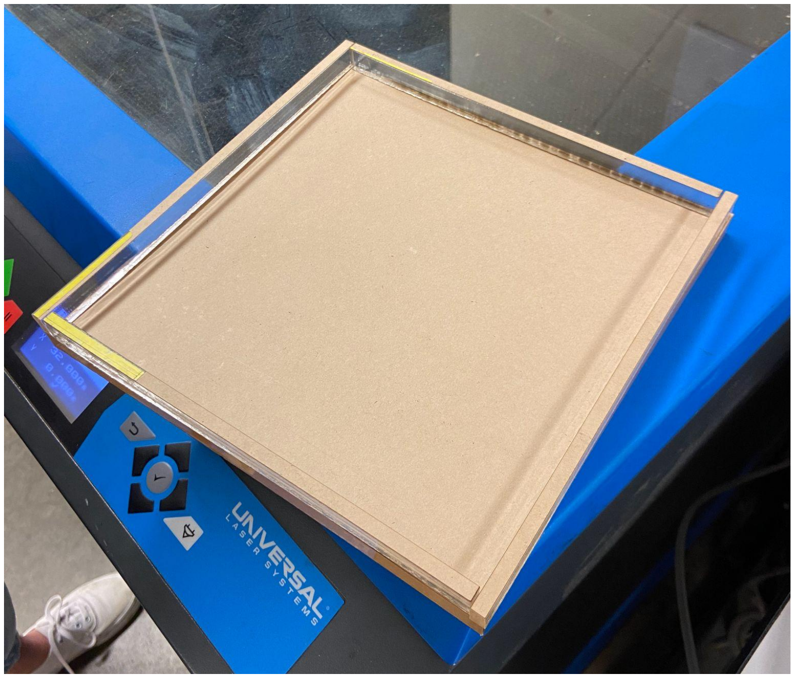


Figure 15. Laser Cut Pieces.

Handle

To build the handle of the device, obtain a hollow steel tube with a diameter of 1”, wall thickness of 0.095,” and a length of at least 30”. Mark the tube with a sharpie marker after measuring 11” from one end. Feed this end into the tube bender from the front side, and align the marking with the tube bender. Bend the tube to 90 degrees. Use an angle gauge to verify that it has reached 90 degrees. Once the first bend is complete, remove the tube and mark the location of the end of the bend on the longer side of the rod. Make another mark 8.5” from this marking, to resemble the space of the handle that will be between both bends once it is complete. Make another marking 11” from the last marking. You should have three markings: one immediately after the bend, one 8.5” from that, and one more 11” further than that. Use a steel cold saw to cut off excess tubing, whatever is after the third marking. Once the tube has been shortened to the appropriate length, feed the unbent end of the tube into the tube bender so that the 11” marking is lined up with the machine and so that it is perfectly planar with the first 90 degree bend. Bend the tube to 90 degrees. Use an angle gauge to verify that it has reached 90 degrees. The tube should now be bent into a “U” shaped handle, as shown in Figure 16. Flip the handle so that it is in an upside-down “U” position. Make markings 0.5” and 4.75” from the bottom of each vertical leg of the handle. These markings should be 0.5” from the front plane of the “U,” in the middle from the side view. Use a drill press to drill 5/16” (lower) and 7/32” (upper) diameter holes all the way through the tube.

Figure 16. Steel Handle.

Device Assembly

To assemble the device, first place the foam ink absorber piece into the ink well and glue the acrylic ink well onto the center of the base. Place the lid of the device on top of the base so that the 8” x 8” extruded piece of MDF lies on top of the foam in the ink well. Next, snugly fit the handle on top of the device so the the holes in the handle align with the holes on the sides of the base and lid. Slide 3” pieces of the 3/16” diameter aluminum rods into the top holes on both sides of the lid and handle. Place a ¼” aluminum washer on the inner side of the base and handle, and place a ½” spacer on the outer side of the handle. On both sides of the device, screw a ¼”-20-3” screw into the bottom holes of the handle, through both the spacer and washer. Screw the hinges into both the base and lid, using a screwdriver and the screws associated with these hinges. These are located 1” from the front end of both the lid and base. On both sides, screw two 1.25” #8 screws both above and below the bottom hinge component; these fix the hinge so only the top piece moves. In both the holes on the top face of the base, place 1.5” pieces of the 3/16” diameter rod. Place the ink well cover on top of the ink well. See Figure 20 for final configuration of the device.

Prototype Iterations

As part of the device development process, multiple iterations were created. The series of pictures and explanations below demonstrate the various changes and improvements made to get the device to its final version.

Iteration One

The first iteration of the device was created prior to any testing. The device, shown in Figure 17, had central holes in the base and lateral holes in the lid. Because of this and the many degrees of freedom of the lid, the device was not functional in this state.

Figure 17. Fully Assembled Device, First Prototype.

Iteration Two

The first prototype was manufactured with the base holes in the center, and the lid holes towards the end. This created an unstable design, which contributed to the low functionality of the first prototype. For the second iteration, these hole locations were switched; the holes in the base were moved to the edge and the holes in the lid were moved to the middle. Additionally, the previously mentioned hinges were implemented and screwed into both sides, on both the base and lid. These were added to also help with stability and functionality.

Figure 18. Prototype Iteration Two.

Iteration Three

In early stages of testing with the second iteration of the prototype, it was clear that more reinforcements needed to be added. Regarding the stability of the wood, two reinforcements were added. The lid wooden piece was starting to crack significantly and some bending was evident, so a new lid was manufactured. Due to the visible cracks, wood glue was added wherever necessary. A piece of steel sheet metal was cut to 10”x10,” and screwed into the lid on all four corners; this served as a reinforcer to keep the wood flat. In using the hinges, there was initially too much movement as there were too many degrees of freedom. To limit the motion so only part of the hinge was able to move, two screws were screwed in both above and below the bottom part of the hinge; these fixed the hinge in place. The final addition for the third iteration was creating another acrylic well, as a cover for the ink well. This used a thinner piece of acrylic, and was cut to be larger, with added clearance on all sides.

Figure 19. Prototype Iteration Three.

Iteration Four

The fourth iteration of the stamper is the final prototype. The last component added was a hard stop mechanism, in the form of two pieces of the 3/16” rod. 3/16” diameter holes were drilled into the top face of the base, located 1” from the back end. 2” pieces of the rod were pressed in to fit into these holes; these marked the maximum point where the device could move to.

Figure 20. Prototype Iteration Four, Final Prototype.

Hazard and Risk Identification

Upon manufacturing the device, previous hazard and risk identification was revisited. Initial analysis (from November 2021) gave the following potential hazards: sharp edges of the box and pinch points where the top and bottom wood pieces meet. Planned actions were to round the corners of the box pieces to fix sharp edges, and to include a warning label for the pinch points. While manufacturing, the edges of the box were sanded down; this limited and nearly removed the potential risk correlated to sharp edges. While implementing the steel sheet metal on top of the lid, risk mitigation steps were taken by filing down the sharp edge of the steel which hung off one edge. Additionally, the aluminum rods across the lid and top part of the handle were filed down to avoid catch points. The pinch points were mitigated both through manufacturing and through a warning in the operation manual. Regarding manufacturing, the device only has a 2” base; the original planned height was 2.5.” Because of this, there is a 1.5” gap between the base and lid, helping prevent the user from injuring themselves at a potential pinch point. From additional analysis, there are no new hazards associated with the device.

Operation Manual

Calibration of Ink Sponge Prior to Each Use

1. Before use of the device, remove the acrylic enclosure for the sponge.
2. Remove the ink sponge from the ink well.

3. Then, measure and pour out 150 mLs of ink throughout the top of the foam. When pouring the ink, pour in a manner so that the whole top surface of the sponge will be covered.
4. Spread the ink around the sponge using a wooden dowel so that the liquid is pressed into the ink sponge as shown in Figure 21.

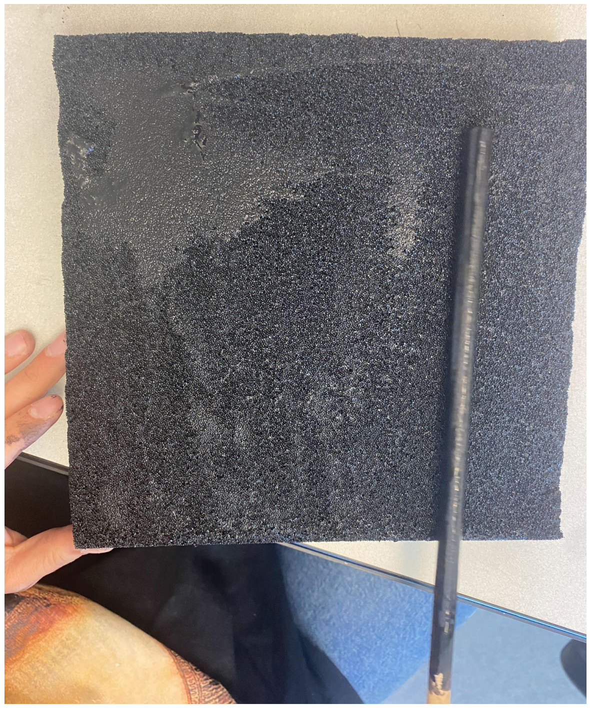


Figure 21. Visual for Step 4 of Initial Calibration of Ink Sponge.

Use of the Device

1. Mount the 8" by 8" sticker paper onto the extruded piece of the lid of the device by applying tape to the four corners of the back side in the position as shown in Figure 22.
2. Return the ink sponge back to the well.
3. Once the paper is mounted, push down the handle with two hands so that the ink foam is compressed. Hold in this position for 6 seconds. Be careful not to jolt the device during this step.
4. Then, lift the handle back up with one hand.
5. Remove the ink sponge from the ink well.
6. Unmount the paper from the device and place on the side to dry. Be careful to avoid smearing the sticker paper during this process.
7. After each stamp, 15 mLs of ink should be added to the sponge to maintain uniformity.
8. After adding the ink, repeat steps 1 – 5.
9. When finished, make sure to put the acrylic ink enclosure back on top of the sponge to prevent the sponge from wetting the lid.

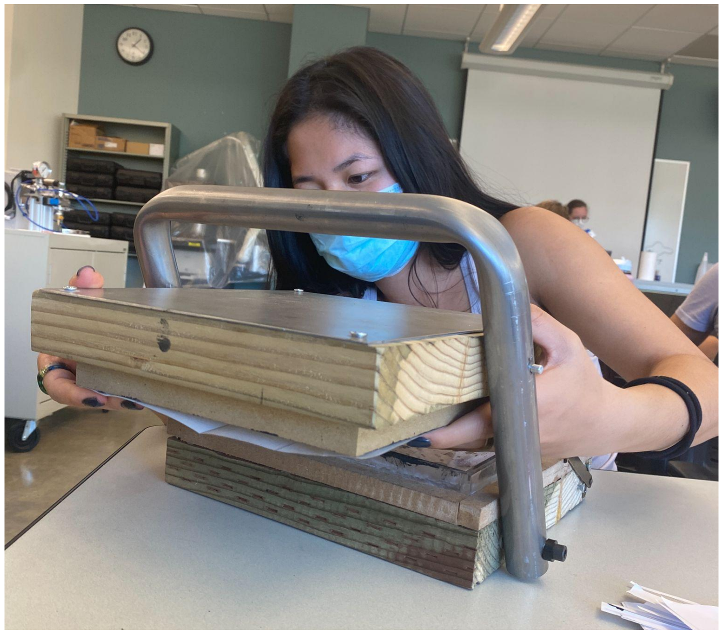


Figure 22. Visual for Step 1 of Use of the Device.

Replacing the Ink Sponge

The ink sponge should be replaced after 5 separate uses of the device. Prior to the first use of the new ink sponge, measure and pour 150 mLs of ink onto the ink sponge. Pour in a manner that distributes the ink throughout the top of the ink sponge. Use a wooden dowel to press the ink into the ink sponge. Then, proceed to Step 3 of "Calibration of Ink Sponge Prior to Each Use."

Warnings

When stamping, do not place hands between the lid and base of the device as pinching might occur. Pinching might also occur between the handle and lid of the device.

Test Plans

Weight and Portability

To validate the customer requirement of the device being lightweight and portable, the device was weighed with a scale. If it weighed more than the specification of 30 lbs, then the device failed the test. This test first occurred Wednesday, February 2nd between the hours of 1 and 4pm. After manufacturing changes added to device weight, the test was performed again on Tuesday, February 15th. This test required a scale that records weight in pounds to the tenths place. The lab space needed for this protocol was room 330 in the Engineering IV building. No other personnel were needed besides the

FeverDots team. If the device was more than 10 lbs above 30 lbs, the main change to be considered would have been switching to a lighter wood material.

Durability

To validate the customer requirement of durability, the amount of cracks in the wood, if any, were counted and measured with a ruler in inches. This occurred on one of the final days of testing as it had gone through repeated use at this point. It was established that if the total crack length summed up to more than 10”, the device would fail the test. A crack was defined as anything that was visible on the device without having to disassemble and any cracks that went through the entirety of the wood. This test occurred on Tuesday, March 1st. The only equipment that was required was a ruler in inches. The lab space needed for this protocol was room 330 and 329 in the Engineering IV building. No other personnel were needed besides the FeverDots team. The original contingency plan for this test was to make adjustments to the base and lid so that they would be more durable, including adding a metal sheet to provide structural reinforcement.

Figure 23. Durability Test.

Simple Assembly

The customer requirement of simple assembly refers to the device allowing simple assembly for the creation of FeverDots. To ensure the process of device operation is simple, the number of operational steps were counted. The number of steps were not to be excessive (less than 10), and steps were to flow together easily. This test was performed on Thursday, March 3rd between 1-2PM. There were no equipment required for this test. The lab space needed for this protocol were room 330 or 329 in the Engineering IV building. No other personnel were needed besides the FeverDots team. A contingency plan for this test was to combine or remove any steps, or if possible, to reduce the steps required for operation.

Dry Weight Specification for Ink

The dry weight specification for ink test was intended to assess if the device was able to achieve uniformity in ink application across the sticker paper and if it could achieve the dry weight specification of ink (0.015 g/in²). The steps of conducting this test are outlined below.
Prior to ink application:

1. Create 16 zones of 2” x 2” squares on the 8” x 8” sticker paper.
2. Label each paper 1 – 7 and each zone A – O on the back (the side that will not be inked) as shown in Figure 24**.**
3. Weigh each 8” x 8” piece of sticker paper, in grams, using a balance to determine its initial weight.
4. Measure the length and width of the paper, then calculate the area in in².
5. For each paper, divide the initial weight of the sticker paper by 16 to get an approximate value of the weight for each zone. Also measure the length and width of each zone in in².

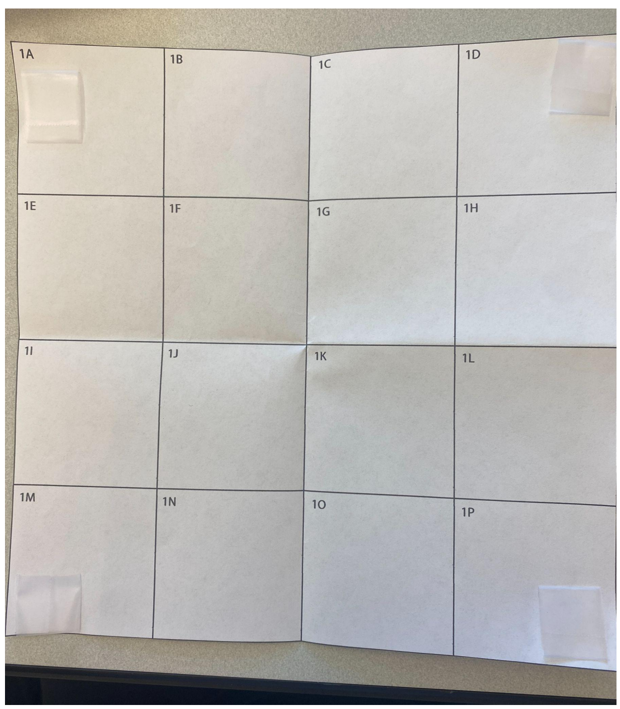


Figure 24. Testing Zones for Dry Weight.

Starting at ink application:

6. Deposit ink onto the sponge and record this initial amount.
7. Use the device to transfer ink to the same sticker paper.
8. Remove the inked sticker paper and load the next one.
9. Add more ink to the sponge in between the succeeding stamps and record this amount in mLs.

10. After 48 hours (to give the ink time to fully dry), cut the sticker paper up into the 16 zones.
11. Use a balance to weigh each of the squares and record this weight.
12. Divide this value by the area (approximately 4 in^2), this value is inked paper weight.
13. Calculate the difference between the inked paper weight and the initial paper weight; this is the value of the dry weight of ink.
14. The percent difference of the experimental value of the dry weight of ink will be calculated against the given specification for each of the individual squares.

A power analysis with assumed incidences of 80% that the sponsors achieve the exact dry weight specification and 90% that the device would achieve the specification, an alpha level of significance of 0.05, and a power of 80% yielded a sample size of 107 squares. To achieve this, this protocol was executed with 7 sticker papers (112 squares) using acrylic paint. The expected results were to have a 13.33% difference between the experimental value and the specification as this corresponds with the specification's tolerance of $\pm$ 0.002 g/in^2. If the percent difference was above 13.33%, then that sample was deemed as a failure. Results were analyzed with a one-sample t-test. The null hypothesis was: There is no significant difference between the dry weights of the paper, compared with the specification.

Application of ink onto the sticker paper occurred on February 1st, 15th, 22nd, 24th, and March 1st. Cutting and weighing of the sticker paper along with analysis of the results took place on February 3rd, 17th, 24th, and March 1st and 3rd. The lab space needed for this protocol was room 330 or 329 in the Engineering IV building. No other personnel were needed besides the FeverDots team. This test required a balance that records mass in grams to the thousandths place, a laptop with Microsoft Excel, and 5 mL pipettes. Other materials needed include the device, 8" x 8" matte white sticker paper*, acrylic paint, water, a ruler in inches, and scissors.

If the device were to consistently fail this test, the original contingencies included adjusting the amount of force the user applies to the handle, adjusting the amount of ink that is applied to the foam, or changing the type of foam that is used to apply the ink.

*Only the first trial of this experiment used white matte sticker paper. Due to extreme shipping delays for more paper, the rest of testing was conducted with white printer paper as approved by the sponsors.

Ink Distribution

The ink distribution test was intended to analyze how well the ink spreads throughout the sticker area. The steps of conducting this test are outlined below:

1. Measure the amount of ink applied to the sponge, in milliliters.
2. Apply ink to a separate sticker paper using the device. (This test can be conducted in conjunction with the dry weight test.)
3. Allow the papers to dry for 48 hours.
4. After 48 hours, take pictures of each of the sticker papers. The papers should be lying flat on a light colored table. To limit environment variability, each picture will be taken between the hours of 1-2PM away from any windows in the same room. Two iPhone flashlights will be held 12

inches above the sticker paper to supply additional lighting without adding the variability that a flash photo would.

5. Next, upload the images to the application ImageJ. Convert to a 16-bit grayscale.
6. Crop the image to the edges of the sticker paper. If there is any remaining background, convert the background color to white and use the “Clear Outside” button under the Edit menu.
7. Use the Threshold tool to apply a threshold to the control image. Set the minimum threshold set to 0.
8. To set the upper threshold, select a paper from the experiments that appears to be the most visually uniform and adjust the maximum threshold slider until it covers the inked portion of the sticker paper. The value that achieves this will be used as the maximum threshold for the remaining papers.
9. Apply these thresholds to each of the remaining samples, and calculate the percent area using the Measure tool.

A power analysis with assumed incidences of 70% that the sponsors achieve a percentage of area covered of 90% and 95% that the device would achieve the same percentage of area, an alpha level of significance of 0.05, and a power of 80% yielded a sample size of 19 sticker papers. To achieve this, this protocol will be executed with 19 sticker papers using acrylic paint. However, if time and resources are limited, a lower sample size such as 9 sticker papers will be used which will yield a power of 24.8%. The expected result is to have 85% – 90% of the area covered with the right ink thickness determined by the threshold. If the percentage of area falls below 85%, then the test trial fails. Results will be analyzed with a one sample t-test. The null hypothesis will be stated as: there is no significant difference between the percentage of area covered of the paper, compared with the specification of 85%.

Application of ink occurred on February 1st and 24th and March 1st. Image analysis took place on February 3rd and March 1st and 3rd. The lab space needed for this protocol included room 329 or 330 in the Engineering IV building. No other personnel were needed besides the FeverDots team. Equipment for this test included a laptop with the ImageJ application and Microsoft Excel downloaded, an iPhone Pro 11 camera, two other iPhone flashlights, 5 mL pipette. Necessary materials include the device as well as 8” x 8” matte white sticker paper*, water, and acrylic paint.

If the device did not pass this test, the following contingency plans were made: adjustment of force applied to the handle by the user, adjustment of how much ink is used, or a change in the foam that is used.

*Only the first trial of this experiment used white matte sticker paper. Due to extreme shipping delays for more paper, the rest of testing was conducted with white printer paper as approved by the sponsors.

Force Uniformity

The force uniformity test was intended to analyze how evenly force was distributed from the lid to the base with each cycle of use of the FeverDots stamping device. The steps of conducting this test are outlined below:

1. Create 16 spheres of PlayDoh, as shown in Figure 25. Used a balance to ensure these spheres weigh very similar amounts.
2. Place the spheres in the centers of all 16 zones on an 8”x8” paper. Each of these zones should have dimensions of 2”x 2”.
3. Place the paper on top of the inkwell.
4. Use the device to press the lid down onto the paper.
5. After using the device, take a picture of each sheet of sticker paper. Then upload these images to ImageJ.
6. Use the Measure tool in ImageJ to determine the diameter of each of the 16 circles.

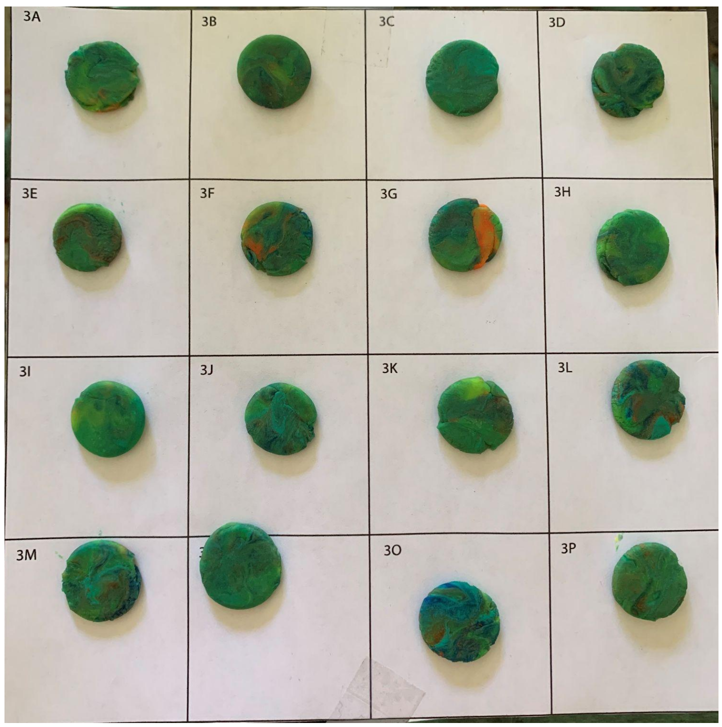


Figure 25. Testing Paper With Playdough After a Cycle of Compression.

A power analysis with assumed uniform force distribution covering 85% - 95% of the sheet, an alpha level of significance of 0.05, and a power of 80% yielded a sample size of 280 data points. For this reason, this test was repeated 7 times. Results were then analyzed by collecting the diameters of the spheres in each of the 16 zones from all 7 tests after compression. An ANOVA comparison test was conducted in Minitab to compare the diameters of the spheres with respect to the zones they were found in. A quantified target of at least 85% total uniformity across the surface of force application was set as the minimum threshold for the uniformity customer requirement. This means that at least 85% (13.6 zones) of the area of compression shows no significant difference in force distribution per the findings of the ANOVA comparison test.

The null hypothesis was the following: the diameters of PlayDoh after compression are significantly different. The alternative hypothesis was the following: There is no significant difference in the diameters of PlayDoh after compression.

The lab space needed for this protocol included room 329 or 330 in the Engineering IV building. No other personnel were needed besides the FeverDots team. Equipment for this test include a laptop with the ImageJ application and Minitab downloaded, and an iPhone Pro 11 camera. Necessary materials include the stamping device prototype as well as 8” x 8” matte white sticker paper, and acrylic paint. All seven rounds of testing were completed on Monday, February 14th from 3PM - 4PM. For each round of testing, the tester sat in the same seat in the same fashion, with their dominant hand on the handle. In the case that device did not satisfy the requirements associated with the force uniformity test, the following changes were discussed. Positioning of the handlebar would be altered to assure a more even and parallel compression movement. Extra parts could also be added to the lid of the device to aid the lid in coming down and contacting the base as uniformly as possible.

Minimum Force

The Minimum Force Test was used to determine the force threshold to move the pieces of the device. This test was used for verification of the “easy to use” customer requirement, quantified by a target of a 27N ± 4N force threshold for both locations. The steps of conducting this test are outlined below:

1. Use a spring scale to initially move the device.
2. Record the measured force at this point.

This test consists of 2 factors with 3 levels each. One factor is the user, with one level for each (Rita, Kameryn, and Heidi). The other factor is the force intensity, quantified as the levels of exerted force (minimum, target, and maximum). Each level of force intensity was tested with the expected outcome that 27N ± 4N is a suitable force for the device to perform its suited function. Each user performed 3 rounds of the test, with low/medium/high effort exerted. Power analysis using an 80% power level, 95% significance, and an estimated standard deviation of 1.7 gave the sample size to be 8. Each time the user performed the test, they performed 8 runs of each experiment. Given 9 experiment types, this gave 72 data values.

The null hypothesis was the following: the user and the force intensity exerted have no effect on device functionality and performance. The alternative hypothesis was the following: the user and the force intensity exerted do affect device functionality and performance. Therefore, the null hypothesis was $\mu=27N$; the alternative hypothesis was $\mu\neq27N$.

The lab space needed for this protocol included room 329 or 330 in the Engineering IV building. No other personnel were needed besides the FeverDots team. The only required equipment for this test was a spring scale, as well as the stamping device itself. The first round of testing was run on Tuesday, February 8th from 2-3PM. After manufacturing changes were made, a second round of testing (all 9 experiments) occurred on Tuesday, February 15th from 2-3PM. For each round of testing, the user sat in the same seat in the same fashion, with their dominant hand on the handle.

To analyze data from the Minimum Force Test, all 72 measured force values were imported into Minitab. The force sets were analyzed at each individual level (all min forces together, all med forces together, and all max forces together). Three separate 1-sample t-tests were run, comparing each to the spec of 27N. The analysis determined if the user, while exerting a certain level of force, still exerts enough force to move the device functionally. Samples were considered to pass the test if the samples in each test level had no statistically significant difference to the spec, and if there was a significant difference between all three force levels. If the device were to fail the Minimum Force Test, additional warnings and a specific description and demonstration would have been provided for the user as to how much force to exert for operation.

Survey - Human Use Study

To collect feedback on human use of FeverDots, a 30-day human use study was conducted with the other BMED 456 students. While being asked to participate, each student was given two sheets of FeverDots with 15 stickers each. One sheet had circles, lips and heart-shaped FeverDots; the other sheet had circles, butterflies, and cat-shaped FeverDots. Students were reminded of the study at the mid-way point of the 30 days, and the survey was sent out at the end of the 30 days. All questions in the survey are located in the Appendix.

Testing Data and Analyses

Weight and Portability

The device was first weighed at 10.4 lb. This was the first prototype iteration, prior to the addition of the steel sheet metal piece. The device was weighed a second time at 12.2 lb. No statistical analysis was required for this test. The 12.2 lb measurement was compared against the specification of a maximum of 30 lb; the device successfully passed this test.

Durability

Prior to the test for durability, it was noticed that the lid of the device was warping due to the force from pushing down the handle multiple times. As mentioned, a steel sheet was screwed on top of a newly manufactured lid to prevent significant warping. Any minor cracks in the base and new lid were sealed with wood glue to prevent them from spreading any further. This test was conducted on the last day of testing. Three cracks were identified on the left and right sides of the lid, and along the width of the bottom of the base, respectively. Their total length measured 12.5 inches. The device failed this test because the crack lengths summed to greater than the predefined threshold of 10 inches.

Table 4. Summary of Durability Test.

Crack Number	Crack Location	Length (inches)
1	Left side of the lid	1.4375
2	Right side of the lid	1.4375
3	Bottom of the base	9.625
	Total	12.5

Simple Assembly

This test was conducted with each trial of stamping with the FeverDots device. It was found that continuous use of the device (multiple stamps) after the initial set up required only 9 simple steps. The device passed the simple assembly test by meeting the engineering specifications which required the number of operational steps for a single cycle of device use to be less than 10 in order to satisfy the customer requirement of having a relatively simple to use device.

Dry Weight Specification for Ink

This test was conducted for 5 trials. The first trial, where no ink was added in between each pass, showed poor results as the average dry weights for each paper had a greater than 50% difference from the specification of 0.015 ± 0.002 g/in^2. The t-test analysis revealed that the null hypothesis of $\mu=0.015$ had to be rejected and that the results were significantly different from the specification as the p-values were all less than 0.05. An example table of the p-values from Trial 1 is shown below, in Table 5. Tables for the rest of the trials will be found in the Appendix. The t-tests for the rest of the trials also showed that the null hypothesis had to be rejected in each case.

To attempt to mitigate this, the team added and recorded a range of 4 – 25 mls of ink in between each pass after analyzing trial 1’s results. Figure 26 images the dry weight of ink averages for each paper that resulted from each of the different trials. As shown, none of the trials were able to achieve an average that met the specification. On the other hand, Figure 26 reveals there was a general increase in getting closer to the specification with each test, similar to the Ink Distribution Test.

It is important to note, however, that all trials after Trial II were used with printer paper due to a severe shipping delay in the arrival of more sticker paper. Additionally, it was decided by the sponsors to conduct all testing with acrylic paint and to no longer conduct more rounds with the thermochromic paint for budgetary reasons.

Table 5. Data Summary from Trial I of the Dry Weight of Ink Test.

Paper	1	2	3	4	5	6	7
Amount of Ink Added	0	0	0	0	0	0	0
Average Dry Weight (g/in^2)	0.0061	0.0055	0.0052	0.0050	0.0036	0.0035	0.0023
Average % Difference	59.58	63.34	65.25	66.51	75.80	76.56	84.49
P-value	3.93E-07	1.94E-07	1.33E-09	2.09E-09	3.02E-08	5.31E-12	1.18E-12

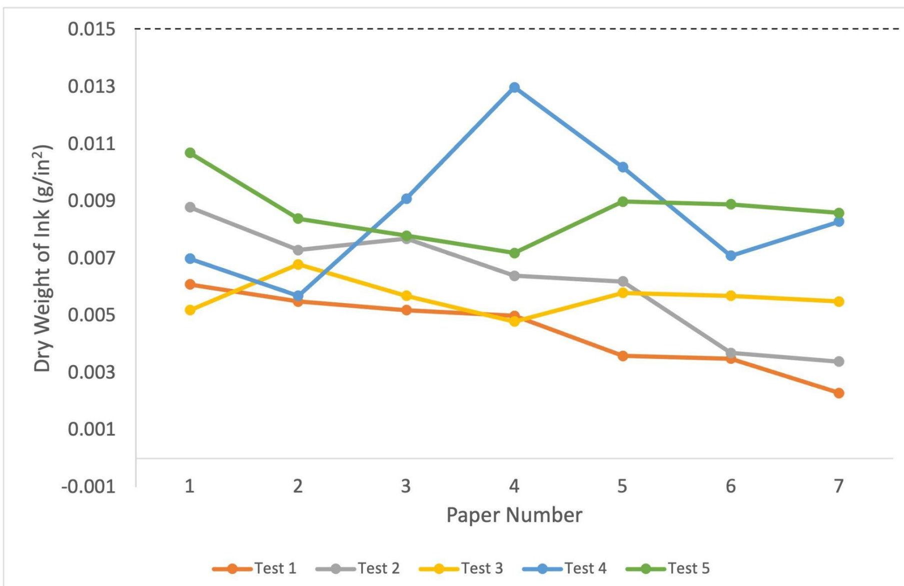


Figure 26. Dry Weight of Ink Test Summary.

Ink Distribution

This test was conducted for 3 trials. Due to time and resource limitations of paint, the test was conducted using 9 samples. The first trial was conducted with matte sticker paper, while the second and third trials were conducted with printer paper. The device failed all three trials because the averages of the percent areas did not reach the 85% threshold as specified in the protocol. The first test used 0 mls of ink between each stamp. The second and third tests used 15 mls of ink between each stamp. The averages of each test were 57.64%, 59.81%, and 74.20%. However, it is important to note that the results did increase over each trial as shown in Figure 27.

Table 6. Summary Table for Ink Distribution Tests.

Test Number	1	2	3
Average % Area	57.64%	59.81%	74.20%
P-Value	1.26E-05	2.13E-06	1.03E-03

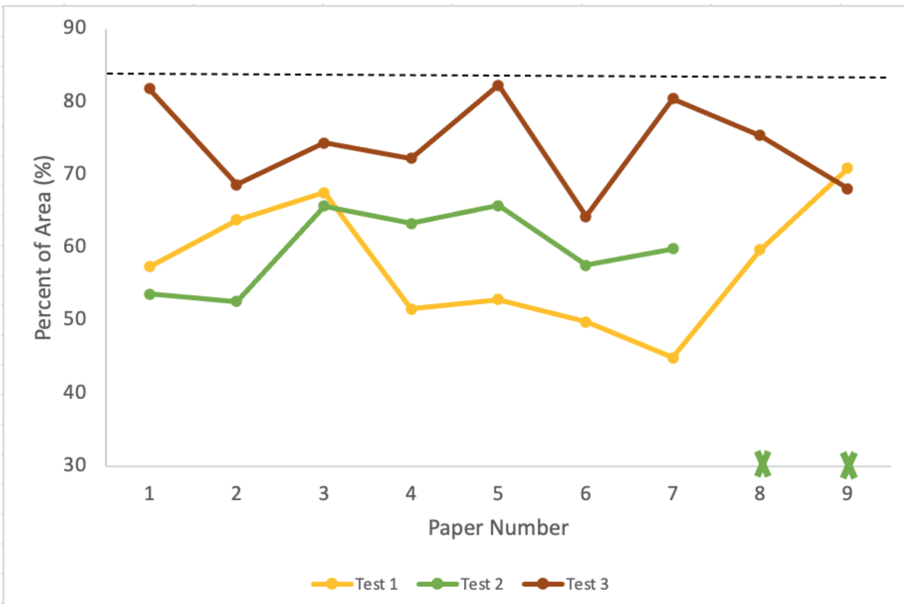


Figure 27. Ink Distribution Test Summary.

Force Uniformity

An ANOVA comparison test was used to analyze the data observed in the force uniformity test. Seven trial runs yielded a total of 112 data points, 7 for each of the 16 alphabetically categorized zones marked on each sheet of sticker paper. The ANOVA comparison test with α=0.05 found no significant difference in the diameters of compressed balls of playdough in all zones except for zones "J" and "G". Key values (averages) are located in Table 7, below. The complete set of data can be found in the Appendix. The sticker paper zones are shown in Figure 28 below where the two statistically different zones are colored yellow.

Table 7. Summarized Data from Force Uniformity Tests.

Zone	Average Diameter (inches)
A	*0.8327*
B	*0.8232*
C	*0.855*
D	*0.8407*
E	*0.8381*
F	*0.7984*
G	*0.7808*
H	*0.8092*
I	*0.8181*
J	*0.7884*
K	*0.822*
L	*0.8415*
M	*0.8785*
N	*0.8334*
O	*0.8368*
P	*0.855*

Not Significantly Different	Significantly Different

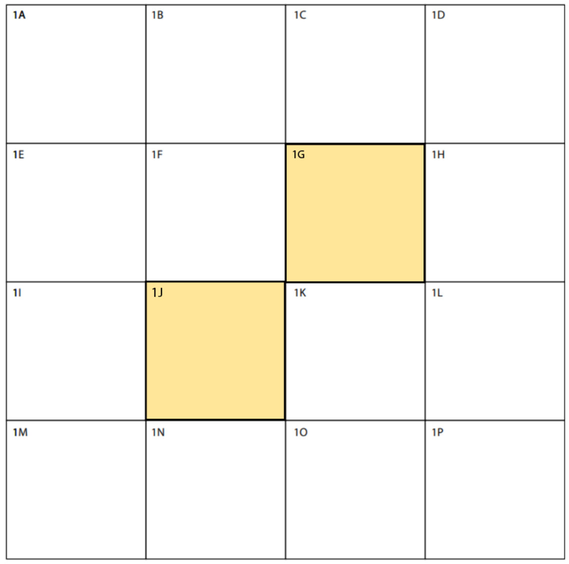


Figure 28. Force Distribution Test Visual.

Since 14 of the 16 (87.5%) zones were found to not be statistically significant in terms of the diameter lengths of each ball of playdough, the device passed the Force Uniformity test as it surpassed the desired engineering specification set at a minimum of 85% uniform force application across the sticker paper.

Minimum Force

The data from the Minimum Force Test was analyzed by three 1-sample t-tests, one for each of low/medium/high intensities. Each was tested against a null hypothesis of $\mu=27N$, and an alternative hypothesis of $\mu\neq27N$. Key values (mean and p-values) are located in Table 8. All recorded data values are included in the Appendix. The data in Table 8 is from the second round of testing (after manufacturing changes). Additionally, all data values from the first round of testing (prior to manufacturing changes) are located in the Appendix.

Table 8. Summarized Data from Minimum Force Test.

Test	Mean Force (N)	P-value
Low Intensity	26.381	0.327
Medium Intensity	25.69	0.153
High Intensity	19.62	0.00

This data demonstrates that both the low and medium intensity rounds of testing did pass the test; the p-values mean we can accept the null hypothesis of $\mu=27N$. However, the high intensity rounds were not within range of the desired forces. The low and medium rounds of testing were performed more realistically than the high rounds; to mimic high intensity forces, the users exerted sudden, jolt-like movements. These sudden movements did not produce the desired outcome, so an additional guidance statement was added to the operation manual. When the user operates the device at a normal pace and takes a standard amount of caution, they will not run into an issue of the device not being easy to use.

Survey - Human Use Study

After collecting all 16 survey responses, the data was analyzed and summarized to provide to our sponsors. Overall, respondents had positive feedback regarding the use of FeverDots. The responses regarding comfort and ease of use were highly rated. Participants generally wore FeverDots weekly; the lack of daily use was mostly due to forgetting about them. The full survey responses were presented to the sponsors; this summary is located in the Appendix.

Discussion

The outcomes of all tests performed, in the context of the customer requirements and desired specifications, are outlined in Table 9. The following requirements were met, through testing: portable, simple assembly, easy to use, and uniform force. The portable requirement, quantified by the 30 lb maximum weight, was verified by weighing the device (12.2 lb). The simple assembly requirement, quantified by counting the number of operational steps, was verified as it came out to be 9. The easy to use requirement, quantified by the amount of force needed to move the handle, was verified by the device passing the Minimum Force test. The uniform force customer requirement, quantified by 85% uniform force, was verified by the device passing the Force Uniformity Test. The following requirements were not met during testing: durability, effective ink transfer, and uniform ink coverage. The durability test was not passed, as the number of cracks measured was greater than 10”; however, additional wood reinforcements were added to keep the device in a durable condition. The effective ink transfer and uniform ink coverage tests did improve with the number of trials conducted, but the desired specifications were unable to be reached. The effective ink transfer requirement, quantified by the dry weight of ink, consistently got values under the specification; more ink between stamps would be necessary to achieve this specification. The uniform ink coverage test also got values lower than the desired range; this specification could not be met as the method of ink addition was not controlled enough.

Table 9. Specifications and Outcomes

Requirement	**Specification**	**Test**	**Pass/Fail**
Portable	30lb max	Weigh Device	Pass
Durable	10” cracks max	Measure Cracks	Fail
Simple Assembly	10 Steps max	Count Operational Steps	Pass
Easy to Use	27±4N	Minimum Force Test	Pass
Effective Ink Transfer	0.015±0.002 g/in^2	Dry Weight of Ink Test	Fail
Uniform Force	≥85% Equal	Force Distribution Test	Pass
Uniform Ink Coverage	≥85% Equal	Ink Distribution Test	Fail

Some limitations in testing that are worth noting were seen during the Ink Distribution Test and the Dry Weight of Ink Test. There are some assumptions that both tests were affected by the use of testing materials different from the materials that would ideally be used for the device. These substitute materials include regular printer paper in the place of typically thicker sticker paper and water-diluted black acrylic paint in the place of the thermochromic ink. Since the printer paper is thinner and may have different wettability properties than sticker paper, the results of our testing may not match the results the team anticipated. Another limitation was seen with the use of water-diluted black acrylic paint which is suspected to be a contributing factor to the variable ink application as seen throughout the stamping trials. The excessive amount of water mixed into the acrylic paint used to mimic the viscosity of the thermochromic ink and the porosity of the ink sponge may have caused the bubbly and patchy ink pattern seen after stamping trials. An example is pictured in Figure 29. In addition to the difficulty found mimicking the actual materials used to make FeverDots, it was difficult to measure the dry weight of ink due to the small dry weight specification and corresponding tolerance. Another limitation noticed during testing was seen during the Minimum Force Test, as the spring scale used was difficult to handle and get results as accurate as testers would have hoped for. Finally, some limitations seen during the Force Uniformity Test include the use of a scale that was not as precise as desired in measuring the weight of each Playdough sphere and in precisely measuring the diameters of each compressed sphere with the Imagej Measure Tool.

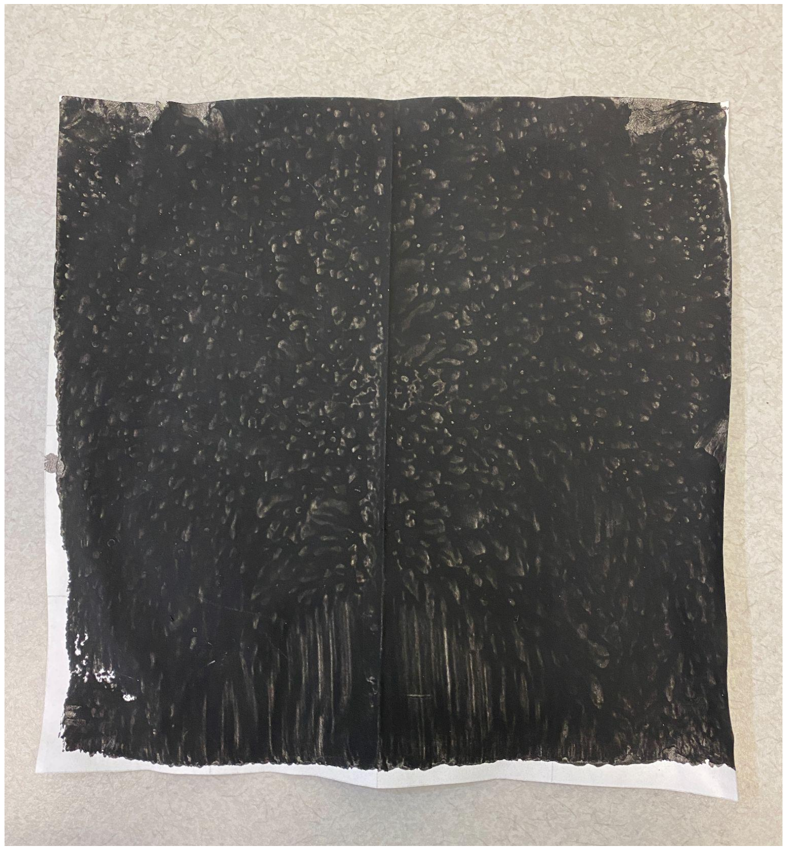


Figure 29. Example of Bubbly Texture from Ink Application.

If more time was given for this project, a future direction would include trying different materials for the function of transferring ink. The material that is currently used (a super-cushioning polyurethane foam) helps in absorbing the compressive force, but as seen in the results, it leaves a bubbly texture when inking the substrate. To try to mitigate this effect, a material with a smaller porosity would be purchased and tested. For example, Cut-N-Dry stamp pad felt, another material commonly used for stamp pads, could be purchased and placed on top of the current ink sponge. This way, the polyurethane foam would still prevent excessive compression, but the felt would act as the ink transferer. Increasing the length of the handle and perfecting and iterating a sticker paper roll attachment are two other future directions that would increase ease of use of the device and its efficiency. Increasing the length of the handle would allow for easier substrate attachment and removal, and using the roll attachment would rid the need of having to use tape to mount the paper onto the device.

Conclusions

The FeverDots manufacturing device was designed to produce 8” x 8” uniformly inked sheets of paper that would later have various shapes cut out of them. Customer requirements guided the design and iteration process to make sure that the final model was easy to use, durable, portable, and able to apply ink in a uniform manner. The FeverDots stamping device was manufactured in the Cal Poly Machine

Shops using the materials of wood, acrylic, foam, and steel. The final device and its functionality were tested repeatedly, and design flaws were filtered out until the final prototype was produced. The final product did not satisfy all of the engineering specifications developed from the customer requirements, largely due to time constraints and other complications including material limitations during testing. However, the team developed possible solutions for future implementation and testing to optimize and improve the design. The overall takeaways from the FeverDots manufacturing device design, building, iterating, and testing processes were positive and educational.

Appendix

Statement of Work Additional Content

Executive Summary

FeverDots are color-changing stickers used to indicate fever, and this project aims to develop and implement an efficient manufacturing method for them. This Statement of Work (SOW) outlines the steps and goals of this project. This SOW is written by the FeverDots Senior Project Team, with the help of Dr. Heylman, for Caroline Jurado and Margaret Shaw of Wellhouse Enterprises.

Project Management

To develop an efficient manufacturing method, potential options will be weighed and compared, to ultimately determine what factors are necessary. The first ten weeks of this project will be spent researching, creating a conceptual prototype, and deciding on a design and plan. The second ten weeks will be spent creating a functional prototype, testing prototypes, and manufacturing the final product. Concurrently, an IRB study will be conducted, starting in the first ten weeks. The conceptual prototype will be done by the end of October, evaluated through Conceptual Design Review. The functional prototype will be done by the middle of January, confirming the design decisions. Finally, the full project will be completed by the second week of March. The proposal for the IRB study will be submitted in October, with hopes of completing the study in February.

Table 10. Initial List of Tasks Making Up Network Diagram

FeverDots						
ID	ℹ	Task Mode	Task Name	Duration	Start	Finish
2	✓	📌	IFU	6 days	Wed 9/29/21	Wed 10/6/21
3	✓	📌	Budget	6 days	Wed 9/29/21	Wed 10/6/21
4	✓	📌	House of Quality	6 days	Wed 9/29/21	Wed 10/6/21
7		📌	Test and Analyze Previous Yea	8 days	Mon 10/4/21	Wed 10/13/21
8		📌	Research Competitor Product	10 days	Mon 10/4/21	Fri 10/15/21
5		📌	Statement of Work	7 days	Tue 10/5/21	Wed 10/13/21
6		📌	Status Update Memo 1	2 days	Fri 10/15/21	Mon 10/18/21
9		📌	Pugh Chart	2 days	Tue 10/19/21	Wed 10/20/21
11		📌	Conceptual Model	7 days	Tue 10/19/21	Wed 10/27/21
10		📌	Status Update Memo 1	3 days	Thu 10/21/21	Mon 10/25/21
12		📌	Conceptual Design Review	3 days	Mon 11/1/21	Wed 11/3/21
13		📌	Status Update Memo 2	3 days	Thu 11/4/21	Mon 11/8/21
14		📌	Compare Methods	10 days	Mon 11/8/21	Fri 11/19/21
15		📌	Status Update Memo 3	3 days	Thu 11/11/21	Mon 11/15/21
1		📌	CAD of Design	5 days	Fri 11/12/21	Thu 11/18/21
16		📌	Status Update Memo 3	3 days	Mon 11/29/21	Wed 12/1/21
17		📌	Winter Status Update Memo 1	3 days	Fri 1/7/22	Tue 1/11/22
19		📌	Create Functional Prototype	10 days	Wed 1/12/22	Tue 1/25/22
18		📌	Winter Status Update Memo 2	3 days	Tue 1/18/22	Thu 1/20/22
20		📌	Functional Prototype Demo/T	3 days	Fri 1/21/22	Tue 1/25/22
21		📌	Select Manufacturing Process	7 days	Wed 1/26/22	Thu 2/3/22
26		📌	Perform IRB Human Use Study	30 days	Wed 1/26/22	Tue 3/8/22
22		📌	Winter Status Update Memo 3	3 days	Fri 2/4/22	Tue 2/8/22
23		📌	Winter Status Update Memo 4	3 days	Fri 2/11/22	Tue 2/15/22
24		📌	Winter Status Update Memo 5	3 days	Fri 2/18/22	Tue 2/22/22
25		📌	Winter Status Upate Memo 6	3 days	Fri 2/25/22	Tue 3/1/22
27		📌	Final Design Review	3 days	Tue 3/8/22	Thu 3/10/22

Initial Budget

A budget was established, based on expected project materials and costs. Expected needed materials include 3D printing material for final product, adhesive, steel hinges, and miscellaneous additional hardware. The planned budget comes out to be roughly $630, detailed in Figure 30 below.

				Planned				
Item Description	Product Number	Purpose	Associated Task	Unit	Quantity	Planned Cost/Unit	Total Cost	Notes
12"x24"" HDPE Sheet w/ 1.75" thickn	N/A	For use as the base of the stamping mechanis	Final Product	EA	1	$ 69.34	$ 69.34	
12"x24" HDPE Sheet w/ 3" thickness	N/A	for use as the top of the clamp	Final Product	EA	1	$ 117.11	$ 117.11	
12"x24" Rubber Sheet	G7395607	applicator for ink	Protoype & Final	EA	2	$ 18.55	$ 37.10	
Spray Adhesive	400G22	adhere rubber to top of clamp	Testing	EA	1	$ 17.02	$ 17.02	
7" Diameter HDPE Rod w/ 36" in Leng	N/A	Lever for stamping mechanism	Final Product	EA	1	$ 307.00	$ 307.00	
Additional Hardware - Threaded Screv	Multiple	Connecting all parts to one another	Protoype and FInal	EA	TBD	TBD	$60.00	
4"x1" Steel Strap Hinge	1RCF7	adhering the base to the clamp	Protoype and Final	EA	4	$ 4.74	$ 18.96	
Black-Pink 95°F Thermochromic Ink	N/A	Ink	Testing	12oz		N/A	N/A	supplied by sponsor
PLA 3-D printing material	N/A	Prototype model	Testing	EA	N/A	N/A	N/A	supplied by innovaton sandbox
						Total Cost	$ 626.53	

Figure 30. Initial Proposed Budget.

Conclusion

This project aims to develop and implement an efficient manufacturing method for FeverDots by utilizing and analyzing the product requirements given to the team by Caroline Jurado and Margaret Shaw and turning them into an actual tangible and effective product. This SOW is written by the FeverDots Senior Project team to encompass the current standing and progression made in the project as well as outline what is to come in the near future. Next steps include determination of details of potential designs, then selecting one and developing a conceptual model.

Conjoint Analysis

Table 11. Conjoint Analysis Factors and Levels.

Factor	Level 1	Level 2
Device Operating Method	Manual	Automation
Stickers per Cycle	100	250
Ink Application Mechanism	Stamp/Clamp	Roller

Statistical analysis

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.57413381
R Square	0.32962963
Adjusted R S	0.30005447
Standard Err	0.94194209
Observations	72

ANOVA

	df	SS	MS	F	Significance F
Regression	3	29.6666667	9.88888889	11.145488	4.884E-06
Residual	68	60.3333333	0.8872549		
Total	71	90			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	8.94444444	1.5220779	5.87646956	1.396E-07	5.90718528	11.9817036	5.90718528	11.9817036
Manual/Autc	-1.7777778	0.3139807	-5.6620607	3.2775E-07	-2.4043165	-1.1512391	-2.4043165	-1.1512391
100/250 Stic	-1.4444444	0.44403576	-3.2529913	0.00177966	-2.330504	-0.5583849	-2.330504	-0.5583849
Stamp,clamp	-0.8333333	0.3139807	-2.654091	0.00989317	-1.4598721	-0.2067946	-1.4598721	-0.2067946

Figure 31. Statistical Analysis from Conjoint Analysis.

$Y = 8.944 - 1.778X_1 - 1.444X_2 - 0.8333X_3$

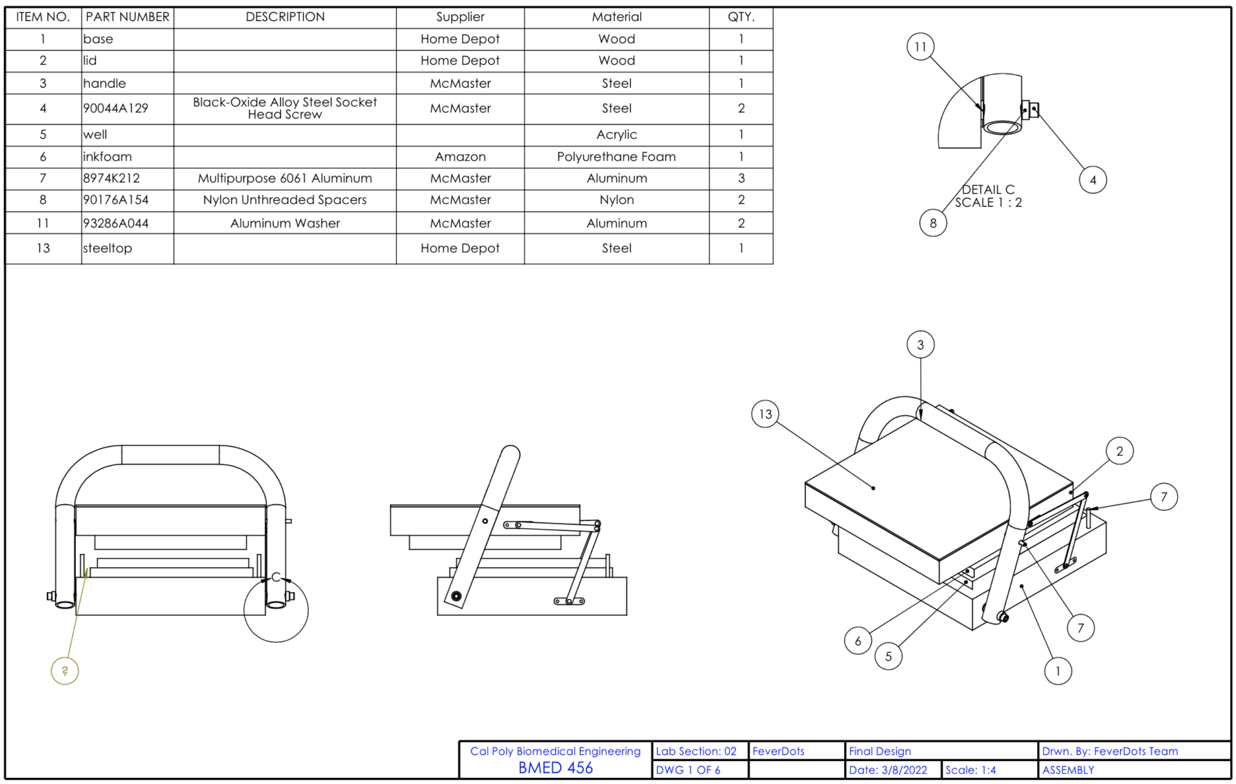
X_1: Manual vs automatic device - negative coefficient demonstrates a preferred interest in an automatic device instead of manual, indirectly proportional

X_2: 100 vs 250 stickers - negative coefficient demonstrates a preferred interest in 250 stickers per cycle instead of 100, indirectly proportional
X_3: stamp/clamp vs rolling ink application mechanism - negative coefficient demonstrates a preferred interest in rolling ink application mechanism

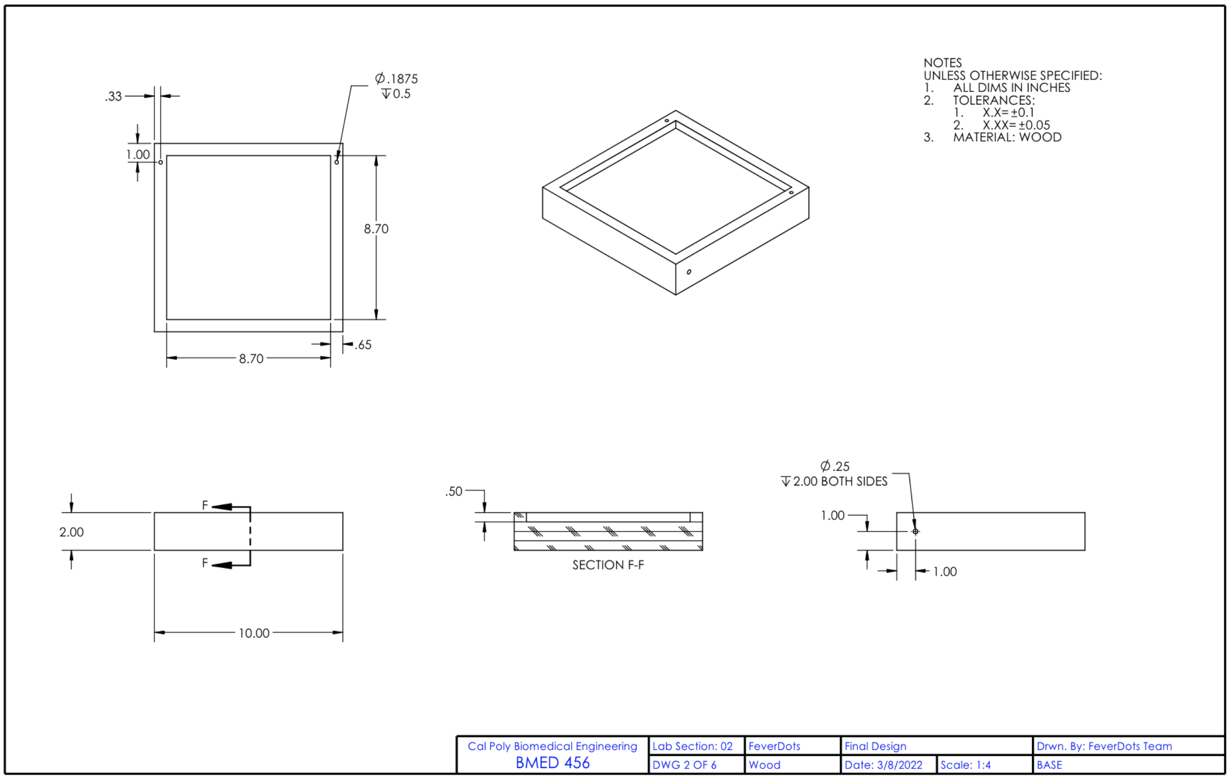
All 3 factors were significant (p-value < 0.05)

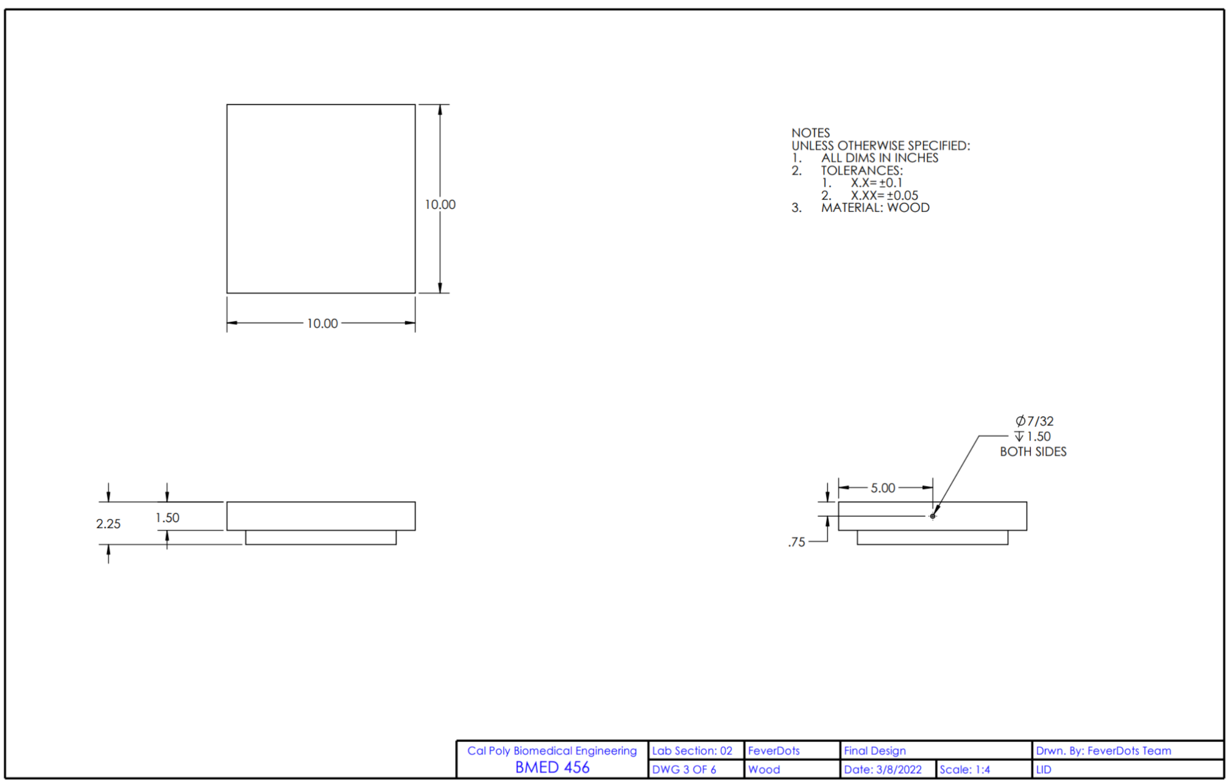
- X_1: 43.84% contribution to attractiveness
- X_2: 35.61% contribution to attractiveness
- X_3: 20.55% contribution to attractiveness

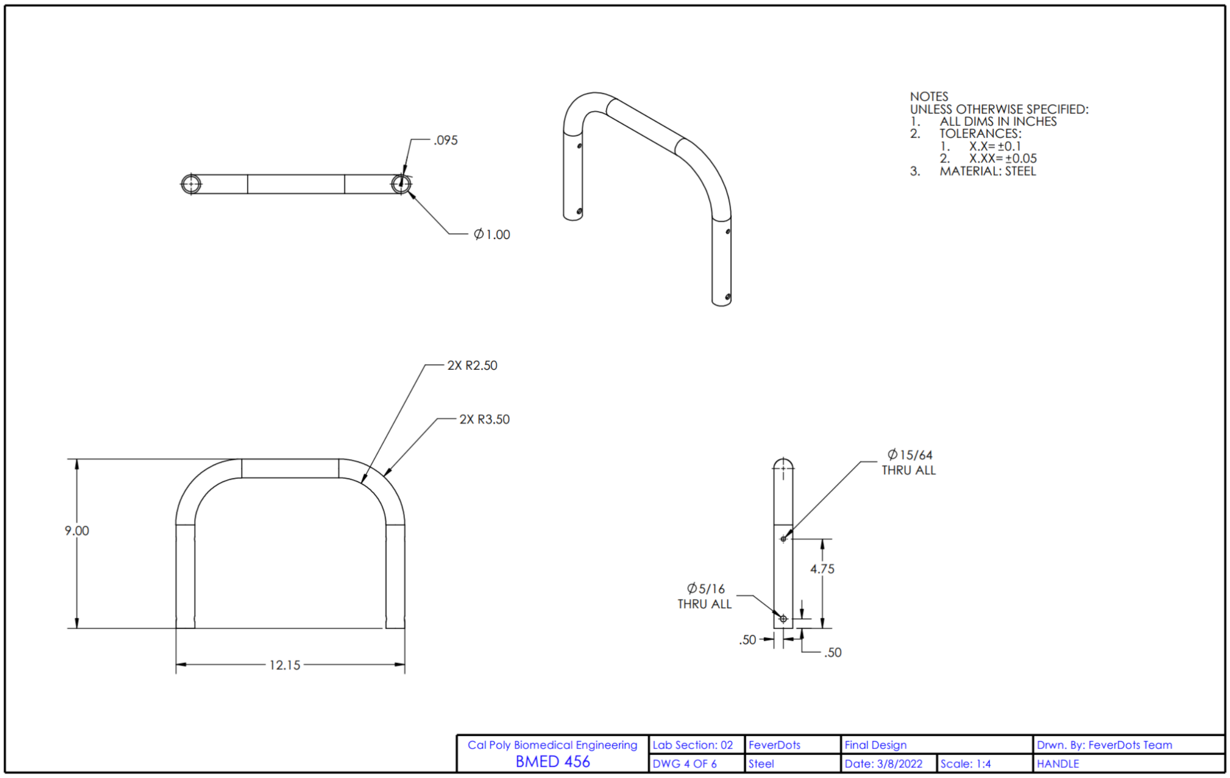
Assembly and Part Drawings

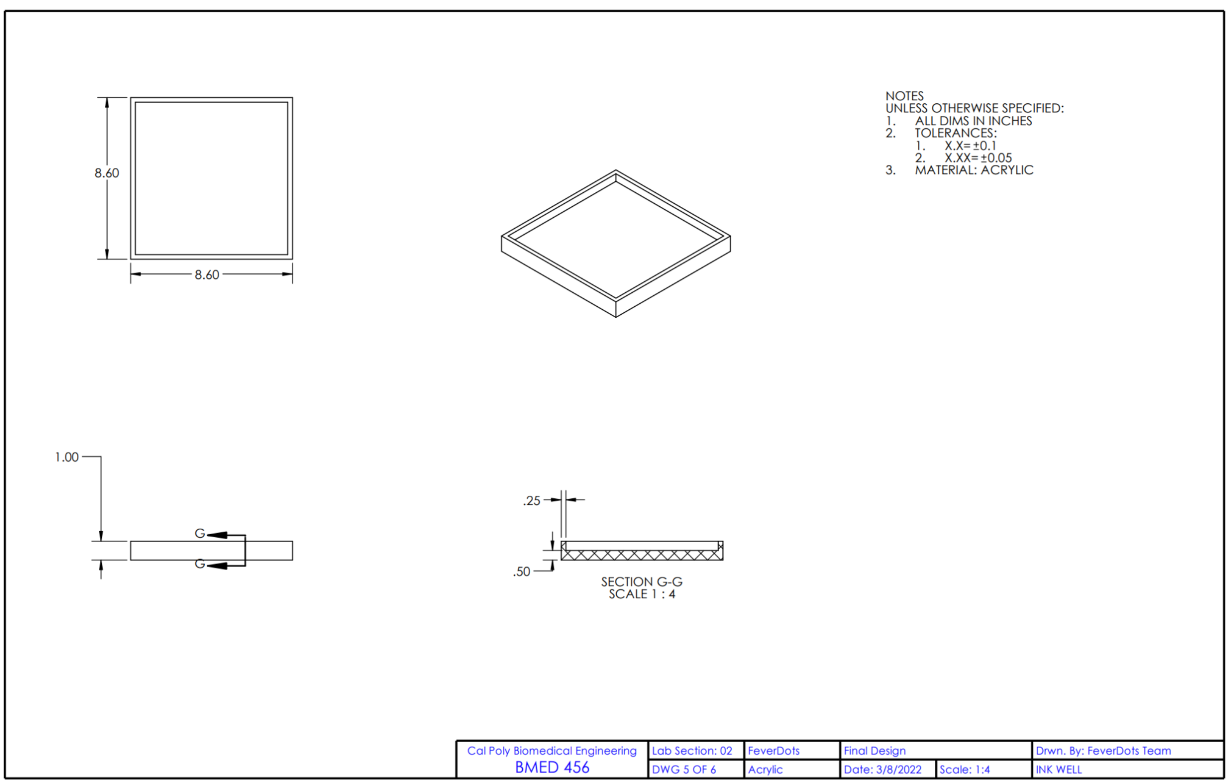


ITEM NO.	PART NUMBER	DESCRIPTION	Supplier	Material	QTY.
1	base		Home Depot	Wood	1
2	lid		Home Depot	Wood	1
3	handle		McMaster	Steel	1
4	90044A129	Black-Oxide Alloy Steel Socket Head Screw	McMaster	Steel	2
5	well			Acrylic	1
6	inkfoam		Amazon	Polyurethane Foam	1
7	8974K212	Multipurpose 6061 Aluminum	McMaster	Aluminum	3
8	90176A154	Nylon Unthreaded Spacers	McMaster	Nylon	2
11	93286A044	Aluminum Washer	McMaster	Aluminum	2
13	steeltop		Home Depot	Steel	1


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
1. X.X= ±0.1
2. X.XX= ±0.05
3. MATERIAL: WOOD
Ø.1875
↧0.5
.33
1.00
8.70
8.70
.65
2.00
F
F
10.00
.50
SECTION F-F
Ø.25
↧2.00 BOTH SIDES
1.00
1.00
Cal Poly Biomedical Engineering
BMED 456
Lab Section: 02
DWG 2 OF 6
FeverDots
Wood
Final Design
Date: 3/8/2022
Scale: 1:4
Drwn. By: FeverDots Team
BASE


NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
1. X.X= ±0.1
2. X.XX= ±0.05
3. MATERIAL: WOOD
10.00
10.00
2.25
1.50
Ø7/32
↧1.50
BOTH SIDES
5.00
.75
Cal Poly Biomedical Engineering
BMED 456
Lab Section: 02
DWG 3 OF 6
FeverDots
Wood
Final Design
Date: 3/8/2022
Scale: 1:4
Drwn. By: FeverDots Team
LID


.095
Ø1.00
2X R2.50
2X R3.50
9.00
12.15
Ø15/64
THRU ALL
4.75
Ø5/16
THRU ALL
.50
.50
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
1. X.X= ±0.1
2. X.XX= ±0.05
3. MATERIAL: STEEL
Cal Poly Biomedical Engineering
BMED 456
Lab Section: 02
DWG 4 OF 6
FeverDots
Steel
Final Design
Date: 3/8/2022
Scale: 1:4
Drwn. By: FeverDots Team
HANDLE


8.60
8.60
1.00
G
G
.25
.50
SECTION G-G
SCALE 1 : 4
NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMS IN INCHES
2. TOLERANCES:
1. X.X= ±0.1
2. X.XX= ±0.05
3. MATERIAL: ACRYLIC
Cal Poly Biomedical Engineering
BMED 456
Lab Section: 02
DWG 5 OF 6
FeverDots
Acrylic
Final Design
Date: 3/8/2022
Scale: 1:4
Drwn. By: FeverDots Team
INK WELL

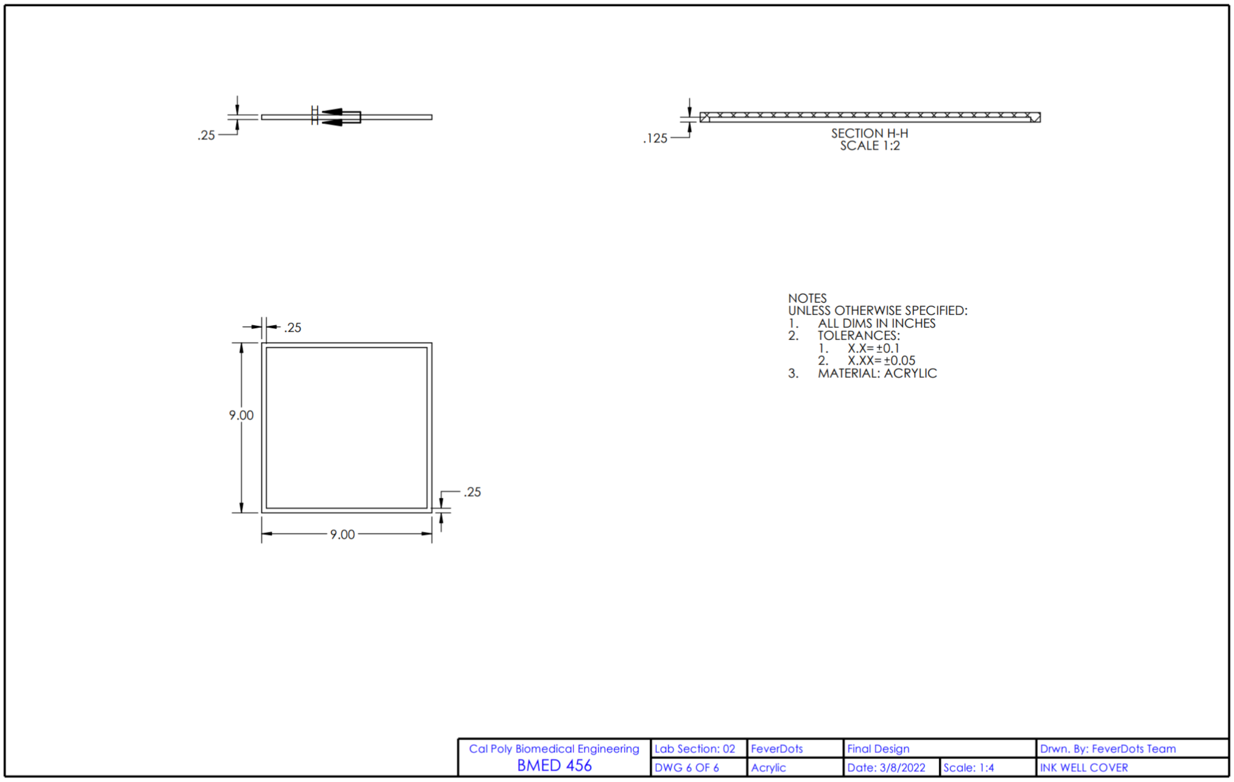


Figure 32. Detailed Part Drawings and Assembly Drawing.

Human Use Study Survey Questions

Below is the list of questions included in the survey following the human use study:

- Gender?
- Age?
- How often did you wear FeverDots?
    - Daily, Weekly, Every other day, Did not wear them
    - If you did not wear them, why?
- How easy was it to handle the stickers?
    - Scale of 1-5, 1 = very easy, 5 = very hard
- Were the stickers comfortable to wear?
    - Scale of 1-5, 1 = very comfortable, 5 = very uncomfortable
    - Explain.
- What sheet of FeverDots did you prefer?
    - circles/lips/hearts or circles/butterflies/cats
- What shapes of FeverDots would you like to see?
- Did the dots ever change from black to pink while you were wearing them?
    - Yes/No
    - Explain reason
- Any other feedback?

Dry Weight of Ink Test Trials Data Summary

Table 12. Data Summary from Trial 2 of the Dry Weight of Ink Test.

Paper	1	2	3	4	5	6	7
Amount of Ink Added	0	4	5	5	4	5	5
Average Dry Weight (g/in^2)	0.0088	0.0073	0.0077	0.0064	0.0062	0.0037	0.0034
Average % Difference	43.31	51.55	48.67	57.44	58.40	75.05	77.38
P-value	4.36E-06	1.77E-10	5.61E-08	4.36E-08	2.77E-11	1.18E-11	5.01E-13

Table 13. Data Summary from Trial 3 of the Dry Weight of Ink Test.

Paper	1	2	3	4	5	6	7
Amount of Ink Added	10	10	10	15	15	15	20
Average Dry Weight (g/in^2)	0.0052	0.0068	0.0057	0.0048	0.00578	0.0057	0.0055
Average % Difference	65.25	54.56	61.77	67.94	61.16	61.75	63.36
P-value	1.81E-12	7.98E-13	1.43E-12	1.48E-13	1.78E-13	4.83E-13	5.14E-14

Table 14. Data Summary from Trial 4 of the Dry Weight of Ink Test.

Paper	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Amount of Ink Added	0	0	15	15	20	15	15
Average Dry Weight (g/in^2)	0.0070	0.0057	0.0091	0.0125	0.0102	0.0071	0.0083
Average % Difference	53.66	62.16	39.11	16.61	32.01	52.5	44.53
P-value	4.4E-14	9.54E-14	1.8E-07	3.1E-03	6.11E-08	1.1E-07	1.4E-08

Table 15. Data Summary from Trial 5 of the Dry Weight of Ink Test.

Paper	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Amount of Ink Added	10	10	10	15	15	15	15
Average Dry Weight (g/in^2)	0.0107	0.0084	0.0078	0.0072	0.0098	0.0089	0.0086
Average % Difference	28.99	43.68	48.28	51.89	34.48	40.51	42.51
P-value	2.82E-08	5.18E-10	5.94E-13	4.26E-15	2.27E-08	6.03E-11	1.58E-11

Force Uniformity Test Data

Table 16. Force Uniformity Trials 1-7.

		Zone															
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Trial Number	1	0.797	0.837	0.852	0.809	0.918	0.794	0.788	0.858	0.774	0.73	0.838	0.923	0.875	0.81	0.855	0.933
	2	0.835	0.852	0.945	0.922	0.81	0.832	0.827	0.834	0.745	0.831	0.789	0.833	0.791	0.785	0.828	0.851
	3	0.812	0.844	0.862	0.822	0.791	0.854	0.84	0.822	0.845	0.816	0.88	0.886	0.92	0.932	0.885	0.877
	4	0.85	0.821	0.848	0.873	0.821	0.734	0.784	0.822	0.862	0.826	0.843	0.856	0.905	0.85	0.891	0.85
	5	0.797	0.767	0.822	0.796	0.836	0.767	0.696	0.743	0.802	0.724	0.784	0.79	0.816	0.803	0.81	0.799
	6	0.853	0.831	0.843	0.821	0.861	0.826	0.727	0.788	0.855	0.798	0.83	0.844	0.961	0.838	0.769	0.898
	7	0.885	0.811	0.813	0.842	0.83	0.782	0.804	0.798	0.844	0.794	0.79	0.759	0.882	0.816	0.82	0.777
	Average Diameter (in)	0.832714	0.823286	0.855	0.840714	0.838143	0.798429	0.780857	0.809286	0.818143	0.788429	0.822	0.841571	0.878571	0.833429	0.836857	0.855
												Not Significantly different			Significantly Different		

All Measurements in inches*

Minimum Force Test Data

Round One

Table 17. Minimum Force Trial One Data.

Heidi	Force 1 (N)	Force 2 (N)	Force 3 (N)	Force 4 (N)	Force 5 (N)	Force 6 (N)	Force 7 (N)	Force 8 (N)	Average (N)
Low	14.715	20.601	15.0093	17.658	12.753	16.677	13.2435	13.734	15.55
Med	22.563	22.8573	22.1706	18.2466	20.601	19.4238	21.582	20.601	21.01
High	19.62	18.8352	18.2466	20.9934	19.2276	22.6611	20.2086	18.639	19.80

Kammie	Force 1 (N)	Force 2 (N)	Force 3 (N)	Force 4 (N)	Force 5 (N)	Force 6 (N)	Force 7 (N)	Force 8 (N)	Average (N)
Low	19.2276	17.658	17.5599	16.2846	17.658	18.3447	18.639	20.601	18.25
Med	13.734	15.696	16.677	12.753	15.696	15.696	16.677	15.696	15.33
High	12.753	11.772	14.715	6.867	6.867	8.829	16.677	10.791	11.16

Rita	Force 1 (N)	Force 2 (N)	Force 3 (N)	Force 4 (N)	Force 5 (N)	Force 6 (N)	Force 7 (N)	Force 8 (N)	Average (N)
Low	17.658	18.639	17.658	17.9523	19.62	17.658	17.658	16.677	17.94
Med	19.62	19.62	18.639	20.601	17.658	20.601	19.62	19.62	19.50
High	8.1423	14.715	8.829	8.4366	11.772	16.677	10.5948	11.1834	11.29

Round Two

Table 18. Minimum Force Trial Two Data.

Heidi	Force 1 (N)	Force 2 (N)	Force 3 (N)	Force 4 (N)	Force 5 (N)	Force 6 (N)	Force 7 (N)	Force 8 (N)	Average (N)
Low	26.487	24.2307	28.6452	26.2908	25.6041	26.9775	26.0946	25.7022	26.25
Med	29.43	31.6863	31.0977	32.8635	30.2148	31.1958	24.2307	30.2148	30.12
High	21.1896	30.5091	30.7053	22.8573	29.2338	31.9806	30.2148	25.3098	27.75

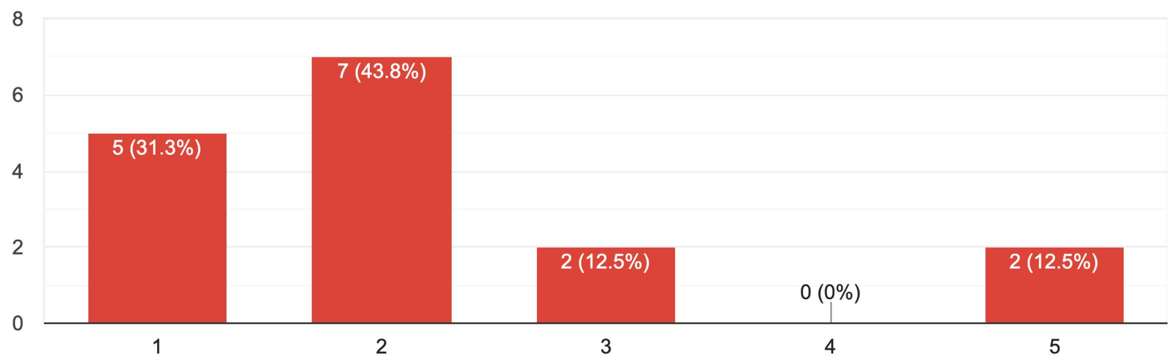
Kammie	Force 1 (N)	Force 2 (N)	Force 3 (N)	Force 4 (N)	Force 5 (N)	Force 6 (N)	Force 7 (N)	Force 8 (N)	Average (N)
Low	19.4238	17.7561	22.1706	27.7623	29.1357	25.6041	25.3098	26.7813	24.24
Med	22.0725	26.6832	21.9744	25.8003	23.2497	24.9174	25.1136	20.8953	23.84
High	17.4618	16.9713	21.1896	12.9492	13.9302	23.1516	12.5568	13.0473	16.41

Rita	Force 1 (N)	Force 2 (N)	Force 3 (N)	Force 4 (N)	Force 5 (N)	Force 6 (N)	Force 7 (N)	Force 8 (N)	Average (N)
Low	27.468	28.5471	29.1357	27.5661	29.3319	28.449	30.411	28.2528	28.65
Med	24.0345	23.4459	17.7561	24.9174	27.5661	21.6801	28.449	17.0694	23.11
High	14.0283	10.791	14.0283	11.0853	18.639	12.753	17.658	18.639	14.70

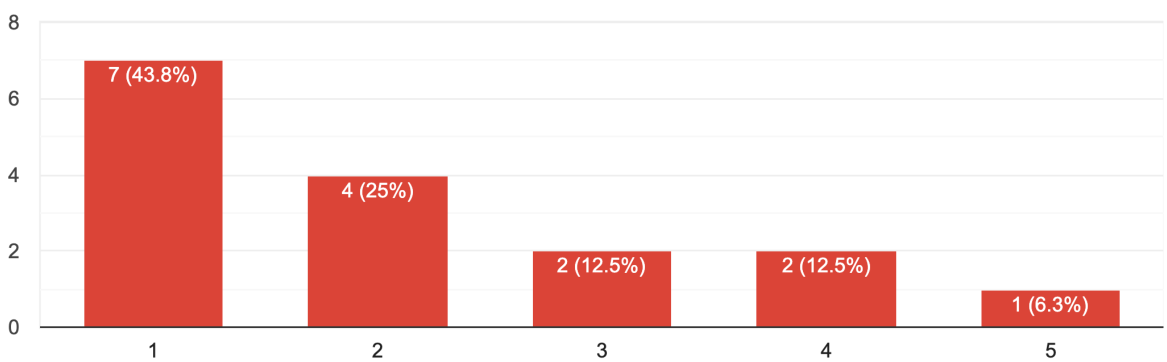
Human Use Study Survey Responses

All members of the BMED 456 Class were asked to participate in a human use study over 30 days. They were given FeverDots and instructed to wear them each day for 30 days. A survey was given out at the end of the 30 days, the results are summarized below. Most participants wore their FeverDots at least weekly, with one participant wearing them every other day.

Were the dots easy to handle? (1 = very comfortable, 5 = very uncomfortable)
Average = 2.13

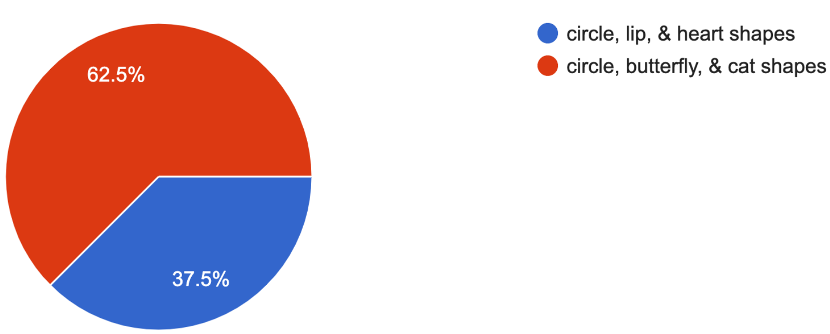


How comfortable were the stickers? (1 = very comfortable, 5 = very uncomfortable)
Average = 2.125



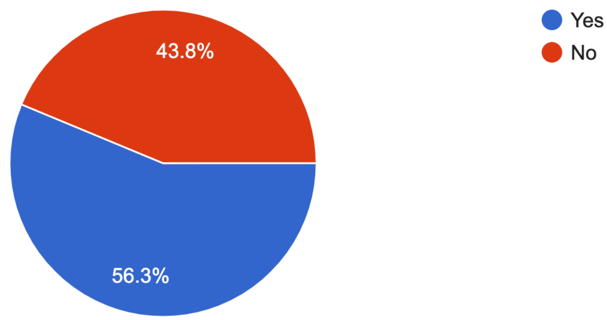
Reasons:
- Forgot they were wearing them
- Allergic to adhesive
- Scratched off accidentally

Which shape(s) were preferred?



Ideas for New Shapes
- Stars
- Crescent moon
- Basketball
- Football
- Apple
- Snail

Did the dots change color?



Reasons for Color Change

- Outside
- In the shower

Other Feedback

- Hard to see the purpose in wearing them daily
- Difficult to not monitor your dot yourself
- Adhesive was irritating
- Hard to know where best to put it