

Technical Design Review

Pet Brush Project

Group C

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Executive Summary

The group aimed to create a pet product that would be innovative and more efficient than current products on the market. After conducting surveys and doing research, the group decided to create a pet hairbrush that would allow users to efficiently brush their pets, collect fur, and remove it. The group focused on the problems that pet owners were finding with current products on the market. Brushes would tangle with collected fur. The task of brushing a pet was also tiresome as some pets do not enjoy brushing. Testing was done to ensure the brush's comfort and effectiveness. The final prototype of the Flexbrush allowed for pet owners to collect more fur when brushing and made the process of brushing a pet more ergonomic.

The Problem Definition and Concept reviews allowed for the team to better understand the problems that pet owners face and create solutions. There were two surveys conducted that were sent to college students that owned pets. The group's beginning target audience were college students that owned pets. The group wanted to alleviate some challenges that owning pets in dorms creates. The first preliminary survey analyzed how pet owners perceived several common pet care tasks (Appendix D, Figure D). Pet clean up was rated the lowest from college pet owners, and the group decided to conduct another survey to narrow down problems that owners encounter. Pet owners wanted a product that was efficient, reliable, and low cost. Participants in the survey responded that they had trouble with products like pet hair brushes and nail trimmers. From there the group created preliminary designs that focused on the pet hairbrushes (Appendix G). The group decided to proceed with a biomimetic design inspired by cat papillae (small keratin spikes on their tongues used for grooming). The group also aimed to alleviate difficulties of brushing the entire pet by creating a hinge for the brush that would allow the brush to curve around the pet.

From the preliminary designs, the group proceeded to create a mid-range prototype of the brush that was unique to other products on the market. The bristles were the first part that was designed, and they were 3D printed (Appendix L, Figure L2). The first prototype of bristles were found to be too sharp, and the group redesigned them to be staggered and rounded more at the ends (Appendix L, Figure L1). The group created a hinge composed of four different parts: the horizontal pivot, hinge linkage, and two springs (Appendix K). The group 3D printed the horizontal pivot and hinge linkage. They were first zip tied together, and later metal bolts and springs were used. The prototype was tested with five different cats. The main requirements for the brush were: time to clean hair out of brush, total brush mass, material cost, force to break one bristle, brush strokes to clean pet, and pet opinion (Appendix M, Table A1). Respectively, the final scores were 5, 1, 1, 3, 4, and 4. Time to clean hair out of the brush ranked the highest. Using this testing rubric, the final prototype scored a 20/28.

The final prototype satisfied the pet owner's needs found from the surveys and research conducted. The group created a prototype that differentiated itself from competitors with its biomimetic bristles and flexible hinge. The group would use more time and resources to create a more refined product that is mass-producible. The group will move forward to market the brush and continue research. The Flexbrush is a new innovation in pet care that allows pet owners to comfortably and easily brush their pets.

R1 - Problem Definition Review

1. Introduction and Value Proposition

In 2021, over 70% of U.S. households owned a pet [1]. People keep pets in their household for loyalty, companionship, and affection, among many other reasons.

However, pets can also be messy or disruptive or demand much of their owners' time. They are dependent on humans to provide them with food, water, and health care. Some aspects of pet care can be tedious or frustrating for the pet owner. With this in mind, this review identifies a target problem with pet ownership to address. To do this, research is conducted to identify the most important problems pet owners face.

Pet owners are very focused and dedicated to the health and wellbeing of their pets; however, pet care can be difficult for owners. After conducting two surveys and doing thorough research, the team has found that pet owners are focused on efficient and low-cost products for their pets. 37.9% of survey participants reported that they negatively perceived cleaning up after their pets (Appendix D). Pet owners surveyed indicated that they wanted a product to be reliable and helpful. The group is moving towards creating a product that will assist busy pet owners with the process of cleaning their pets so it is easier and more efficient. Even though the project is targeted towards busy college students that own pets, a solution can be used by all pet owners. The group's solution will take less effort and time out of pet owners' days.

2. Problem Definition

2.1 Task

This project addresses the task of cleaning up for one or more pets.

2.2 User Experience Chart

A user experience chart for college students who own pets is presented in Appendix B, Table B1.

2.3 Pains

- Owning pets is time-consuming: Pet owners must spend their time on their pets. For example, they have to walk their pets outside or clean up after their pets. Not all of this time is enjoyable.
- The pets can hurt others or damage objects: Pets can sometimes act aggressively towards people or objects. They bite or scratch using their claws especially when they feel unsafe. Some pets also mark their territory or scratch or chew furniture.
- Needs someone to take care of the pets when the owners are not around: If owners need to be away from the house, they must find alternate pet care arrangements. Some pets also suffer from separation anxiety when their owners are not present.

- Owners must bring their pets to a veterinarian in case of sickness: It is the responsibility of the pet owners to pay attention to their pets' health and well-being.
- Pets may disturb their owners' sleep if they are hungry or bored.

2.4 Gains

- Getting comfort and companionship with pets: Pets bring companionship to a household and are thought of as part of the family.
- Having a healthy and happy pet: Pet owners want their pets to be healthy and happy.
- Spending less time on pet maintenance: Maintenance and grooming for pets can take a lot of time and money. A lot of people are busy and it takes a lot of effort to care for a pet.
- Service animals: A lot of dogs are used as service animals that assist people with disabilities to help them with day to day tasks.

2.5 Discussion

These pains and gains were chosen as interactions that a typical user (a college student) may have with pet care. Several alternative tasks were considered before pet care was decided (Appendix A, Tables A1 and A2). For example, the main benefit of having pets, their comfort and companionship, is a significant gain. Similarly, bringing the pets to the vet is listed as a pain, as it can be stressful, expensive, and unpleasant for both pets and humans. To decide which issue with pet ownership is the most significant, research needs to be conducted.

3. Research Plan

3.1 Research Questions

In order to determine what the most substantial issues with pet ownership are, research is required. Both qualitative and quantitative data will assist in deciding which issues to focus on. This plan gathers data on the current state of the pet products industry and the struggles that pet owners face. By collecting this, the most prominent problems faced by users can be found and existing solutions can be examined. The research goals and methods are presented in Table C1 (Appendix C).

3.2 Preliminary Survey Methodology

To narrow the scope of the project, it is necessary to know what aspects of pet care pet owners struggle most with. To find this information, a survey is created.

The survey is designed to not collect sensitive information from the respondents. As the survey is focused more on pets than their owners, very little information is collected about the pet owner. Each submission will be assigned a number, so the respondent's identity will not be included in the survey results. Respondents are informed at the beginning of the survey that none of the questions are mandatory and they may opt out of the survey at any time by contacting the survey administrator.

The survey asks users to rate four activities on a 1-5 scale: cleaning up after their pets, feeding their pets, transporting their pets, and training their pets. The data is sorted into two categories: respondents who own one or more dogs and those who own one or more cats. This enables average scores to be generated for both of the most common pet types. Responses that own both cats and dogs are counted in both categories. Survey questions and responses are available in Appendix D.

3.3 User Need Survey Methodology

With the information from the preliminary survey enabling the decision of a target problem, further research must be conducted. To understand what struggles users have cleaning up after their pets, a secondary user needs survey is presented. By analyzing these users' needs, a solution can target and address the most needs that users feel are most important. Survey questions and average responses are presented in Appendix E.

3.4 Discussion

Research must be conducted to determine what problems pet owners most frequently face. Using a combination of existing data, articles, and conducting a survey, information can be collected that can shape the decision of a problem to address. With the planned research, it will be possible to decide on one problem to target. With a target problem, a solution can be created. The research questions are designed to enable insights into problems faced by pet owners and the state of the pet industry. For example, research question 5 is designed to determine what difficulties pet owners have with transporting their pets. If pet owners respond that they have significant difficulties transporting their pets, that could be identified as a problem and possible solutions could be generated.

4. Research Results

4.1 Preliminary Survey Results

After conducting a preliminary survey (described in Appendix D), 51 “valid” responses were received. Responses are considered valid when they consented to their answers being recorded and indicated that they owned a pet. One response was not in English and was removed from the data. If they did not consent to being recorded, they were removed from the data. If they did not own a pet, they were not considered as they are outside of the target demographic. The survey was distributed mainly to Ohio State University students through group messages for several student organizations. The average scores, broken down by type of pet and overall, are presented in Appendix D, Table D1.

As seen in Appendix D, Figure D1, where combined data from all pet owners surveyed is presented, most of the data follows a somewhat normal distribution. Pet clean-up is rated the lowest on average.

The lowest-ranked activity is cleaning up after dogs, followed by cleaning up or feeding cats. The highest-ranked activity is feeding dogs, followed by transporting dogs. Based on this information, along with open-ended responses from questioned users, the problem is narrowed to cleaning up after pets. Average results are presented in Appendix D, Table D1.

4.2 User Need Survey Results

After conducting the user needs survey, several insights were apparent in the data:

- Pet owners preferred a solution to be pet-safe, helpful, and reliable, in that order.
- Cost was not as significant of a factor, with “low cost” being the lowest-ranked need in the survey.
- When asked to rank existing products, some patterns emerged:
- Pet hair brushes were ranked highly in all aspects, being the highest ranked product listed in four out of the six needs.
- Pet nail trimmers were consistently ranked quite poorly in all aspects, landing near the bottom of the ranking in most aspects.

Additional data on these results is presented in Appendix E. Table E1 presents survey respondents’ average rankings of various needs on a 1 to 5 scale, with 5 being the most important. Table E2 presents respondents’ rankings of how well various products fulfill those same needs. Squares highlighted in green indicate that this product was ranked highest in that need, with yellow indicating second place. Table E3 presents all of the responses that consented to their answers being published anonymously.

4.3 End Users

To better characterize the end user, an example end user was created. “Molly Thompson” is a fictional 20-year-old female college student. She represents college students who own pets. Like many college students, she is busy with classwork and has limited time to spend caring for or playing with her pet. Because of this, she could benefit from a solution that would alleviate some of the work of pet care. A detailed description of this fictional persona is available in Appendix F, Figure F1.

Ease of use, cost, reliability, helpfulness, speed, and pet safety are all important traits in a product or solution for a pet user. As such, these are selected as end user needs.

To rank the user needs in Appendix F, Table F1, a score is assigned based on how much the hypothetical user may value a certain need. For example, ease of use is given a score of 4 out of 5, as not all users are experienced with complicated technology. If a product requires detailed knowledge of the underlying technology, it is not very helpful to a user who is not familiar with it. As such, ease of use is ranked highly. According to data from the American Pet Products Association, 27% of pet owners in 2021 were Baby Boomers [8]. Older generations may not have experience configuring and troubleshooting smart-home devices, and as such, a solution that is easy to use and understand is more valuable to them. Even for those such as the example user who are more technologically literate, an easy solution saves time and effort.

To refine the needed rankings, a pairwise comparison is made in Appendix F, Table F2. This matches user needs against each other. A more important need is selected from each pair. If the need at the top is more important, a 1 is put in the cell. If the need on the left is more important, a 0 is put in the cell.

To determine the more important need of each pairing, research can be conducted. For example, in all pairings with pet-safe, pet-safe is given priority. Owners care significantly about the safety of their pets, and any product that is not safe for a pet is not a good solution for a pet owner. M. Giordano and L. Strampe begin their article with a list of dos and don'ts when caring for a cat, emphasizing the importance of taking care of the pet [10]. Likewise, between helpful and fast, helpful is given priority. A solution that is fast, but is not helpful, gets nothing done quickly and is not useful to the user.

4.4 Market Character

A) Stakeholders

Apart from the end user, several stakeholders must be acknowledged. Most obvious is the pet or pets. The product must work alongside the pet and cannot be frightening (such as a vacuum cleaner) or obnoxious to the pet. This means that it cannot produce loud sounds, move fast, have a strong smell, or be otherwise threatening to a pet.

Additionally, the pet owner may live with other people. Their needs must also be addressed; for example a solution cannot be loud or intrusive to their privacy. Similarly, neighbors may need to be considered if the owner lives in a dorm or apartment.

The pet industry is very large, and numerous companies exist selling pet related products. These are considered as stakeholders as well. Any physical product will need distribution channels, adding retailers, distributors, and manufacturers to the list of stakeholders. A table of stakeholder needs is presented in Appendix F, Table F4.

B) Market Size

Over 70% of households in the United States have one or more pets [1]. This leads to a pet industry that, in 2020, generated \$103.6 billion. The largest segments of this market are pet food and treats (\$44.1 bn) and supplies, live animals, and over-the-counter medicine (\$23.4 bn) [8].

Specific to pet cleaning, the pet grooming market was valued at \$3,872 million in 2017, with consumable goods like shampoo and conditioner accounting for a large portion of sales. Combs and brushes are second in sales. [13]

C) Current Alternatives

With so many pets, pet owners must clean up after their pets. Pets generate waste and shed fur, which can be difficult to remove from upholstered furniture. Respondents to the preliminary survey indicated cleaning up as the worst task, with an average score of 2.9 out of 5, lower than the other tasks listed. Cleaning up after waste is not comfortable for humans either - a significant number of respondents to the preliminary survey mentioned the smell of pet waste as a challenge to cleaning up. Several also mentioned managing shed fur as a challenge. Of course, many products are already available to aid pet clean-up. Appendix F, Table F3 presents several of these solutions and indicates which user needs they satisfy. In it, spaces are marked with an "X" when the user's need is fulfilled.

4.5 Discussion

The survey conducted allows the group to understand the frustration surrounding cleaning up after pets. The pet owners and the pets themselves are the largest stakeholders for pet care. They use and are affected by products; however, the pet care industry benefits from every pet product purchase. With most households owning pets, the pet care industry is a multibillion-dollar industry that is continuously growing every year. Pet owners are spending more to spoil and take care of their pets. As a result, there are many options for pet care today. Pet owners use litter boxes, hairbrushes, nail trimmers, fecal waste bags, vacuum cleaners, and furniture coverings, among other tools, to clean up after their pets. All of these products are helpful to pet owners, yet most of these take up more time than some people have. Most of the products are easy to use and can be bought at a low price. However, only some of them are reliable which means that it is possible that the other products will be unable to be used over a period of time. The most important thing about these products is that all of them are safe to use on pets. Pet safety has to be deemed important in this case where it is crucial to notice if the pets are hurt when these products are used on them.

5. Design Focus

Based on the responses we received, we found that it is burdensome for pet owners to take good care of their pets, especially in terms of cleaning. A large amount of effort is needed to keep them clean. For college students, much of their time is occupied with classes, assignments, and on-campus jobs. As such, they do not have significant amounts of time to clean up after their pets. Moreover, although there are many pet cleaning products in the market right now, our respondents indicated they were not satisfied with their performance. For example, when asked which pet cleaning product needs improvement, most respondents selected nail clippers and litter boxes. Plus, one of the challenges that the respondents face when cleaning after their pets is that the pets can be messy and smelly. Hence, the group aims to solve these problems and help the pet owners to clean after their pets without having the feeling that it is a burden. The product must focus on aiding the user while being safe for pets, easy to use, reliable, and fast.

R2 - Conceptual Design Review

1. Conceptual Development

1.1. Process Description

Using the data obtained as part of the Problem Definition Review (R1), the group identified cleaning up after pets as a major issue faced by pet owners. After a further survey, this was refined - specifically, pet owners dislike cleaning up pet waste and have trouble with pet maintenance. Participants in the survey felt that many currently available pet cleaning products are not as reliable or helpful as they would like. They wanted lower costing products that were easy to use.

With these characteristics and the time limitation of this project, in mind, several concepts are created. Priority was given to being able to fulfill the user needs that were identified in the Problem Definition Review, ease of use, and reliability. In addition, it is important that a potential solution is viable to design, test, and produce within the allotted time, ruling out complicated mechanical or computerized solutions.

After the team has decided to work on the Pet Care Project, the group proceeds to do a preliminary survey to choose what type of pet care would be the best to work on. Based on the responses, the group discovered that pet cleaning was ranked the lowest compared to other pet care. The group created and distributed another survey that focused on pet cleaning to gauge the improvements pet owners needed. Overall, furniture coverings have been ranked low in the average user rankings because they are not widely used by pet owners. However, it would be best if the group could design better furniture covering which fulfill the user needs. The cover would have to be easy, helpful, low cost, reliable, and pet safe. Even though there will be some constraints to the covers, they need to have varying sizes to account for different types of furniture. The group will work towards making an easily producible and adaptable furniture covering for pets.

From the data gathered from the surveys, pets can be hard to brush and it is difficult to clean up all the fur. There are a lot of other pet care products and problems when cleaning up after a pet, but fur is something that a lot of pet owners hate as it gets all over furniture and clothes. The main idea around the brush is that it sucks up the hair as pet owners brush their pet (Appendix G, Figure G4). It is handheld and cordless. The advantages of this device is that it would be a fast and easy alternative to regular bushes where owners have to pluck out the hair in the brush. The hair doesn't get all over the place because the device would suck the hair up and store it. The brush is meant to take some frustration and time out of brushing pets.

Another idea of the brush is by placing it on the palm side of the gloves (Appendix G, Figure G3). The gloves will be produced in a variety of sizes so that all pet owners could use them. However, it would be troublesome for the users to buy different sizes of the gloves in order to brush their pets. The advantage of this design is that its brush has papillae-shaped bristles which imitates cats' tongues. The design of the bristles will be so efficient to brush and trap the pets' fur on the bristles.

1.2. Brainstorming Results

From the data gathered from the surveys, pets can be hard to brush and it is difficult to clean up all the fur [2]. There are a lot of other pet care products and problems when cleaning up after a pet, but fur is something that a lot of pet owners hate as it gets all over furniture and clothes. The group wants to focus on cleaning up pet fur and managing fur when brushing pets.

Several different solutions were roughly drawn up to try and solve this problem. Ranga's first design focuses mainly on the bristles of the brush (Appendix G, Figure G2). These bristles would mimic the papillae on a cat tongue that allow them to efficiently clean themselves [14].

The second design by Dan follows a similar concept to the first with the bristles, but the concept is a glove that allows owners to easily brush their pet. The bristles are located on the palm of the glove and could offer a pet-friendlier alternative that helps pet owners clean their pets with just a wave of a hand (Appendix G, Figure G3). However, the bristles are not created to hold the pet hairs and have to be cleaned manually.

Design three from Angelina is a brush that would suck up the hair as the pet was brushed (Appendix G, Figure G4). The advantage of this device is that it would be a fast and easy alternative to regular bushes where owners have to pluck out the hair in the brush. The hair doesn't get all over the place because the device would suck the hair up and store it. The brush is meant to take some frustration and time out of brushing pets.

Mira's design is furniture covering that would be sturdy enough to hold up to pets' claws. At the same time, it would be able to wrap the entire furniture piece. It would be waterproof and reusable, so it could handle leaks from pets, saving owners money. It would be sturdy enough to be used for longer periods compared to other covers, so owners would not have to buy many covers. There is a zip underneath it, so it will be easy to attach and remove the cover (Appendix G, Figure G6).

Two designs were generated as a group based on elements of each individual design. These two are presented in Appendix G, Figures G7 and G8. The first design is a pivoting hairbrush with a two-axis joint similar to one found in some razors (for example, the Gillette ProGlide razors). The pivoting head of the brush would ideally enable it to conform to the contours of a pet more easily.

The second design proposed was an attachment for a vacuum cleaner that would specialize in removing pet hairs from couches and other surfaces, which can be very challenging for normal vacuum cleaners. A system of hooks (similar to those found on hook-and-loop fasteners such as Velcro) could trap fur more effectively than a standard vacuum cleaner and be easier to clean.

2. Concept Selection

Using the user needs to be discussed in the Problem Definition Review, concepts were selected down to two viable concepts. The first was the swiveling hairbrush (Appendix G, Figure G7), and the second was the pet grooming glove (Appendix G, Figure G3). These were chosen as they were deemed to be feasible in the time frame given and to satisfy the user needs to be identified in the PDR (ease of use, reliability, and pet safety).

A Pugh scoring matrix was generated using weights from the pairwise comparison chart generated in the PDR. The two concepts were scored against a control product, a self-cleaning slicker brush found on Amazon [15]. This control product was chosen as it was indicated as a best-seller on Amazon.

The Pugh scoring matrix (Appendix H, Table H1) indicated that the swivel brush design would be most useful and appealing to end-users. Compared to the HERTZKO self-cleaning slicker brush, the swivel brush would be more pet-safe, affordable, easy to use, and reliable. Brushes like the HERTZKO self-cleaning slicker brush allow users to push the fur off of the bristles with a button, yet it does not work efficiently enough. Fur is still left at the end of the brush and is difficult to get out. The group believes the swivel brush design to be more efficient than the HERTZKO brush and the glove brush design. The glove design would be faster and more helpful in the Pugh scoring matrix, but after further consideration, the group believes that it could be less effective than more traditional bristles. The swivel brush design gives a more versatile range of motion when brushing and allows for more fur to be caught with the bristles. The group finds the swivel hairbrush to be the best solution among the three and will pursue it going forward (Appendix G, Figure G7).

3. Grand Concept & Prototyping Plan

3.1. Grand Concept Design

The swivel brush design will be chosen as the group's Grand Concept Design because after some reconsiderations, the group think it is the best option compared to the others (Appendix G, Figure G7). The product is designed to have horizontal and vertical pivots, so it will be easy to contour around the body shape of the pet allowing for the owner to easily brush the pet. The pivots are attached to ordinary bolts which will form hinges that let the pivots rotate and turn smoothly. In the survey conducted, the participants described having trouble brushing their pets. The prototype brush would allow pet owners to brush difficult areas on their pet (Appendix G, Figure G10 and Appendix I, Figure I1). The swivel brush is also expected to have semi-flexible bristles all over the bottom of the brush since these soft and durable bristles can provide a therapeutic combination of deep pressure and tactile stimulation to help self-regulate and calm down the pets (Appendix I, Figure I2). This design is great for the users to brush the pets because sometimes pets act aggressively and it is hard to brush them. The size of the swivel brush is 3" x 4" inches with approximately 100 of papillae-shaped bristles while the handle will be 5" inches.

Papillae-shaped bristles are chosen because the shape enables the fur to stick on the bristles easily since it looks like a hook. However, in Figure G10, the bristles are not shown since the sketch is not finalized. The challenge to make these bristles comes in the process of manufacturing them. Their small size makes them challenging for FDM 3D printers that have not been carefully calibrated. The durability of bristles and body parts should also be tested before the product is delivered to market.

3.2. Prototyping Plan

The main objective of this prototyping plan is to create a pet hairbrush that adapts to the differing body shapes of pets. The detailed sketch focuses more on the mechanism that allows the brush to

contour to different surfaces (Appendix G, Figure G10 and Appendix I, Figure I2). The mechanism is a greater focus for the group to make it as efficient and reliable as possible. Pieces like the handle and bristles will be easier to manufacture and create. End users want a product that they can rely on to be easy to use. A simple prototype will be created first as a proof-of-concept to test the validity of the idea. Additive manufacturing is ideal for prototyping several of these parts, as they are fairly small and do not need to bear significant loads. These include the swivel and the brush. As for the materials, the group aims to use wood for the handle, ABS for the swivel and the brush holder and bristles.

Several pieces are more simple, and as such ordinary bolts can be used to form the hinges of the horizontal and vertical pivots. While these will not be very smooth, and will wear away the plastic over time, for a proof of concept they are acceptable. In addition, a small strip of steel will serve as a spring which acts to keep the brush in its centered orientation. For the prototype, many joints are far larger than necessary due to the relative weakness of 3D printed materials (and the large $\frac{1}{4}$ "-20 bolts planned). These can easily be scaled down or replaced with smaller pins for future iterations of the design (Appendix G, Figure G10).

A 3D-printed preliminary bristle assembly (Appendix G, Figure G11) was created to test the basic papilla design. This prototype proved to be rather sharp, scratching human skin when tested on it. Its durability was acceptable, and no bristles broke under casual testing. Due to the sharpness, it was decided not to test this prototype further. Instead, a second prototype will be 3D-printed with bristles that are angled further down and have a larger tip to make them duller. The new bristles are shown in Appendix I, Figure I2. In addition, the backplate was redesigned to use laser cutting instead of 3D printing for faster manufacturing (Appendix I, Figure I3).

4. Prototype Design Requirements & Verification Plan

4.1. Prototype Design Requirements

Six design requirements were identified and established, presented in Table 1 below. These design requirements are used to guide further development of the project and identify what changes need to be made to a prototype.

Table 1: Design Requirements

Design Requirements	Value Range	Ideal Value	Design Impact
Time to clean hair out of brush	0 - 120 seconds	< 30 seconds	Bristles modified to lower value (easier to use)
Total brush mass	0 - 500 grams	< 100 grams	Parts optimized for lower mass (lighter)
Brush material cost	\$0 - \$10	< \$5	Optimized for lower cost (cheaper brush)
Force to break one bristle	0 - 3 lbs	> 3 lbs	Bristle must withstand normal use (higher breaking force is better)
Brush strokes to adequately clean pet	1 - 10	< 3	Bristles modified to lower value (quicker cleaning)
Pet opinion	1 - 10	> 8	Bristles modified to minimize discomfort and increase pet opinion (more pet-safe)

4.2. Testing Methodology and Verification Plan

Tests are established for all of the design requirements identified in Table 1 above. These tests will be used to evaluate whether a prototype meets the requirements.

1. To test the time to clean the hairbrush, the hair brush will be used for some time until it has some hair trapped in it. A timer will be started, and the amount of time required to remove the trapped hair (fewer than 20 hairs remaining) will be recorded. This emulates the typical use of a hair brush. 5 trials.
2. The total brush mass will be measured using a balance after cleaning the brush of any trapped hair. 1 trial. The brush material cost will be calculated from CAD models. This does not include the cost of manufacturing, as the manufacture of the prototype is significantly different from the manufacture of a mass-market prototype. 1 trial.
3. To test the bristle breakage force, one bristle, mounted to a base, will have a force applied to its tip horizontally and will be tested to destruction. The final failure force will be recorded. This test aims to ensure that a bristle design is not fragile and can stand up to usage, drops, and handling. 3 trials.

4. To test the efficacy of the bristles, the number of brush strokes needed to adequately clean a pet will be measured. First, the brush will be used on a small section of a pet. Brushing continues until there is no more significant accumulation of fur on the brush (fewer than 20 individual hairs on the last stroke with no large clumps), which is cleaned between strokes. The number of strokes is recorded. 5 trials.
5. To test the comfort of the brush for the pet, pets' opinions will be scored. The brush will be used on a pet. Brushing continues for up to five minutes. A score from 1 (bad) to 10 (good) is given based on whether the pet seems to enjoy the brushing. 3 trials.

4.3. Correlation Matrix & Verification Scorecard

To generate the correlation matrix (Table 2) and scorecard (Table 3, page 17), design requirements and user needs are compared and given correlation values. Based on these, the design requirements are given weights that represent their importance to the design. Then, a rubric for each test is generated for the scorecard.

Table 2: Correlation Matrix

Prototype Requirements Correlation	Time to clean hair brush	Total brush mass	Total brush material cost	Force to break one bristle	Strokes to clean pet	Pet Opinion	Weight from PDR [1]
User Needs					3	9	5
Pet-safe					9	3	0
Fast	9						1
Affordable			9				
Helpful	3	1		1	9	3	4
Reliable				9			2
Easy to use	9	3		3	9	3	3
Importance	39	13	9	31	78	66	

Table 3: Testing Scorecard

Requirement	Range	Score Rubric									Score
		8	7	6	5	4	3	2	1	0	
Time to clean hair out of brush (5 pts)	0 - 120 seconds				≤ 8 0 s	≤ 9 0 s	≤ 1 00 s	≤ 1 10 s	≤ 1 20 s	> 1 20 s	
Total brush mass (1pt)	0 - 500 g								< 2 50 g	> 2 50 g	
Brush material cost (1pt)	\$0-20								$<$ \$1 0	$>$ \$1 0	
Force to break one bristle (3pts)	0-3 lbs of force						≥ 3 lbs	≥ 2 lbs	≥ 1 lb	< 1 lb	
Brush strokes to adequately clean pet (8pts)	1-10	1	2	3	4	5	6	7	8	≥ 9	
Pet opinion (7pts)	1-10		10	9	8	7	6	5	4	< 3	

R3 - Detailed Design Review

1. Project Management

1.1. Finalized Prototype Plan

A swivel brush designed for pets is chosen to be the group's final prototype. The hairbrush will consist of five major components prototyped to a mid-range functionality level. The five components will be accompanied by springs and bolts to connect them. While these will not be very smooth and will wear away the plastic over time, for a prototype they are acceptable. The less complicated parts are the handle and back of the hairbrush. These will be made of lightweight and readily available materials like wood or plastic. The rotating hinge supported by the spring is a key feature that will allow users to brush around the pet with less effort. The moving and rotating hinge will adjust to different parts of the pet's body while brushing it. Common materials like bolts and springs will be used to create the hinge. The design of curved bristles was modeled after the papillae on cat tongues. The design of the bristles is meant to collect more hair while also allowing for the hair to be easily removed from the brush. The bristles of the brush are going to be 3-D printed to create a specific curved shape. The hinges and bristles are the main prototyping focus and will be on the higher range of functionality. The group plans to design a prototype that will have an advantage on other products with the different hinges and special bristle design.

1.2. Goals and Deliverables

The main goal of the team is to create a brush that is unique and has advantageous features compared to other products on the market. The bristles are one of the two main focuses of the team. The group is going to design and print bristles that easily gather hair and make it easier to remove the hair from the brush. The group is going to utilize the curved shape of the bristles to accomplish this. The rotating hinges are a highlight in the design of the brush. The hinge will be assembled to curve around the shape of the pet and return to its normal position. The group wanted to create a product that eases the process of brushing a pet. The group is going to create the hinges to work with the user as they try to navigate the brush around the pet's body.

Other than that, the group is also looking forward to inventing a good brush that can make pets happy. The group prioritizes how much the pets seem to enjoy the brushing based on the scorecard that has been created.

1.3. Project Management Schedule

The team has produced a comprehensive schedule (Appendix J, Table J1) using a Gantt chart (Appendix J, Figure J1) consisting of tasks that are prioritized to complete the final product on time. All group members have also been assigned different responsibilities to be completed within the time range. If there is a time conflict or past due, the group has to find any available time and finish the task as soon as possible. This schedule will allow the needed tasks to be coordinated between team members.

2. User Validation Plan

2.1. User Needs

To ensure that the end user needs established in the Problem Definition Review for this project are met, a validation plan must be created. In the Problem Definition Review, a pairwise comparison chart was used to rank the user needs to determine their importance to the final design. Using this technique, it was determined that it was most important to be pet-safe, helpful, and easy to use, in that order.

The first change made driven by end user needs was in the bristle assembly. The first bristle prototype failed the first requirement, as its bristles were too sharp, and when tested on a human arm, would mildly scratch the skin. Because of this issue, the first prototype was revised to create a second. The second prototype's bristles are bent farther down and have a larger tip diameter, making them less sharp and harsh on the skin. The bristles are also staggered to collect more hair. This prototype is a vast improvement in pet-safety and efficiency from the first.

In order to make more changes such as this, a method must be established to evaluate how well a prototype meets certain end user needs. Given the limited time available (and the challenge of testing with pets on campus, where most students cannot have pets in their dorms), large-scale user testing is not feasible.

Because of these limitations, user testing must be done by team members and their friends with their own pets. While this creates some drawbacks, as team members who worked to design the product may not have the same view of it as the average consumer, it is not feasible to test the product with more users in the limited time available. The user testing will be done in person which means all team members need to find people who own pets and test the prototype. During the test, the team has to record all results in order to search for any drawbacks of the prototype.

To evaluate how well the prototype meets the top three user needs (pet safety, helpfulness, and ease of use), a simple 1-10 scale can be used. The user will use the brush with their pet and score the brush in each category based on how well it meets that need. The user's name will be kept confidential. The user will also rank the value provided by the brush on the same 1-10 scale. Based on these data, the effectiveness of the prototype can be determined.

3. Social and Economic Value

3.1. Value Matrix

The product offers a significant number of benefits to various stakeholders. These benefits are shown below in Table 4 (Page 20).

Table 4. Value matrix.

	Value Categories			
Stakeholders	Economic	Social	Environmental	Functionality
Pet owners	Generate profits by buying the hairbrush and increase the hairbrush's popularity. There will be more competition in the market since the product has its specific feature which might be implemented by other companies too	Creates a community of pet owners who shares experiences of brushing their pets	A more reliable brush will allow pet owners to own it for an extended amount of time compared to other brushes.	Pet owners can brush their pets more easily with papillae-shaped bristles
Pets	N/A	Bond with pet owners since they feel comfortable when they get brushed	N/A	Gain enjoyment from grooming
Investors	Generate a return on investment through sales.	N/A	N/A	Having a well-performing product is easy to generate more revenue
Employees	Receive payment for work.	Creates a place of work for employees to socialize in	N/A	More complex parts could make more work and take more time

3.2. Narrative

The pet hairbrush is meant to ease the task of brushing pets for the owners. The brush was designed to make it easier to brush around the pet's body and to collect hair faster than current brushes on the market. The stakeholders for the pet hair brush are mostly impacted in the functionality and economic value categories. The pet owners and the pets are the two bigger stakeholders that the group's project is aimed towards pleasing. The functionality of the brush is extremely important as its main purpose is to be easy to use for pet owners and enjoyable to pets. In this way, it can create a special bond between the pet owners and the pets where the pets will

not be afraid of the owners anymore. The brush cost is important for pet owners as well. From the surveys conducted for the Problem Definition Review, pet owners want reliable and low-cost pet products. Environmental factors for owners are important on a personal preference level. If the brush is more environmentally friendly, the pets will mostly benefit from the functionality aspect of the brush being pet friendly, but it can also be something that the pet enjoys. It could also appeal to a broader range of pet owners, thus increasing the numbers of pet owners. However, as a consequence, the brush will have more competition in the market since every company will compete to produce and promote a better hair brush.

The investors and employees are affected more by the economic value of the pet hairbrush. The more revenue that the brush creates the more jobs and economic value.

4. Detailed Design and Manufacturing

4.1. Prototype Fabrication and Evaluation

The group created the brush to satisfy the user's needs derived from the survey's conducted, competing products, and a coalition of different concept designs. The final prototype consists of 6 major parts: the handle, hinge, the back plate, and the bristles. The handle and backplate are straightforward to manufacture. Drawings of these parts are available in Appendix B. Final CAD models are available via GitHub [16].

For a production version, many parts could be combined: the handle and first hinge component could be one injection-molded part. The bristles and backplate could also be combined (they were separate for prototyping to allow rapid iteration of the bristles' design and due to the limitations of 3D printing). The hinge could potentially be replaced by a single flexible plastic piece as well, and the handle could be integrated with the horizontal pivot.

4.2. Detailed Design

A. Final Prototype Design

Based on the group's findings, the most interesting feature that has been implemented in the prototype is the papillae-shaped bristles which were designed to imitate cats' tongues (Appendix K, Drawing 7). Pets, especially cats, frequently get uncomfortable when their owners try to brush them. This design aims to minimize any discomfort for pets. The final prototype cost \$25.77 at the prices set by the FE Store [18]. This was well within the budget constraint of \$50. The cost of each custom-fabricated part is presented in Appendix N, Table N1..

One of the changes that will be made in the final product is the material used for the bristles. The group aims to use silicone to replace ABS for the brush material since it is much softer and more flexible. This change will help the brush to provide more comfort to the pets when they get brushed.

B. Revised Grand Concept Design

The initial Grand Concept specified bolts and metal springs, but during prototyping, it was found that this was not an ideal combination. Bolts are quite heavy and do not offer any significant advantages. For the prototype, zip ties were instead used to secure the moving elements together, and their elasticity also provided some spring force to return the brush to a neutral orientation (Appendix L, Figure L1). As a result of this, some parts of the prototype, such as the spring holder (Appendix K, Drawing 6) are not used in the final prototype. A final product would not use zip ties, but by using a single-piece injection-molded plastic part for the hinge, cost, weight, and complexity could be reduced.

In addition, the bristle design was revised between its initial design (Appendix L, Figure L3) and its final design (Appendix L, Figure L2), as the initial design was deemed too sharp to test with pets. The newest version of the bristles are rounded more at the ends and staggered to collect more hair.

The final prototype of the brush changed from the initial concept due to both testing and materials available. The hinge system was changed the most to fit the user needs and prototyping limitations. The springs were removed from the prototype as the zip ties produced a similar elasticity that the group aimed for. The hinge performs well in its current configuration, and it is likely that the addition of bolts and metal springs would negatively impact performance more than it would benefit it. The final prototype adequately meets user needs, and testing shows that the brush is efficient and satisfies many design criteria.

R4 - Technical Design Review

1. Prototype Design

Based on user needs defined in the Problem Definition Review, the group designed and fabricated a prototype (Appendix L, Figure L1) described in the Conceptual Design Review. This prototype features unique biomimetic bristles (Appendix L, Figure L2) modeled after the papillae found on cat tongues and a hinge that allows the brush to better conform to a pet's body. Construction of the prototype is discussed in the Detailed Design Review.

2. Verification Results

After constructing a functioning prototype of the pet brush, the group conducted tests to determine its efficacy. Based on user needs established in the Problem Definition Review, a testing scorecard was included with the Conceptual Design Review. Final scores are presented in Appendix M. Based on the tests defined there, the group conducted initial testing with several pets. The results of the first tests were presented in the Preliminary Verification presentation [18].

Tests were conducted as prescribed by the CDR. After brushing a pet for some time, the time it took to clean out the brush was measured. For many brushes, this can be frustrating due to the tendency of pet hair to become entangled or trapped in the brush. It was found that this brush design is not as susceptible to tangles and hair is readily removable. As such, a score of 5 was assigned in this category.

The brush's mass contributes to its ease of use - a heavy brush will not be as easy or comfortable for a pet. In part because of the initial intention to use steel bolts to fasten the brush's hinge together, this was initially a concern. With the zip-tie based hinge, however, it is comfortable to use and its mass is well below the target set. The zip ties add a negligible amount of mass. As such, mass was estimated using CAD models at 0.21 lbs (95 grams) [16]. As such, one point was assigned in this category. Due to challenges sourcing appropriate springs, springs were not included on the final prototype. The friction between the hinge components is adequate to hold the brush in a fixed position during brushing and the zip ties' elasticity can offer some force returning the brush to a neutral position. Despite this, the brush performed well even without springs, and based on the observed challenges, the addition of springs may not improve its performance.

The brush's material cost is minimal thanks to its 3D-printed construction. Based on the cost of ABS plastic (around \$0.65 per cubic inch) [17], the overall material cost of the brush if made of solid ABS would be \$3.19. This cost does not include manufacturing, waste, packaging, or labor. This cost is below the \$10 target set, meaning the design receives one point in that category.

The force to break one bristle was set as a metric as survey respondents expressed that product reliability was an important factor for them. Due to technical limitations, force measurement could not be performed as initially planned in the CDR. With the time available, there was not a way to easily apply and measure force in such a specific way to test the bristle's breakage force. In handling the brush normally, no bristles were damaged.

The amount of brush strokes to adequately clean the pet was found to be 5. A lower amount of brush strokes was important to minimize the amount of time it took to clean the pet. Efficiency was important to the user's needs as data from the surveys showed that pet cleanup often took too much time. The brush was both tested on long and short-haired cats. For short-haired cats, the average amount of strokes necessary to brush the pet was 5. The longer haired cats took about 8 strokes to brush because of the larger volume of hair. The amount of strokes is dependent on the type of pet hair; therefore, an average score of 4 on the testing score card was assigned. This testing showed that further refinement of the bristle geometry may be necessary to commercialize such a product. Elongating the bristles slightly may help it deal with longer fur (which may stack further from the skin) more effectively.

In any pet product, the pet can be a very important decision maker. It is very important that a brush be comfortable for the pet being brushed as well as for the user. As such, the pet's opinion was subjectively evaluated. If the pet appeared to be uncomfortable or under duress, fewer points would be awarded. If the pet was comfortable or enjoying the brushing, more points would be awarded. The first bristle prototype (Appendix L, Figure L3) was not tested with pets, as its bristles were quite sharp. The second prototype (Appendix L, Figure L2) fixed this issue, and testing started with two cats, who both enjoyed the brushing (Appendix L, Figure L4). As such, it was scored at a 7/10 for preliminary testing [18]. After this, additional testing was conducted with other pets. In this testing, an 8/10 was assigned. Overall, the average of 7.5 is used for scoring.

From these data, a final score of 18 is assigned. This score is lower than the preliminary score as the brush does not perform as well with long-haired cats. This score indicates that before commercialization is possible, additional work must be done to refine the geometry of the bristles. This could include testing with more varied pets (such as different species with different types of hair) and additional design towards aspects such as ergonomics for the user.

3. Value and Impact

The product aims to offer value to pet owners by addressing issues that they face with existing pet products. This brush aims to be comfortable for both pet and owner while remaining affordable and convenient. In particular, the unique bristles aim to simplify cleaning and improve durability compared to traditional bristles, which can become tangled with trapped pet hair. A production version would be made using fewer pieces and aim to minimize its environmental impact in packaging and production. It aims to make brushing pets, especially those that struggle or have mats in their fur, more convenient. For investors, sales of the brush can deliver profits. By designing the brush to minimize production costs, it can become competitive and save users money compared to existing solutions, while allowing them to take care of and bond with their pets more easily.

4. Projected Recommendations and Next Steps

The current prototype is mid range, and the group would aim to create a refined and more reproducible product. The hinge design was complex and the springs were found to be fragile.

The group would move towards creating a single piece flexible hinge. The hinge would ideally be a flexible piece with three degrees of motion, instead of the current two degrees the final prototype had. Advancements in the hinge and also the bristles are recommended. The bristles would be made out of a more flexible material that would allow for a greater collection of fur. Different materials would be recommended for the brush that would be more environmentally sustainable and more effective than the current 3D printed parts being used. The group would use the next steps to focus more on making modifications to the brush to make it ready for mass production.

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Appendix A: Brainstorming Tasks

Table A1: Daily Tasks for College Students

No.	Task	No.	Task
1	Managing finances	6	Cleaning up your room
2	Organization	7	Shopping
3	Working out	8	Pet care/playing with pets
4	Commuting / going off campus	9	Communicating with friends
5	Preparing and eating meals	10	Doing laundry

Table A2: Pains and Gains for Pet Care and Laundry

Pet Care		Laundry	
Gains	Pains	Gains	Pains
Happy pets	Takes up time	Clean clothes	There is not enough machines
Companions	Messy	Organization	Poor maintenance
Keeps pets engaged	Your pets could hurt others	Hygiene	Takes time
Healthy Pets	Being away from pets		Pay for detergent

Appendix B: Problem Definition

Table B1. User experience chart for college students who own pets

User Experience Rating	Cleaning up after pets	Feeding pets	Playing with pets	Caring for pet health	Purchasing food for pets	Transporting pets	Protecting furniture from pets	Training pets
++			X					X
+								
0		X						
-				X	X		X	
--	X					X		

Appendix C: Research Plan

Table C1. Research plan

No	Research Question	Qualitative Data Collection	Quantitative Data Collection
1	What is the average number of pets per household?		Online article presenting statistics on pet ownership [2]
2	What types of pets are the most common?		Online article presenting statistics on pet ownership [2]
3	What are pet owners' experiences with cleaning up after their pets?	Preliminary survey question 4	Preliminary survey question 3
4	What are pet owners' experiences with feeding their pets?	Preliminary survey question 6	Preliminary survey question 5
5	What are pet owners' experiences with transporting their pets?	Preliminary survey question 8	Preliminary survey question 7
6	What are pet owners' experiences with training their pets?	Preliminary survey question 10 Online article with advice on pet training [3]	Preliminary survey question 9
7	What other difficulties do pet owners face?	Preliminary survey question 11	
8	How much do people spend on pet health care?		Online article presenting statistics about pet owners' spending on their pets [4]
9	How much money is spent on various pet care expenses?		Online article presenting statistics about the pet industry [5]
10	How much money do people		Online article presenting

	spend on pet training?		the costs of dog training [6]
11	How popular have pets become?		Online article about pet ownership and insurance statistics [1]
12	How many animals are in shelters?		Online article about animal shelters [7]
13	How much money do pet owners spend on pet toys?		Online article with pet industry statistics overview [8]
14	What tools do pet owners use to clean up after their pets?	Online article presenting strategies to clean up after dog messes [9]	
15	What are some supplies pet owners need or want?	Online article presenting cat toys and supplies [10].	

Appendix D: Preliminary Survey

The survey is available at

<https://docs.google.com/forms/d/1msf4Yzq5C03ka6Kc0sQOZ9cD9F2a4vh8uYzQ1Pt2Hb4>

Questions included on the survey: an initial consent: “Please indicate if you consent to your responses being recorded and published anonymously here. Please do not include personally identifying information in your response.”

1. Do you have a pet or pets? (Yes/no)
2. If yes, what kind of pet or pets do you own and how many? (short answer)
3. Rate your experience cleaning up after your pet(s) (5 point negative to positive scale)
4. What difficulties have you experienced cleaning up after your pet(s)? (short answer)
5. Rate your experience feeding your pet(s). (5 point negative to positive scale)
6. What difficulties have you experienced feeding your pet(s)? (short answer)
7. Rate your experience transporting your pet(s). (5 point negative to positive scale)
8. What difficulties have you experienced transporting your pet(s)? (short answer)
9. Rate your experience training your pet(s). (5 point negative to positive scale)
10. What difficulties have you experienced training your pet(s)? (short answer)
11. Are there any other difficulties you have experienced with pet care? (short answer)

Table D1. Preliminary survey average user scores

	Cleaning Up	Feeding	Transporting	Training
Cat owners (1 or more cats)	3.08	3.08	3.79	3.17
Dog owners (1 or more dogs)	2.64	4.43	3.89	3.36
Overall (any number of any pets)	2.90	4.42	3.77	3.25

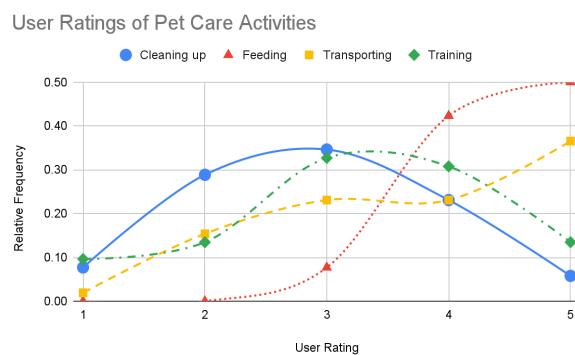


Figure D1. User ratings of pet care activities

Table D2. Activity rating survey responses¹

ID	Dogs	Cats	Other	2)	3) 4)	5)	6)	7)	8)	9)	10)	11)
3	1	0	0	DOG	4 Dirty dirty boy gets muddy a LOT with thick fur	5 We like food in this household	5 Dog tongue out of the window go flop	4 Good boy knows many tricks, but if too excited will be unresponsive	No			
4	0	0	1	1 bird (cockatiel)	2 Birds poop around every 15 minutes so it can be quite a hassle to clean up for everything.	4 Not too much. You just have to provide food daily.	2 The bird is scared of the transportation box.	2 Requires a lot of patience.	Keeping the cage clean/			
5	3	1	0	3 dogs And 1 cat	4	5 Separating dogs to make sure they eat their food and the right amount	5 None	4 Some rescues are harder to train				
6	0	0	1	A goldfish	3 Cleaning the bowl and maintaining the cleanliness	4 No difficulties	5 No difficulties	4 No training	No			
8	1	1	0	1 Cat, 1 Dog (black lab mix), 2 crested eyelash geckos, one ferret	3 Stinky	5 None, besides remembering	4 Dog and cat are very loud	4 Amount of time it takes	So. much. Hair balls.			
9	0	1	0	Cats	5 They scratch me	5 Nothing	5 Nothing	2 They cant be trained	No			
10	0	1	0	Cat and only one	4 The smell.	4 It is a routine, I usually forgot to do that.	3 Since I don't know how to drive, I have to ask others to drive for me.	2 It is very hard to train a cat.	When they sick, I will feel sad and I have to commit my time to take care of them since it I have to observe their activities			
11	0	6	0	6 cats	4 Its very tiring	5 So far so good	5 My cat is very behave in the car	3 My cat doesn't listen to my instruction	No			
12	0	1	0	Cat 1	3 Become aggressive and hurting myself	5 The cat become picky eater	2 Never try it	1 Never try it	The cat injured after getting into fight with other cat			
14					8 2 It is gross, but smells bad if I don't don't	5	4 They can get rowdy but are usually well behaved	4				

¹ Responses which did not have any pets, did not consent to their responses being recorded, or were not in English were removed.

15	1	0	0	1 Dog	3 They chew things and ruin them	5 None	5 None	4 They don't always pick up the training	No
16	1	0	0	1 Dog	3 Cleaning up after going to the bathroom	3 Cleaning up my dogs mess after he eats and drinks	2 Bathroom Breaks, growling to get our attention, smell of the dogs farts in the car	3 Time consuming, sometimes have to pay money for other people to train dogs	Zoomies, trying to relax around my dog
17	1	1	0	1 dog and 1 cat, 2 total	1 Cat urinating on my bed	5 None	5 None	3 N/a	
18	0	2	0	2 cats	2 Smell	4	3	5 They are cats	
19	0	1	0	1 cat	3 Don't like to touché their waste, even with gloves or a scooper	5 They eat too much	4 They are loud in cars	5 They do not like to listen	Nope
20	1	2	0	2 cats and 1 dog	1 I live at the top floor of an apartment building so getting the dog down is a pain. Also carrying cat litter is a pain.	4 Prefer to feed cats over dogs as cats can be fed less often (the don't eat it all in one go).	3 Don't transport them often	1 The Dog is untrainable other than potty training, even after taking him to a training school, the habits easily untrained even with reinforcement.	
21	1			One dog	3 it's messy and often not an easy task if they make a big mess	5 Their food can spill quick easily.	4 My dog does not like to sit still in the car. We have a special seatbelt for him so he can be safe and not disturb us	4 It's hard to communicate exactly what you want them to do without being repetitive or frustrated.	Not really
22	2			I have 2 dogs	2 They sometimes destroy pillows and it can be very tedious to clean up	4 Other than the occasional small appetite, i have rarely had issues with feeding my pets.	5 none	3 They learn commands well and are usually very calm but sometimes they get too excited and it's hard to get them to sit still.	not really no
24		3		3 cats	2 Smelly	5	5	2	Hard to understand what they want
25	1			Dog	2	4	3	4	
26	1			1 Dog	4 Forgetting to bring poop bags, having to hold poop bag, poop bag tearing :(5 Kibble spills	4 My dog falls out of seat from braking. She jumped/fell out of my car window from sticking her head out (we were going very slow)	4 She only listens if she feels like it	Bathing/cleaning her is difficult

27	4			4 dogs	1	It's not fun	3	When they're puppies, they can be a little food aggressive	3	They get hair in the car	4	Can be a long process	No
28	0	0	1	One chinchilla	3	Chinchillas have extremely fine, wispy fur that floats through the air and gathers on random nearby possessions, including my bookshelves and tabletop miniatures collection. If we had an air purifier, it would probably get clogged with fur wisps. Also she's supposed to use the litterbox in the corner of her cage but sometimes she doesn't.	4	None, she is happy to eat the same thing every day: bagged pellets and dry timothy hay. The hay does get stuck in the vacuum, sometimes.	2	She is FAST and HATES being in small confined spaces so I have to use her dust bath as an "elevator" to move her around since it's the only thing she will always get inside willingly.	3	Chinchillas are not really trainable except for litterbox use. At least mine isn't.	Chinchillas are rodents with powerful teeth and they will nibble/consume everything within reach. I have to make sure things are chinchilla-safe before putting them on/in/near the cage, and she's doing slow but steady damage to the cage liners (hard plastic) and the running wheel (painted metal). Also, not every vet is qualified to care for a chinchilla patient; dogs and cats can be seen basically anywhere.
29		1		One Cat	2	Their s*** stinks like hell and we have to spend quite a lot of money on litter sand	4	Their food is expensive and my cat is a pretty picky eater so it's hard to switch to other brands of food	1	Cats are scared of everything so they don't like to move around a lot	1	Cats generally do whatever they want and don't listen to you	Cats hair falls everywhere and sometimes causes allergies
31	3	2		3 dogs and 2 cats	3		5		5		5		
32	1	1		A cat and a dog	1	My dog is still just a puppy and he is having trouble being potty trained. Once you clean up his pee on the wood floor, he pees again, even after taking him outside!	4	My dog hates eating medicine	4	My cat is afraid of cat rides, but we rarely have to take him anywhere besides the vet like once every few years, so it's not a big deal.	1	The dog just doesn't want to be trained... :/	In my family, it's an issue of time. Not having enough time to properly train the dog. He ends up about half-way trained and still pees on the floor...
33		4		4 cats	4	Nothing	5	Nothing	5	Nothing	3	Cats are difficult to train	No

34		10	Cats/>10	4 Some of them might not enjoy being cleaned hence acting a little aggressive	5 -	5 -	4 Sometimes it takes longer than expected	None
35		1	1 Cat	3 None	3 None	2 He scream for he uncomfy	3 It's a cat	No
36		1	One cat	2 I don't like cat poop	4 He's cute when he's hungry but kinda annoying when he wakes me up at 5am for food	4 He looks cute in the carrier but he doesn't like cars and sometimes screams about it	5 He doesn't always like to listen	His insurance doesn't cover yearly wellness checkups
37		1	Cat	5 To make sure their fur is completely dry	4 Sometimes when it come the time they need to eat, they are not at home. So, their feeding time is vary	2 No, difficulties.. all is well	3 It takes a lot of time to train them, sometimes I do not have time to train them because of classes	I have difficulties to know if my cat is sick..so I need to be alert more if they show any weird things
40		5	Cats, 5 of them	2 Laziness because we have to be doing it consistently as daily routines ahahaha	5 No difficulties as it is the best part of having a pet	2 They tend to get aggressive while in vehicles	4 They are quite reluctant to be trained but it's still fun nevertheless	
41		2	rabbit , 2	4 none	4 none	3 my pet don't want to enter the carrier	4 none	Only the part where i have to throw out their poops/faeces
42		2	1 cat and 2 dogs	4 The feces	4 My pet is fat, it wanted to eat frequently	4 He likes to lay on bed	2 Didn't listen to me	yeah , when i need to bath them
43		7	7 cats	3 They litter everywhere	4 Only choose expensive kibbles	5	2	I'm a muslim so we keep our dogs outside
44		2	cat , 2	5 They are not easy to be cleaned, always act like they are super scared when it comes to grooming	5 Finding the right wet food for my cats	5 None	5 They require a lot of time to be trained, but eventually can be trained	their furs keep falling and stick to clothes
45	1	2	1 dog and 2 cats	2 Cleaning the litter box when having 2 cats gets hard bc if you don't do it everyday it stinks	4 Not very many except my one cat always spills his food and my dog eats it	2 All of my pets hate the car rides and it's always a pain	4 getting them to focus	Not that i can think of
46	2		2 dogs	2 Shedding	4 Overfeeding	5 None	3 Getting then to respond	No
47	1		1 dog	4 It smells.	5 None	5 It smells.	5 He is 13 years old.	He will runaway sometimes.

48	2			2 dogs	2	Dealing with messes, smells, or staining on carpet/surfaces.	5	Normally there is no difficulty, but if I'm not home it's difficult to make sure they are fed enough or making sure someone else is able to feed them.	5	None, mine are usually good in the car/going places.	3	Just going through the training process & figuring out what works for the dogs. House/potty training is usually the most difficult.	
49	1			A dog, 1	2	Scrubbing floors	3	Not difficult just not fun	3	My dog like to squirm when being carried	3	Dog is a slow learner so it takes a sec to teach	No
50	3			I own 3 dogs. A husky and two shih tzu.	4	The dificilt part is the smell obviously it stinks but it's normal.	5	None, my dog enjoy their dru dog food with chicken or meat.	5	None the two shih tzu are angel and behave well. The husky is a bit difficult.	4	It was hard since they obey my mom abs my mom doesn't like to train.	Walking all of them.
51	1			1 dog	3	Carpet stains, lingering odors, etc	4	Adjusting pets to new diet requirements	3	Facing my pets anxiety	2	Accidents in the house/cleaning up after them	
52					3	Cleaning a litter box is not ideal	5	none	5	none	3	It takes a lot of reinforcement	no
53	1			Dog 1	2	Picking up the poop	4	The mess my dog makes after eating	3	He runs everywhere and makes me fall a lot	3	He doesn't want to listen and will do whatever he wants	My dog likes to bite
54	2			1 2 dogs, lizard	3	It is a tedious job and sometimes can be more difficult than other times	5	None	4	They take up a lot of room in my car	3	They are stubborn	Shedding on my clothes
55	1			one male pitbull	4	not having a bag	5	he won't eat	4	sometimes he barks in the car	3	he's very stubborn and does not learn easily	he's too cute for his own goof
56	1			One dog	3	grossed out if they throw up inside	5		4	carsick the first time in car	4	Took a long time	
57	1			I own a Maltipoo dog. Just one dog.	2	Finding the correct cleaning product to pick it up. Also the directions for most cleaning products take over a day which is not convenient.	5	Not too many difficulties but I would like there to be more variety since my dog starts to dislike eating the same thing over and over again.	3	My dog gets nervous driving in cars and I even try to put my dog into a seatbelt, which doesn't work out too well and isn't comfortable. I'm always afraid for my dog if I were to get into an accident; would she be able to survive it?	1	Maltipoo breeds are known to be very anxious and our dog seems to have many behavioral problems so training her has been a nightmare. We have considered hiring someone to train her but we found it too expensive. She is on anxiety medication and she is	With this particular breed, I only wish training was more accessible.

										unbearable without it.	
58	1		1 Dog	3	Loose Stool	4	Accommodating my dog's sensitive GI tract	3	Anxiety about riding in cars	3	Noncompliance without food
59		2	2 cats, 2 rats	3	cleaning a litter box is hard on my back, I had a spinal fusion.	4		4		3	
60	2		2 dogs	3	My dogs are still puppies so they're still learning to be house trained	4	One of my dogs jumps on me before dinner time but it's kinda cute.	3	One of my dogs gets car sick	5	Each of them responds better or worse to certain commands

Appendix E: User Need Survey

The survey is available at

<https://docs.google.com/forms/d/1-CalurayVzMRCFD3QIGrRAG-0t-pXnzsyWRw2C3LfE/edit>

Questions included on the survey: an initial consent: “Please indicate if you consent to your responses being recorded and published anonymously here.” Users are asked not to include personally identifying or sensitive information in their responses.

- 1) Number of cats owned (1-10+)
- 2) Number of dogs owned (1-10+)
- 3) Any other pets owned (short answer)
- 4) Do you currently live with your pets? (Yes/no)
- 5) Easy to use (1-5)
- 6) Low-cost (1-5)
- 7) Reliable (1-5)
- 8) Helpful (1-5)
- 9) Fast (1-5)
- 10) Pet safe (1-5)
- 11) Users rate six existing products, indicating which of the above needs they fill. Products include: Litter boxes, pet hair brushes, nail trimmers, poop bags, vacuum cleaners, and furniture coverings.
- 12) Users are asked what product they use the most when cleaning up after their pets. Options include the six above or an “other” option.
- 13) “What pet cleaning product do you feel needs improvement and why?” (Free response)
- 14) “What challenges do you have cleaning up after your pets?” (Free response)

Any responses that did not consent to being recorded were removed.

Two responses were removed as they were not serious responses - one claimed to own 13 monkeys and another included a rant about how vacuum cleaners were unable to pick up rhinoceros feces.

Responses that indicated they did not own pets were excluded from any comparisons or statistics.

Table E1. Average user rankings of various needs

Easy	Low Cost	Reliable	Helpful	Fast	Pet Safe
4.68	3.98	4.79	4.82	4.20	4.96

Table E2. Average user rankings of various existing products

	Litter boxes	Pet hair brush	Nail trimmer	Poop bags	Vacuum cleaners	Furniture coverings
Easy	24	30	14	25	28	6
Helpful	20	34	24	27	31	16
Low cost	18	29	12	28	13	7
Reliable	27	28	20	25	32	11
Fast	7	17	5	16	26	3
Pet safe	17	26	18	18	18	14

Table E3. Pet cleaning product survey results

ID	Cats	Dogs	Other Pets	Lives with Pets	Easy (E)	Low-cost (L)	Reliable (R)	Helpful (H)	Fast (F)	Pet-Safe (S)	Litter Boxes	Pet Hair Brush	Nail Trimmers	Poop Bags	Vacuum Cleaner	Furniture Covering	Most Used	What pet cleaning product do you feel needs improvement and why?	What challenges do you have cleaning up after your pets?
4	9		9, cats	Yes	5	4	5	5	5	5	E	H	DNU	DNU	DNU	DNU	Litter box		
5	0	0	Fish	No	5	5	5	5	5	5	E, L, R	DNU	DNU	DNU	L, H, F	L, R	Litter box	Litter box, make it easier to clean and not smelly	They don't use the things we provide them
7	1			Yes	5	5	5	5	5	5	R, H, F	DNU	DNU	H, F	DNU	DNU	Litter box	Litter box because it cost a lot	Bad smell
8	2	0		Yes	5	2	5	3	5	5	R	L	R	H	L	L	Poop bags	pet disinfectant	do nit sit at one place
9	0	0	Mantoy	No	5	4	5	5	3	5	L, R	E	DNU	R	S	S	Litter box	I'd say litter box since it's definitely a hassle for the pet owner to clean up their pet's poop as it requires a lot of patience and indeed they are hoping for more reliable and efficient type pf products for them to rely on.	Bad odour and thorough cleaning of the litter box
13	0	1		No	5	5	5	5	5	5	DNU	E, L, R, H, F, S	L, R, H	L, H, F	E, R, H, F, S	DNU	Poop bags	Nail trimmers. My dog hates her feet being touched	Poop pags are annoying to get out and pick up the poop. Bags tear sometimes
14	0	1		No	5	3	5	5	4	5	DNU	E, R, H, S	E, H, S	E, L, R	R, F	R, S	Poop bags	Poop bags. They'd can be flimsy and rip easily.	It's messy poop is gross
15	0	1	1 Fish	No	3	4	5	5	3	5	DNU	R, H	R, H	E, L	R	H	Poop bags	Brushes bc I have a schnoodle and he get mats and most brushes aren't made to detangle	My nails break through the poop bag :(
16	1	0		Yes	5	3	5	5	2	5	R, H, S	E, L, R, H, S	R, H, S	H, S	R, F, S	DNU	Litter box	Litter boxes because they stink up the whole house and the good ones are expensive	Consistency in remembering to do it every week

17	0	1		Yes	5	5	4	5	4	5	DNU	E, L, R, H	DNU	E, L, R, H, F, S	R, H, S	DNU	Poop bags	Fur brushes because they are too rough	None
18	1	0		Yes	3	4	3	5	5	5	E, L	E, L, R, H, F, S	R, H	E, L	E, R, H, F	R, H, S	Furniture coverings		
19	0	0	1 hamster	Yes	4	3	4	5	3	5	DNU	E, L, R, H, S	E, R, H, F, S	DNU	DNU	DNU	new bedding		
20	0	1		No	5	2	5	4	5	5	DNU	E, L, H	L, R, H	E, L, R, H, F, S	E, R, H, F	DNU	Poop bags	Nail trimmers. Just a bad experience all around. No one is having a good time but it needs done.	Finding things that are safe but also quick to use.
21	3	1	2 Fish, 1 snail	Yes	5	5	5	5	5	5	E, R, F, S	E, L, R, H, F, S	DNU	DNU	E, R, H	DNU	Litter box	Honestly I think the letterbox should be bigger, with 3 cats sometimes the poop overflows and then the dog tries to eat it. I dont like when the dog eats it.	My dog loves the taste of cat poop so it sometimes cleans the litter box for me
22	2	0		Yes	5	5	5	5	5	5	H	F	S	DNU	L	R	Litter box	vacuum cleaner	clean vacuum cleaner
23	1	0		No	4	3	3	4	5	5	E, L, R, H	H	H	L, H	R, H	H	Litter box	Nail trimmers and litter box	Scooping the litter is time consuming and a hassle when I am crunched for time
24	2	0		Yes	5	4	5	5	3	5	E, R, S	L, R, H, S	E, R, S	E, L, R	E, L	DNU	Litter box	Nail trimmers can sometimes be difficult to use, especially with cats!	Little boxes often stink and sometimes it's impossible to keep up with the accumulation of cat hair.
25	2	2		Yes	5	5	5	5	5	5	E, L, R	DNU	L, R, S	L	E, L, R, H, F	E, L, R, H, S	Vacuum cleaner	Vacuums. They don't pick up the hair enough they need to be able to suction them fast and accurately.	All of the fur
26	2	1		Yes	4	4	5	4	5	5	L, R, S	L, R, F, S	E, L, R, S	E, L, R, H, F	L, R, F	DNU	Vacuum cleaner	Nail trimmers	None
27	2	2		Yes	4	4	5	5	4	5	E, L,	E, H	H	E, L,	E, R,	H	Vacuum	scent neutralizers	scent problems

										R, H			R, H	H		cleaner	don't really work so that should be improved	
28	0	0	No	3	4	4	4	4	5	DNU	DNU	DNU	DNU	DNU	DNU		A pet vacuum cleaner to pick up pet hair all over the house/furniture	Pet hair on furniture and all over the house
29	1	0	Yes	5	4	5	5	4	5	E, L, R, H, F, S	E, L, R, H, F, S	DNU	DNU	E, L, R, H, F, S	E, L, R, H, F, S	Litter box		
30	1	1	Yes	4	3	5	5	4	5	E, L, H, S	L, H, F, S	S	E, L, R, H, F	E, R, H, F	DNU	Litter box	Poop bags, usually not environmentally friendly	Dealing with the smell
31	1	1	none	Yes	5	5	5	5	3	E, R, H, S	E, L, R, H, F, S	L, R, H, S	R, H	E, R, H, S	DNU	Vacuum cleaner	nail trimmers, my dog is always scared of them and hates getting her nails clipped so i wish there was a way to clip her nails without her being stressed	her hair is hard to clean up all of the time, the vacuum doesn't always get all of her hair and her hair is EVERYWHERE
32	0	1	No	5	4	5	5	5	5	DNU	E, S	DNU	E, L, R, H, F, S	E, L, R, H, F, S		Poop bags	Poop bag, need a way to pick it up without reaching down and grabbing it with only the bag.	If she owes in the carpet it is a little hard to clean
33	1	3	No	5	5	4	3	4	5	L, R, F, S			E, L, H, F, S	R, H, F	E, R, H, F	Poop bags	Dog bowls because the food falls out right away	My dog biting me or jumping on me
35	0	1	1 snake	Yes	5	5	5	5	3	DNU	E, L, F	H	E, L, H, S	E, R, H	DNU	Poop bags	Nail trimmers - I feel like they all hurt my dog	None
36	3	3	No	4	3	5	5	3	5	L, R, S	H, S	S	L, R	H, F	DNU	Poop bags	Litter boxes, there has to be a way to reduce the smell	
37	10	0	Yes	5	5	5	5	5	5	E	H	DNU	DNU	DNU	DNU	Litter box	I think everything is fine , but for me i think the automatic litter box is really helpful but quite expensive , so yeah. Maybe , anyone could design a cheaper	I found that it was really challenging for me to dry my pet's fur after bathing them

																	one :) because i really loves cats but it is hard for me to always clean up the litter box while online learning. Thank youuuu, just that for now.		
38	0	3	No	5	3	4	5	3	5	DNU	E, L, R, H, F, S	E, L, R, H, F, S	E, R, S	E, R, H, F, S	DNU	carpet cleaner for accidents	dog hair trimmers because they're always too big for some areas on my dog	none	
39	0	2	No	5	5	5	5	5	5	DNU	E, L, R, H, F, S	DNU	E, L, R, H, F, S	E, H, F	DNU	Poop bags	Vacuum	Hair everywhere	
40	10	0	None	Yes	5	3	5	5	5	E, L, R, S	E, L, H, S	DNU	DNU	DNU	Litter box				
41	0	2	Yes	5	3	4	5	5	3	DNU	E, L, R, H, F, S	R, H	E, L, R, H, F, S	E, F, S	H, S	Vacuum cleaner	Vacuums bc they don't always pick everything up	Stains don't come out	
42																			
43	0	0	5 goldfish	Yes	5	5	5	5	5	E, L, R, H	E, L, R, H	E, L, R, H	E, L, R, H	H	Furniture coverings	Fish	They're too damn loud		
45	0	2	2 fish	Yes	4	4	5	5	3	5	DNU	E, L, H, S	L	E, R, F, S	E, R, H, F	S	Vacuum cleaner	nail trimmers because they can hurt your dog	the mess is there again in another 10 min
46	0	1		Yes	5	3	5	5	3	5	DNU	E, L, R, H, F, S	DNU	E, L, R, F, S	R, H, F, S	DNU	Vacuum cleaner	Vacuum cleaner. They almost never capture all the hair!	Making sure to capture all of the pieces of torn up toys!
47	2	3	No	5	4	4	4	5	5	F	H	F	H, DNU	F	S	Litter box			
48	0	1		Yes	4	3	4	5	3	5	DNU	E, L, R, H, S	L, H, S	L, R, H, F, S	E, R, H, S	E, R, S	Vacuum cleaner	Pet brushes, takes a long time to use	Feel like there's a mess shortly after cleaning
49	0	1	2 fish	No	5	3	5	5	4	5	DNU	R, H, S	E, R, H, S	R, S	E, R, H, S	H, S	Vacuum cleaner	Sprays for floor stains	Some stains are impossible to get out
50	2	1		Yes	4	3	5	5	4	5	E, R	L, H	E, H, S	L, H	E, R, H	DNU	Litter box	Litter that doesn't smell	The smell of the litter

51	1	0		Yes	5	5	5	5	5	5	E, L, R, H				E, L, R, H		Vacuum cleaner			
52	1	0	1 cat	No	4	3	5	5	3	5	E, R, H, S	E, L, R, H, F, S	E, L, R, H, S	E, L, R, H, F, S	E, R, H, F, S	DNU	Litter box	Nail trimmers can be difficult to use when pets squirm	Time	
53	1	2		Yes	5	3	5	5	4	5	H	R	R	E	R	H	Litter box			
54	10	0		Yes	5	3	5	5	4	5	E, H	E, H	DNU	E, R, H	E, F	DNU	Poop bags	Vacuum cleaner. Maybe should create special vacuum for fur that can clean all the fur and automatic sanitize system. It is because to make it easy to clean up the fur that fall and sanitize the house at the area the cats play	To take them for the shower	
55	1	1		Yes	5	5	5	5	5	5	R	R	DNU	DNU	F	H, DNU	Vacuum cleaner	N/A	It smells:/	
56	10	10	Dogs	Yes	5	5	5	5	5	5	E, L, R, H, F, S, DNU	Poop bags								
58	2	0	-	Yes	5	5	5	5	5	5	E	S	H	E	L	S	Poop bags	-	-	
59	0	1		Yes	4	4	5	4	2	5	DNU	E, L, R, F, S	E, H, S	L, R, H, S	E, R, H, F	DNU	Carpet cleaner or windex	Resolve carpet cleaner, too reliant on other Resolve products and barely works without them making it too much of a hassle	It's gross and it's too often and very complicated to use	
60	10	6		No	5	5	5	5	4	5	H	DNU	H, DNU	H	H	H	Litter box			
61	10	0	-	Yes	4	4	5	5	3	5	E, R, H, S	E, R	DNU	DNU	DNU	R, H, S	Litter box	The design of the litter box for low-cost design.	Their poop always went out from the litter box	
62	10		Fish 9	Yes	5	5	5	5	5	5	R	R	E	L	L	L	Litter box	Litter box. To make sure cats poop in the area only	Time	

63	0	2	NA	Yes	5	3	5	5	5	5	DNU	E, L, R, H, F, S	E, R, H, F, S	E, L, R	E, R, H, F, S	DNU	Vacuum cleaner	Vacuum cleaners should all have removable/easy to clean rubber in the revolving pick up brush! It would pick up more hair and be easy to clean.	Vacuums can never pick up all the hair or will push it around on hard surfaces.
64	2	0	1 Rabbit	Yes	5	5	5	5	5	5	E, L, R, H, F, S	DNU	DNU	E, L, R, H, F, S	DNU	Litter box	Litter box for more efficient cleaning	Poop	
65	9	0	None	Yes	5	4	5	5	5	5	E, L, R, H, S	E, L, R, H	H, S	S	R, H	Litter box	Furniture Covering	too many cats sharing the litter box and litter box need to be checked regularly	
66	6	0	Fish	Yes	5	4	5	5	4	5	E, R, H, S	E, L, R, H	DNU	DNU	E, S	E, L, S	Vacuum cleaner	Furniture covering because the one I bought is small and have to buy many to cover the furniture. And it's hard to cover the furniture with the cover.	Products easily broken and does not last long.
67	1	0		Yes	5	5	5	5	5	5	L, H, S	E, L	DNU	DNU	E, R, H, F, S	DNU	Litter box		

Appendix F: End User Needs and Market Character

Molly Thompson



Cat in a harness being held by a pink human in Auderghem, Belgium by Benoit Brummer is licensed under CC 4.0.

Age: 20
Gender: Female
Occupation: Student
Marriage status: Single
Major: Biology Pre-med
Credit hours: 16

Goals:

- To do better in school
- Take better care of her cat

Personality:

- Introverted
- Hardworking
- Analytical
- Even-Tempered
- Private

Bio:
Molly Thompson is a biology major attending OSU. She is currently in her junior year of college, and she is planning to go into the pre-med program. Molly spends a lot of her time doing homework and attending class. She finds it hard sometimes to take care of her cat and keep up with her busy schedule.

Fig. F1. Fictional user profile. Using a photo from [11].

Table F1. End user needs

User Need	Description	Score (1-5)
Easy	Easy to use and understand. Does not require significant technical expertise.	4
Low-cost	Does not cost too much for the user.	2
Reliable	Has a low failure rate and will not require significant maintenance.	3
Helpful	Assists in their pet care needs.	4
Fast	Frees up user's time instead of demanding more of it.	5
Pet-safe	Does not harm or distress the user's pet.	5

Table F2. Pairwise comparison of user needs

	Easy	Low-Cost	Reliable	Helpful	Fast	Pet-Safe	Total	Normalized	Original
Easy	1	1	0	1	0	3	3.0	4	
Low-Cost	0	1	0	0	1	0	1	1.0	2
Reliable	0	1	1	0	1	0	2	2.0	3
Helpful	1	1	1	1	1	0	4	4.0	4
Fast	0	0	0	0	1	0	0	-	5
Pet-Safe	1	1	1	1	1	1	5	5.0	5

Table F3. Available pet cleaning alternatives

User need	Litter box	Pet hair brush	Nail trimmers	Fecal waste bags	Vacuum cleaner	Furniture coverings
Easy		X		X	X	
Low-cost		X	X	X		
Reliable	X			X		X
Helpful	X	X	X	X	X	X
Fast					X	
Pet-safe	X	X	X	X	X	X

Table F4. Stakeholder needs

Need	Owner	Pet	Neighbors	Retailers
Privacy	X		X	
Noise	X	X	X	
Convenience	X			
Packaging	X			X
Pet-safety	X	X		

Appendix G: Brainstorming Concept Sketches

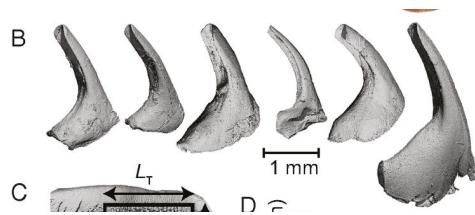
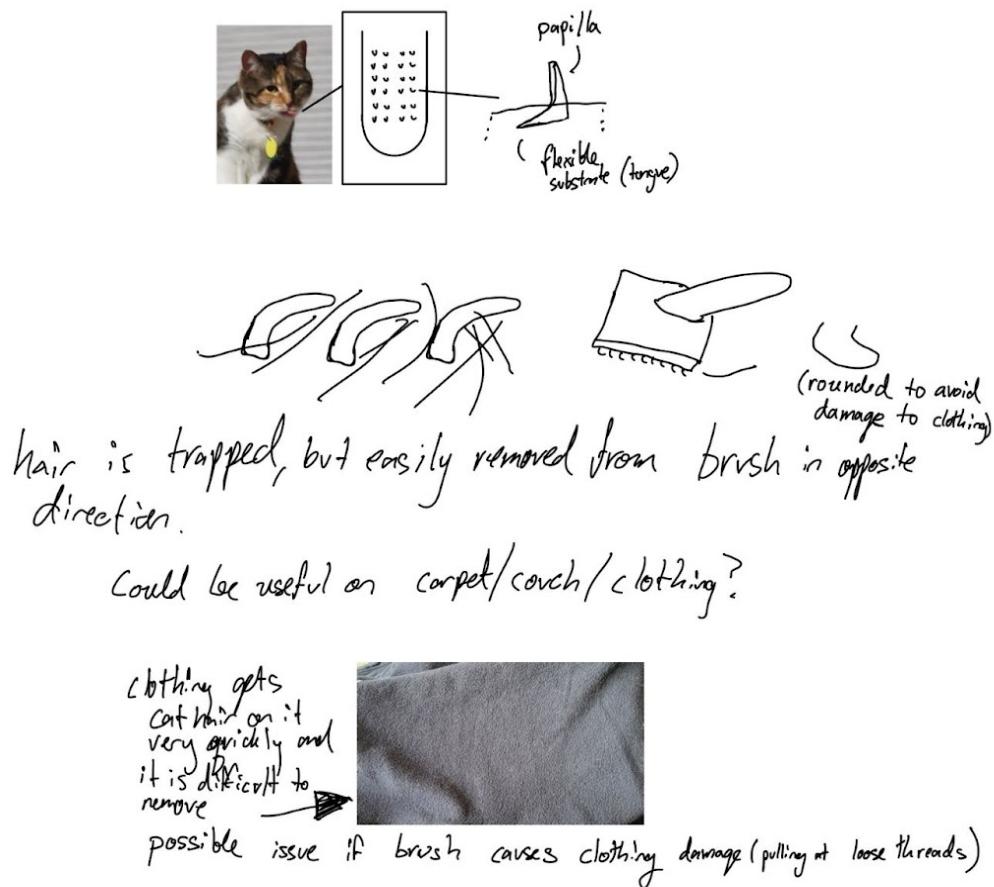


Figure G1. Papillae of various feline species (from [2]).



Ranga Rutiser Sundar
14 Feb. 2022

Figure G2: Brush using simulated papillae (Ranga Rutiser Sundar)

PET HAIR GLOVES

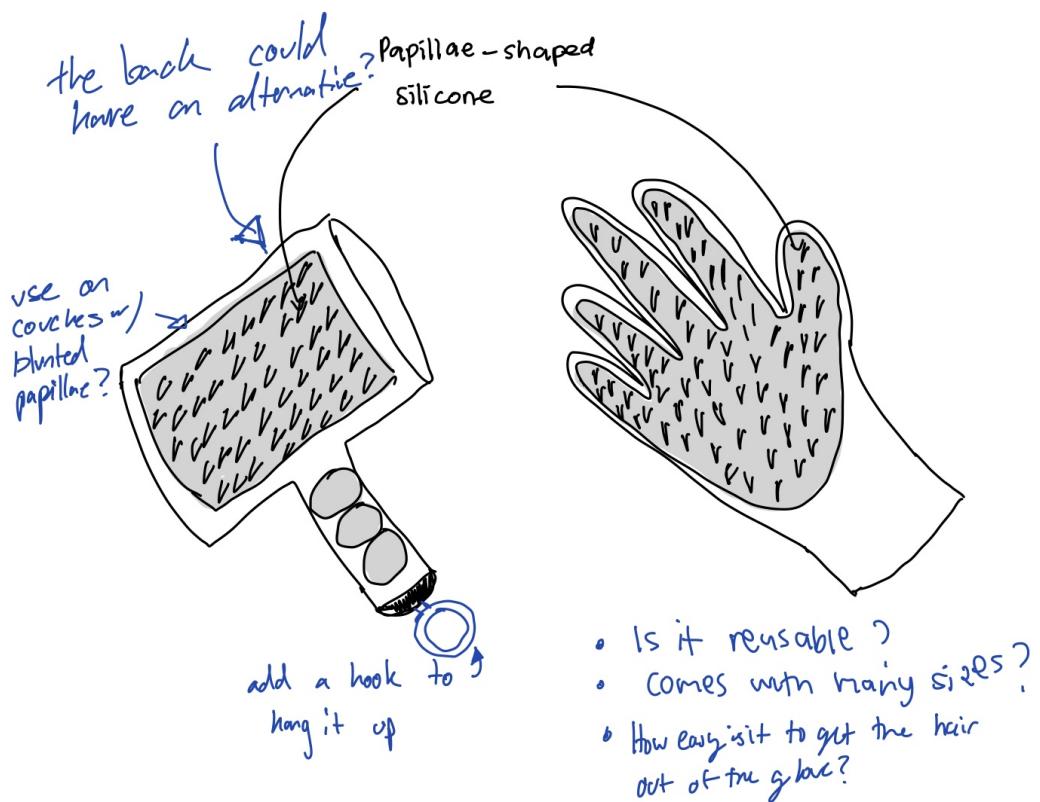


Figure G3: Pet grooming gloves using simulated papillae (Dan Haikal)

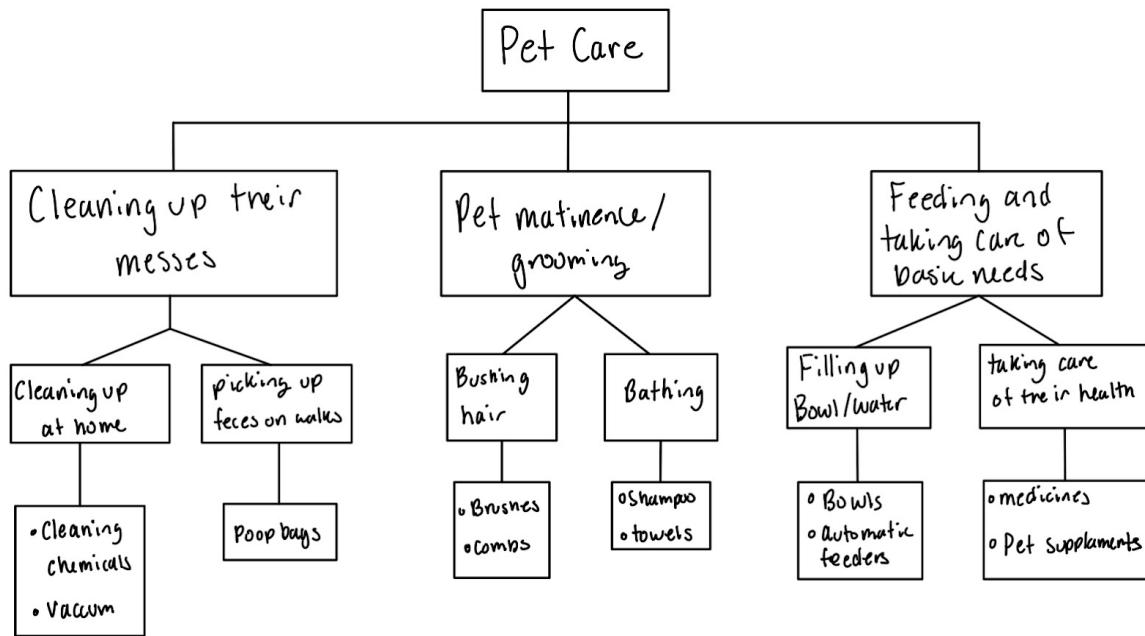


Figure G4: Concept chart (Angelina Barone)

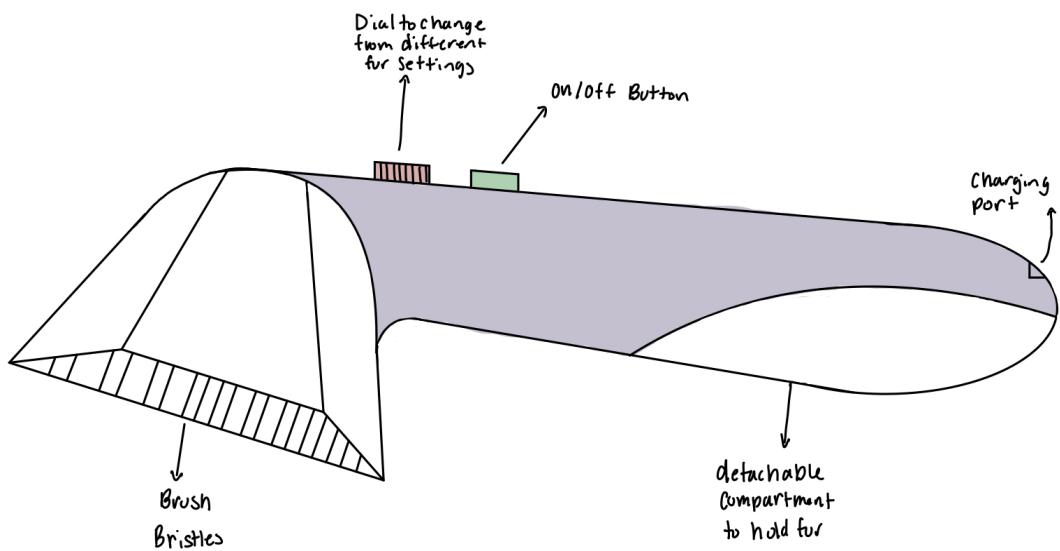


Figure G5: Brush design concept 2 (Angelina Barone)

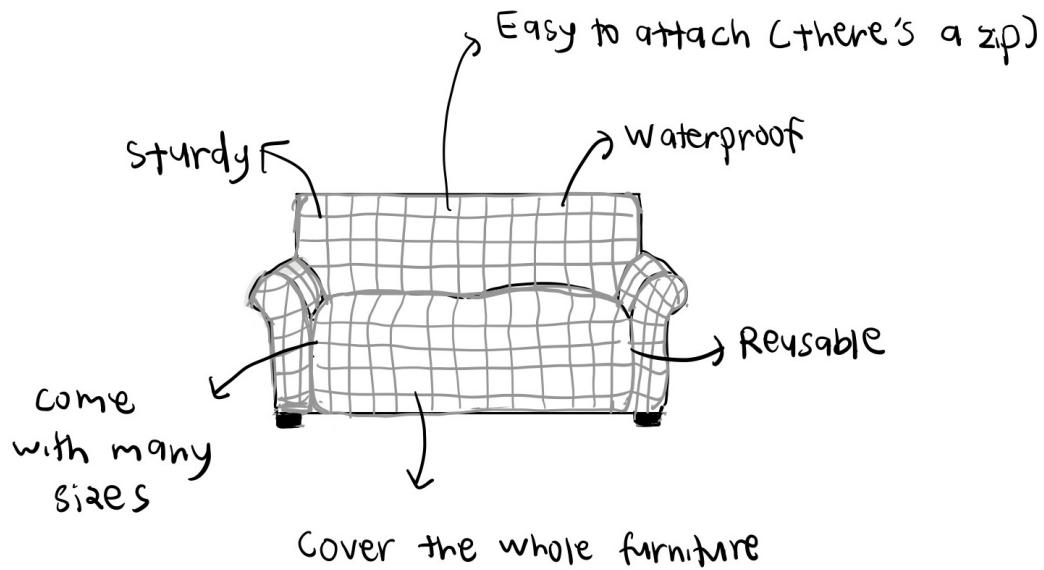


Figure G6: Furniture covering (Mira Faizul)

Pet hairbrush with swiveling handle like some razors could allow better coverage of pet contours

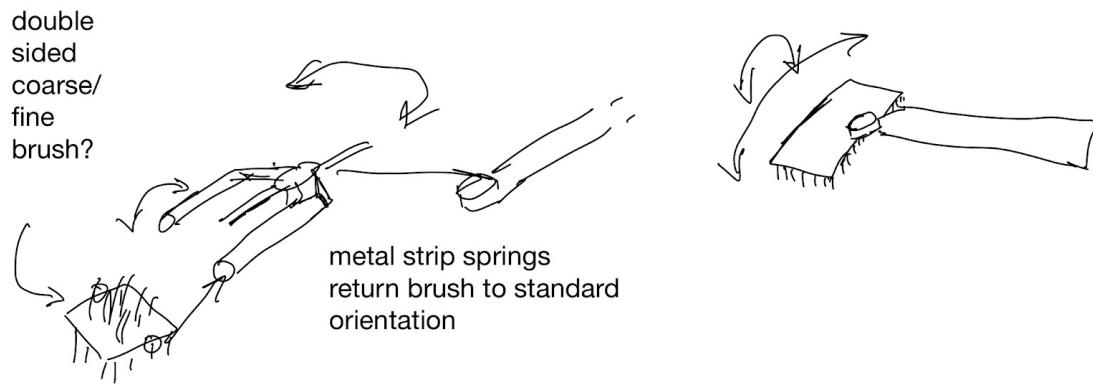
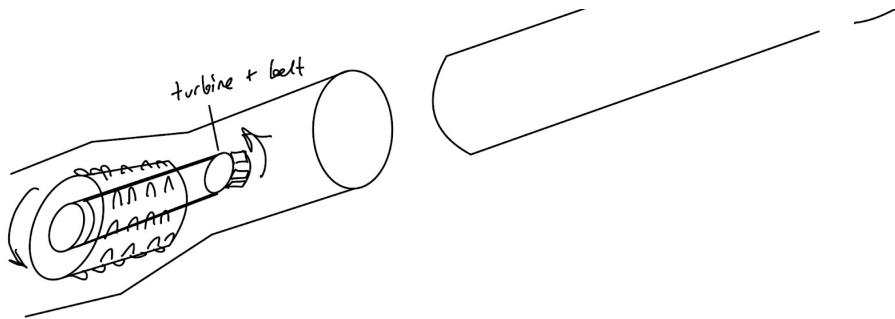


Figure G7: Swivel pet hairbrush (Group)



Vacuum attachment for cleaning up pet hair?

- could clog less than normal
- try to catch pet hair and put it in a bag at the attachment?

Figure G8: Pet hair vacuum attachment (Group)

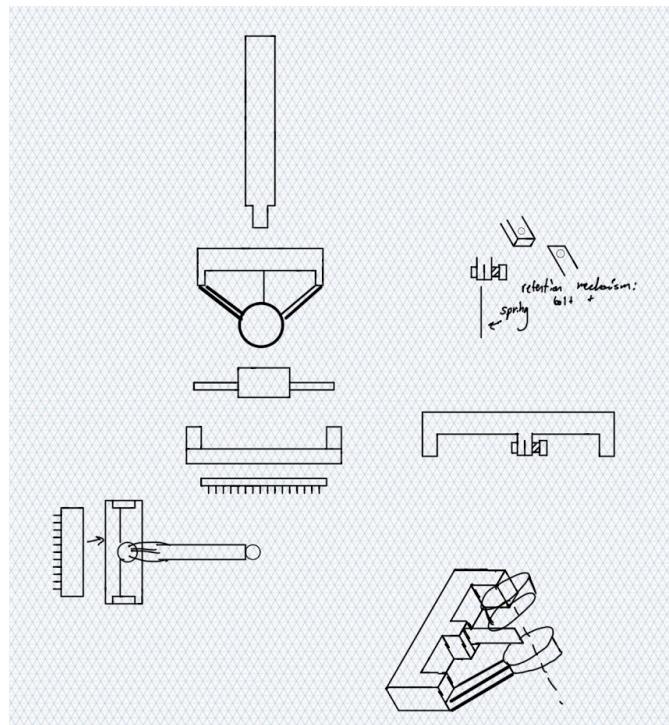


Figure G9: Prototyping plan drawing (parts)

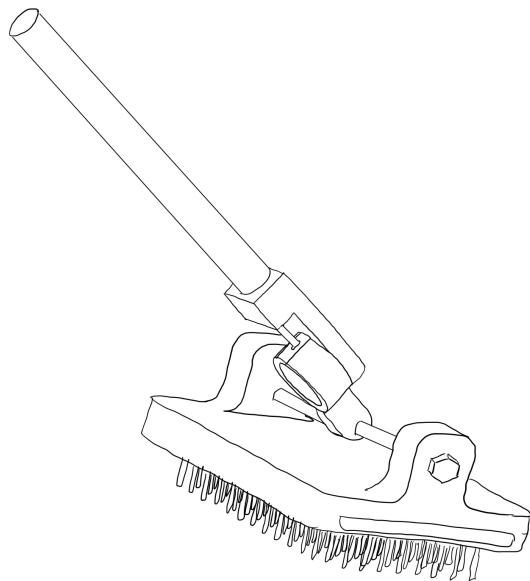


Figure G10: Prototyping plan drawing (whole assembly)

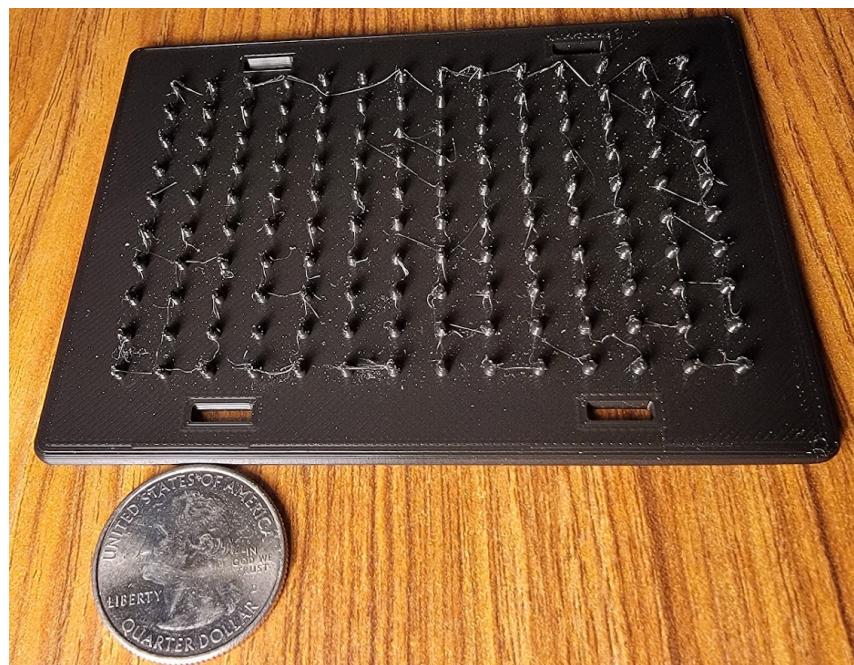


Figure G11: Preliminary bristle part

Appendix H: Pugh Scoring Matrix

Table H1. Pugh scoring matrix

Need	Weight (1-5)	Reference		Swiveling Brush		Glove Brush	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Pet-safe	4.96	3	14.88	4.5	22.32	4.5	22.32
Fast	4.2	4.2	17.64	3.8	15.96	4.4	18.48
Affordable	3.98	4	15.92	4.2	16.72	3.5	13.93
Helpful	4.82	4.5	21.69	3.5	16.87	4.2	20.24
Reliable	4.79	4	19.16	4	19.16	3.5	16.77
Easy to use	4.68	3.5	16.38	4.3	20.12	4	18.72
TOTAL			105.67		111.15		110.46

Appendix I: Grand Concept

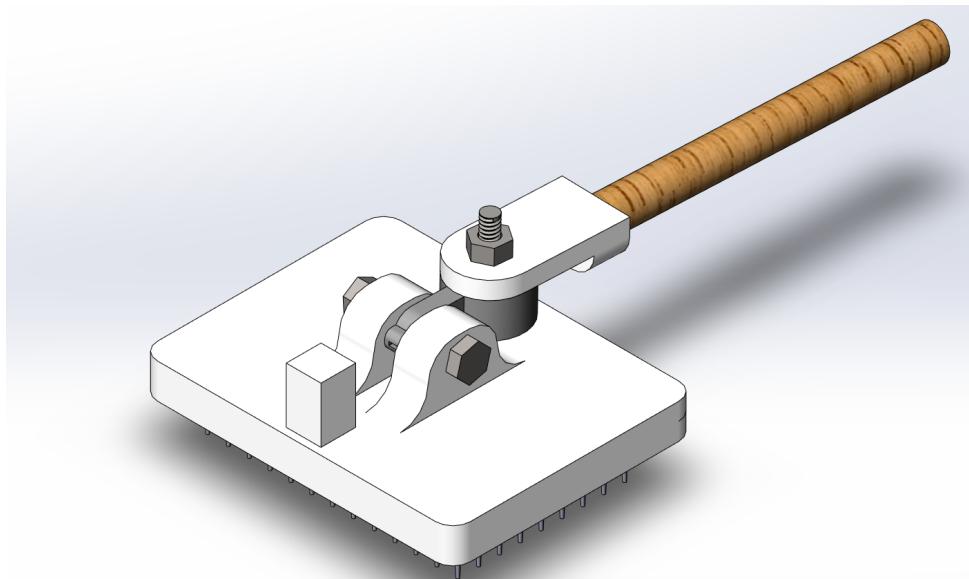


Figure I1. Brush initial concept model (Note: two metal springs are excluded from this model and bristles are not final.)

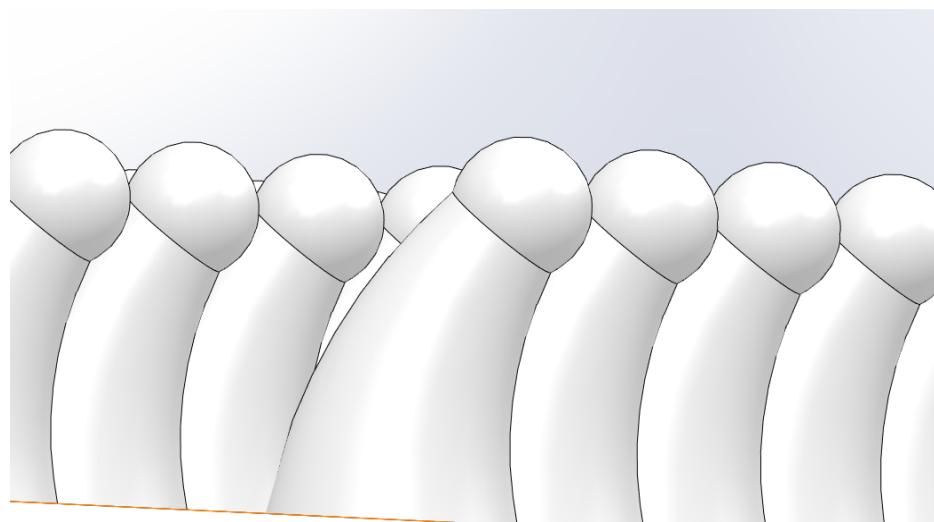


Figure I2. Redesigned bristles

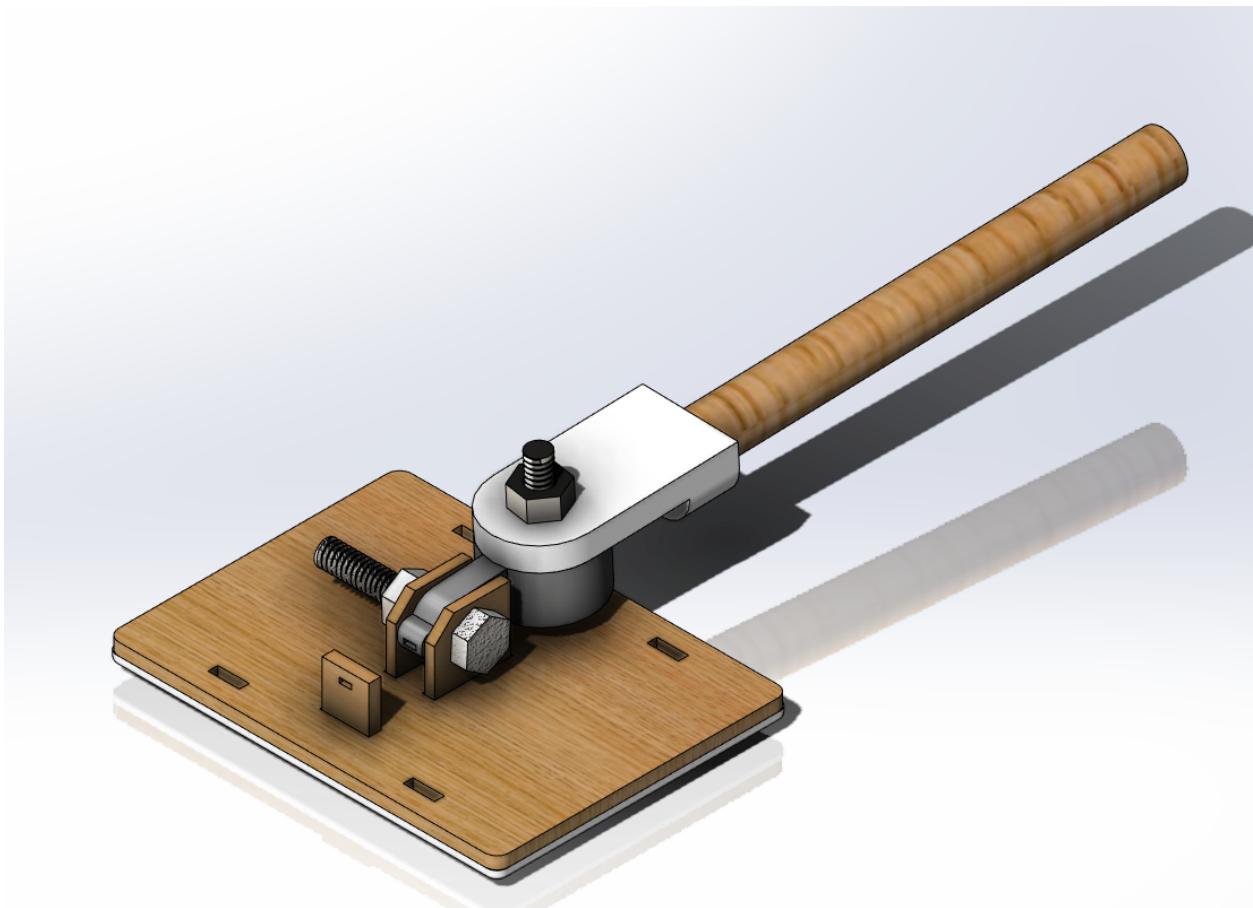


Figure I3: Redesigned backplate

Appendix J: Project Management Schedule

Table J1: Project Management Schedule using Gantt Chart

			Project Start Date	Project End Date	Today's Date
			3/22/22	5/2/22	4/21/22
Task Name/ Description	Approximate work time	Assigned member(s)	Start Date	End Date	Completion percentage
Finish the prototype (P20)	10 hours	Ranga Rutiser Sundar, Angelina Barone	3/22/22	3/30/22	100%
Test prototype (P21)	4 hours	Ranga Rutiser Sundar, Mira Faizul, Angelina Barone	3/28/22	4/4/22	100%
Conduct research to improve prototype (P22)	5 hours	Angelina Barone, Dan Haikal	3/31/22	4/7/22	100%
Improve or modify prototype (P23)	5 hours	Ranga Rutiser Sundar, Angelina Barone	3/28/22	4/14/22	100%
Finalized the prototype (P24)	4 hours	All members	4/4/22	4/21/22	95%
Showcase the prototype (P25)	2 hours	All members	4/21/22	4/21/22	0%

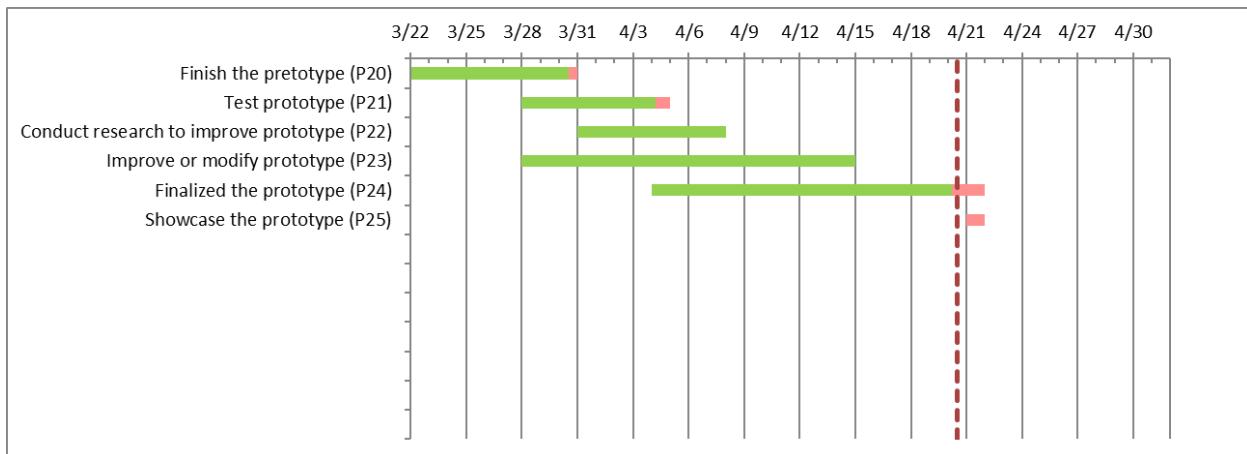


Figure J1: Gantt chart

Appendix K: Working Drawing Packet

Original CAD files are available on the GitHub repository [16].

Drawing A1: Pet Brush Assembly

Drawing A2: Exploded Assembly

Drawing 1: Hinge Linkage

Drawing 2: Horizontal Pivot

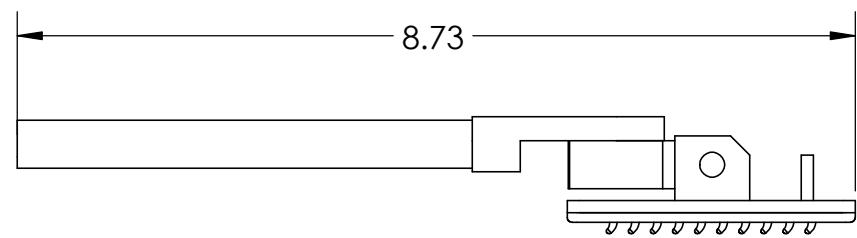
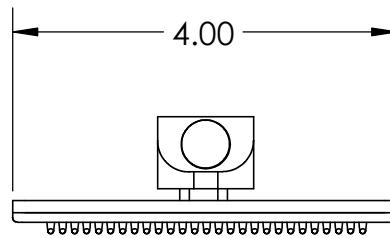
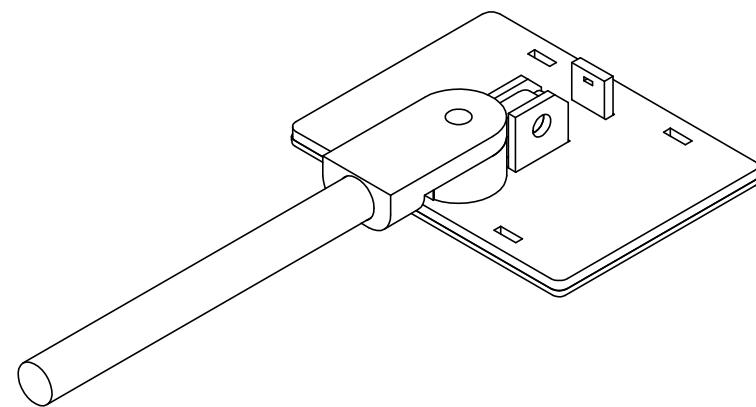
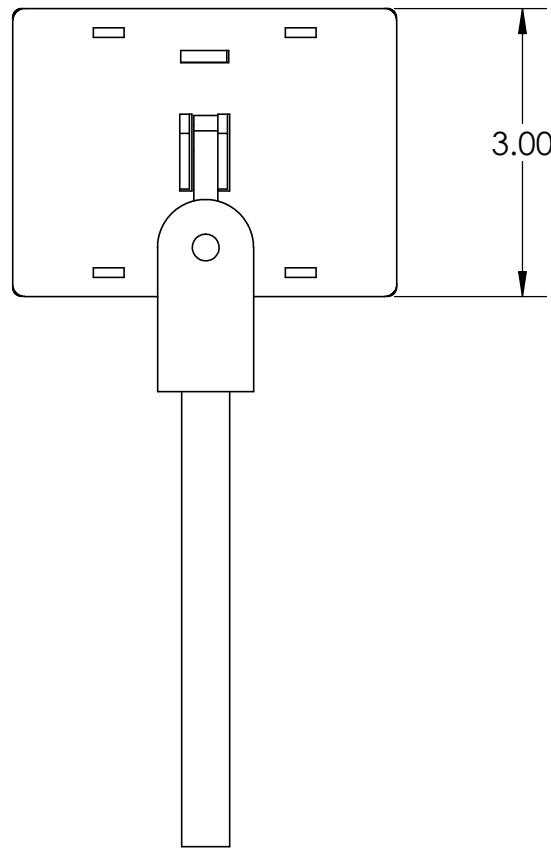
Drawing 3: Handle

Drawing 4: Bristle Backplate

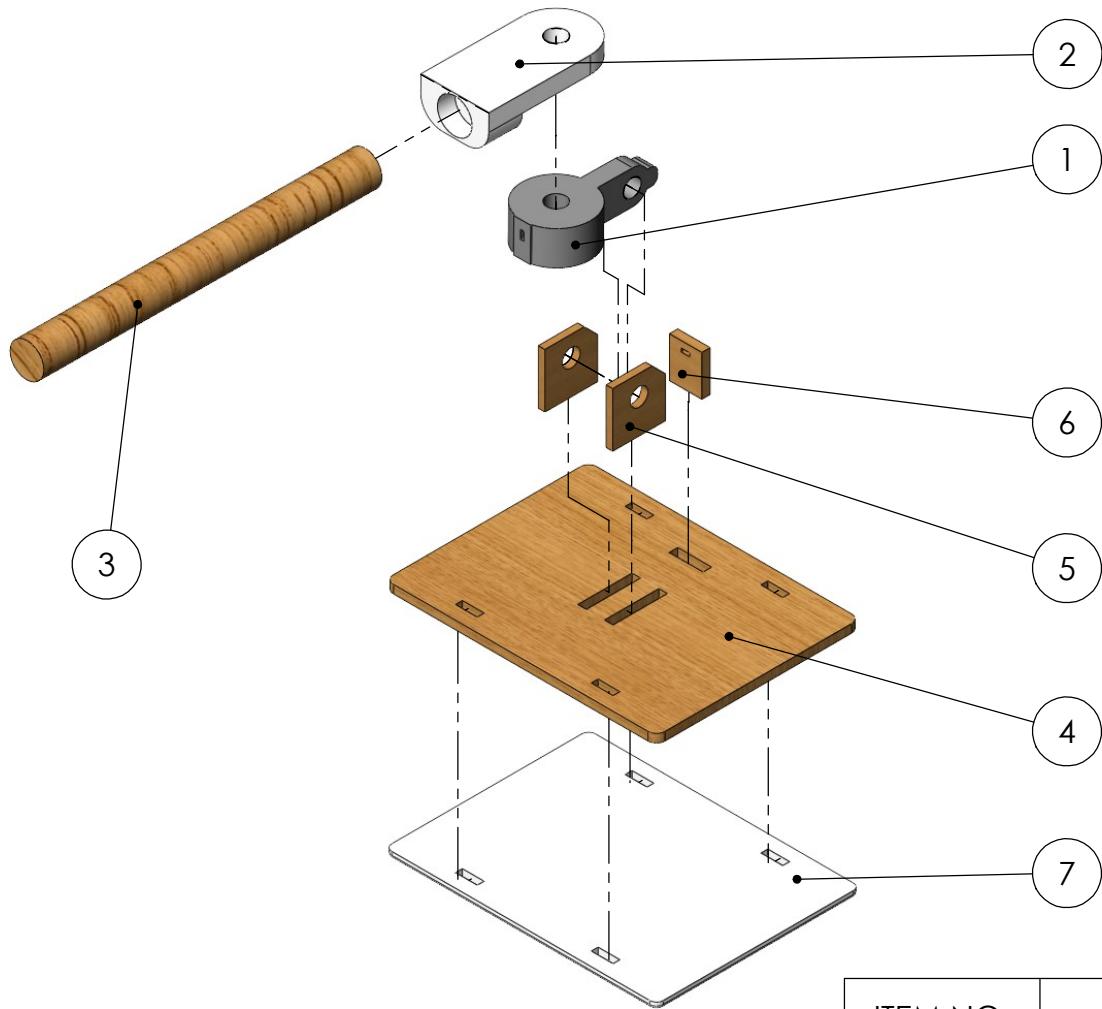
Drawing 5: Vertical Support

Drawing 6: Spring Holder

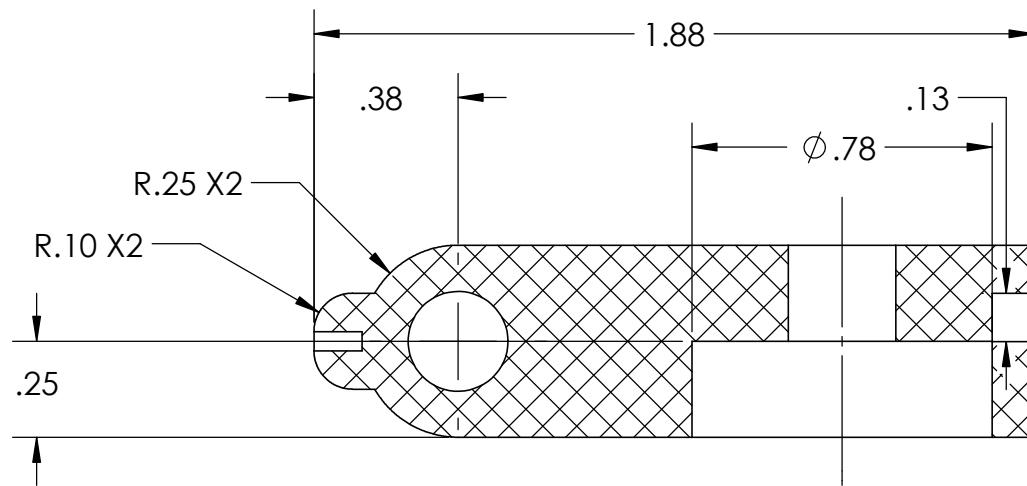
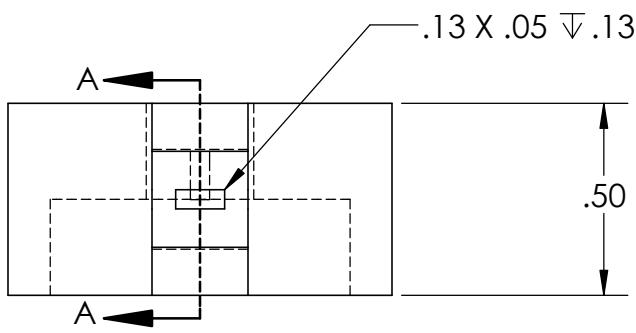
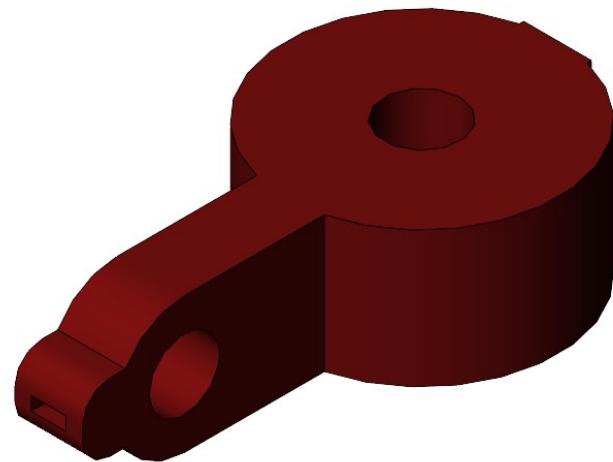
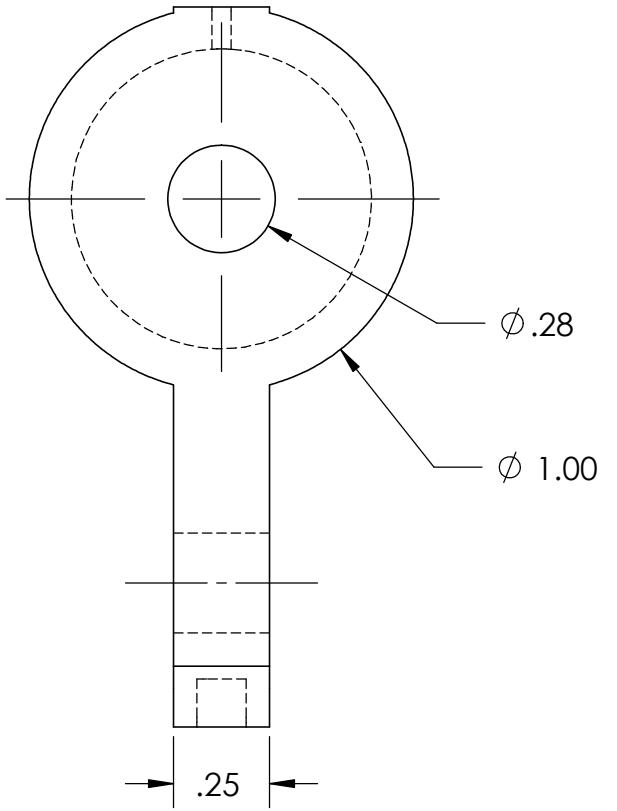
Drawing 7: Bristles



The Ohio State University	Dwg. Title: Pet Brush Assembly	Scale: 1:2	Section: 26469	Units: IPS	Dwg. No.: A1
First Year Engineering	Drawn By: Ranga Rutiser Sundar	Mass: 0.21 lbs	Volume: 4.90 CU IN	Seat: 12	Date: 04/19/2022
SOLIDWORKS Educational Product. For Instructional Use Only.					

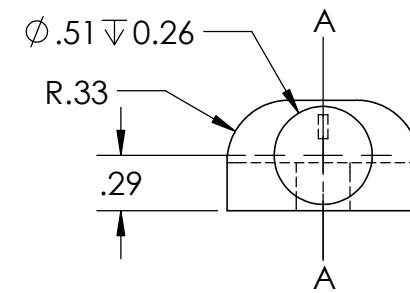
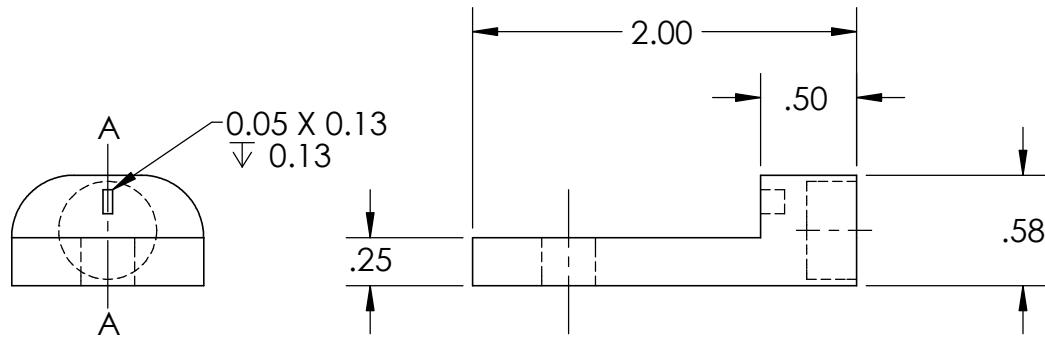
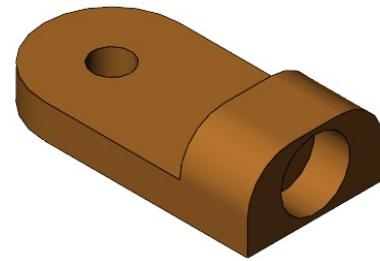
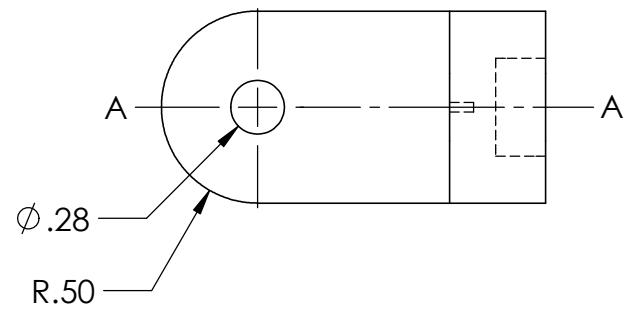


ITEM NO.	PART NUMBER	Materials	QTY.
1	Hinge linkage	ABS	1
2	Horizontal Pivot	ABS	1
3	Handle	Oak	1
4	Bristle backplate	ACRYLIC	1
5	Vertical support	ACRYLIC	2
6	Spring Holder	ACRYLIC	1
7	Bristles	ABS	1



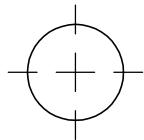
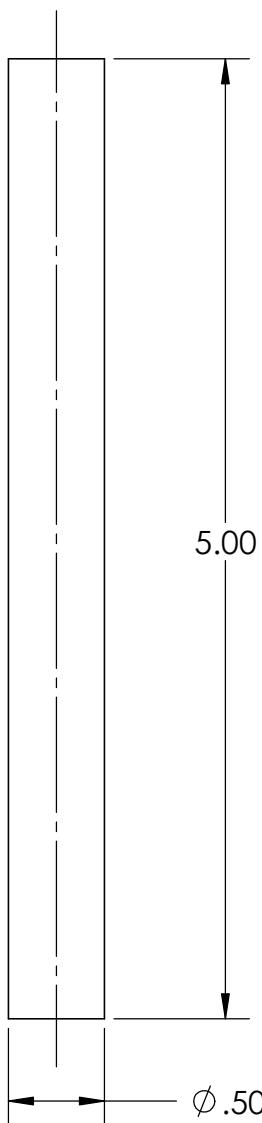
The part is symmetrical from left to right

SECTION A-A
SCALE 2 : 1

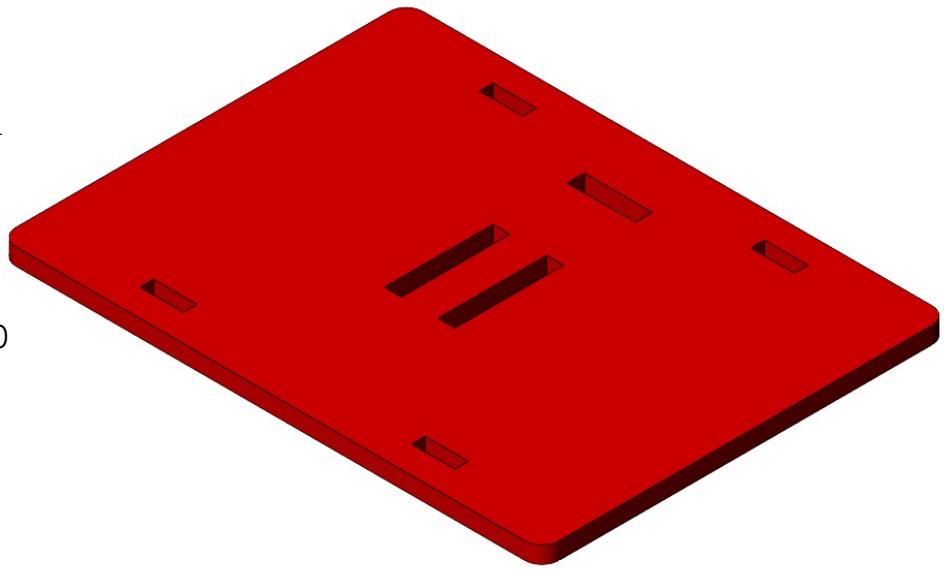
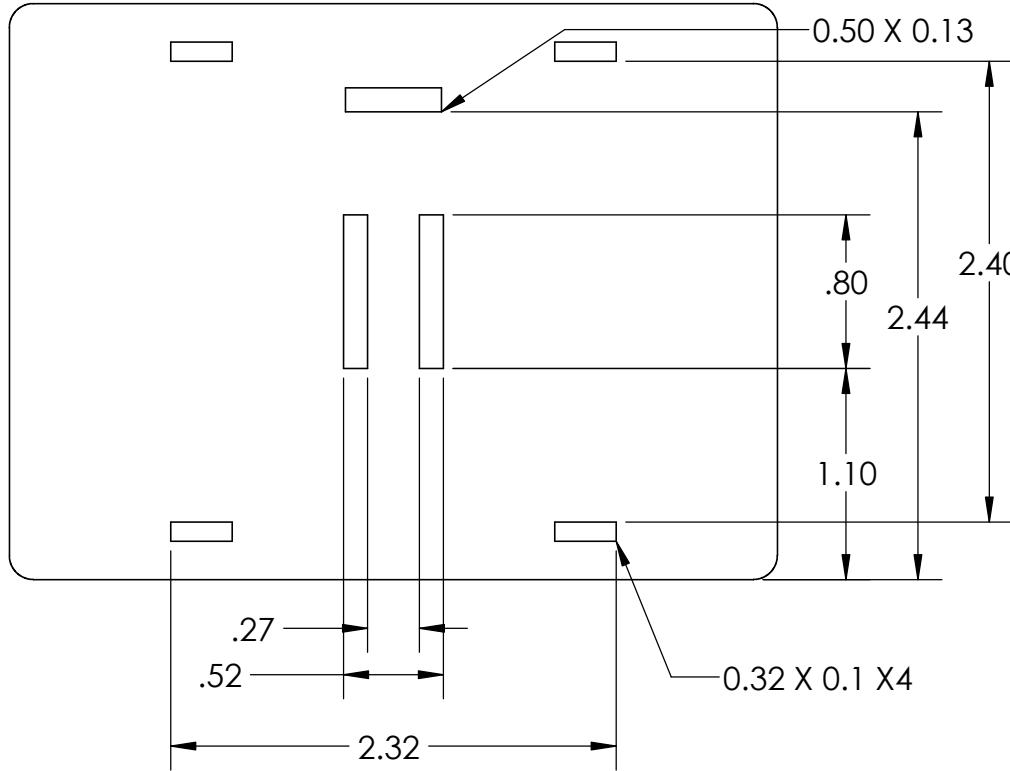


Part is symmetrical across Plane A-A

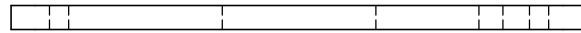
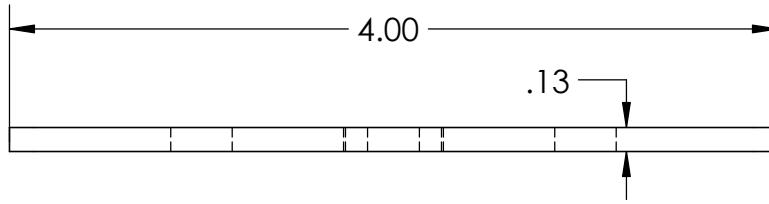
The Ohio State University First Year Engineering	Dwg. Title: Horizontal Pivot Drawn By: Ranga Rutiser Sundar SOLIDWORKS Educational Product. For Instructional Use Only.	Scale: 1:1 Mass: 0.02 lbs	Section: 26469 Volume: 0.54 cu in	Units: IPS Seat: 12	Dwg. No.: 02 Date: 04/19/2022
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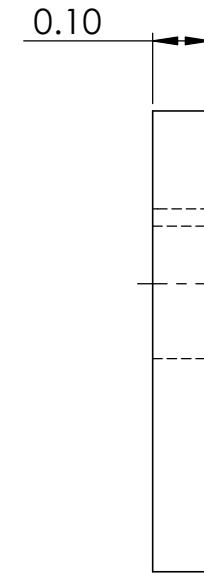
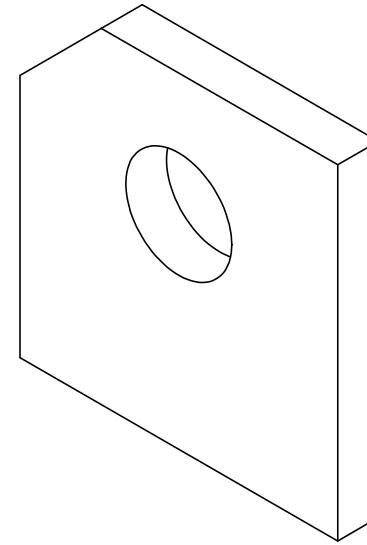
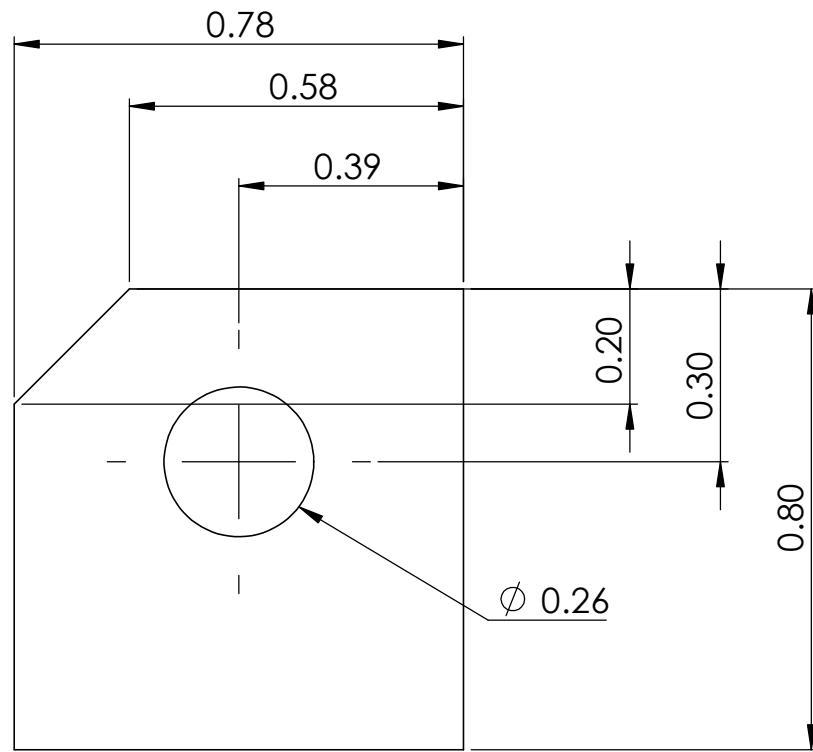
The Ohio State University First Year Engineering	Dwg. Title: Handle Drawn By: Ranga Rutiser Sundar SOLIDWORKS Educational Product. For Instructional Use Only.	Scale: 1:1 Mass: 0.02 lbs	Section: 26469 Volume: 0.98 cu in	Units: IPS Seat: 12	Dwg. No.: 03 Date: 4/19/22
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Unmarked fillets have radius R.13
Object is symmetrical from left to right

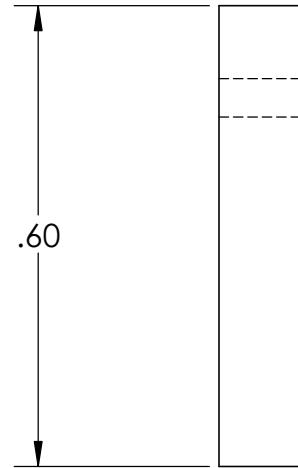
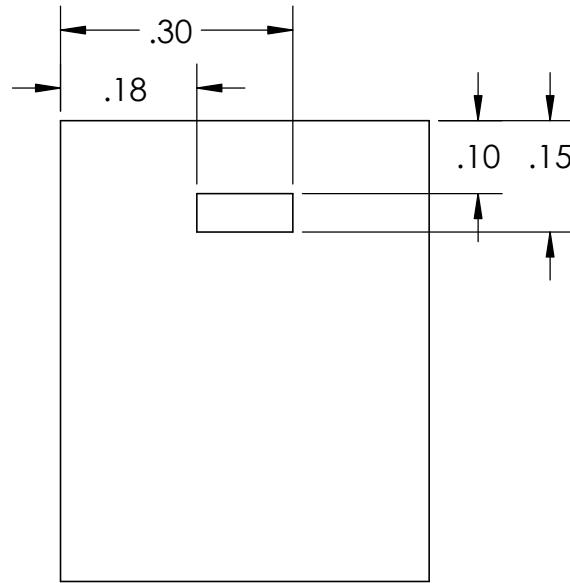
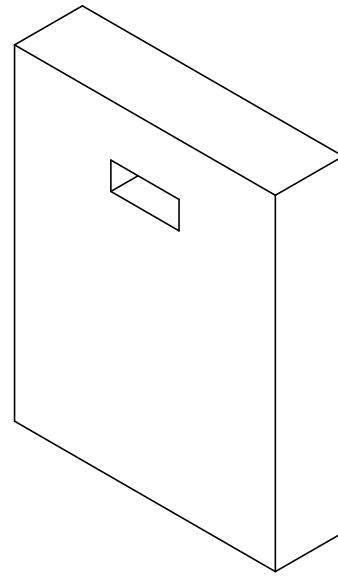
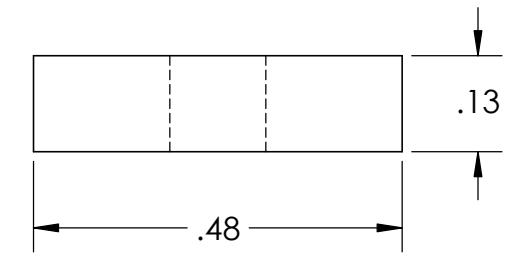


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SOLIDWORKS Educational Product. For Instructional Use Only.					

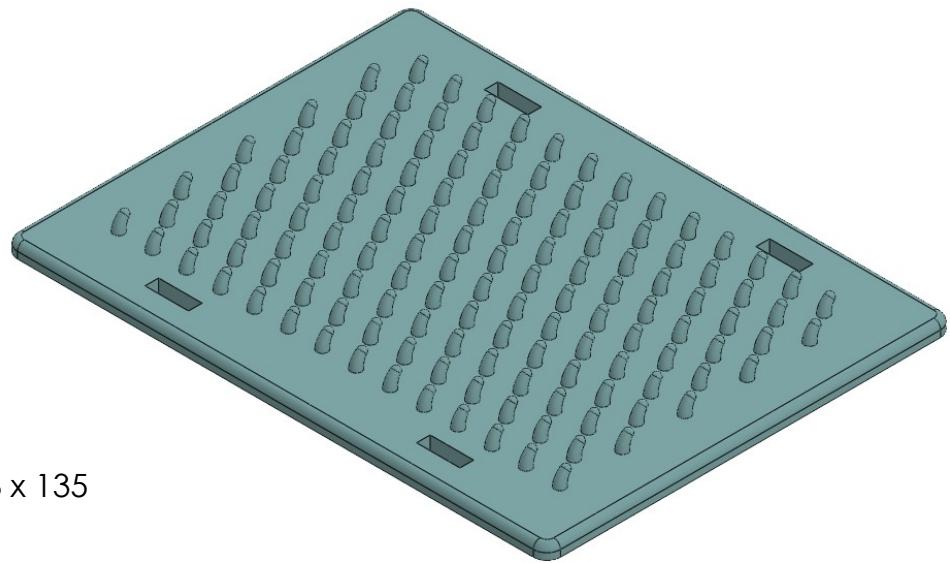
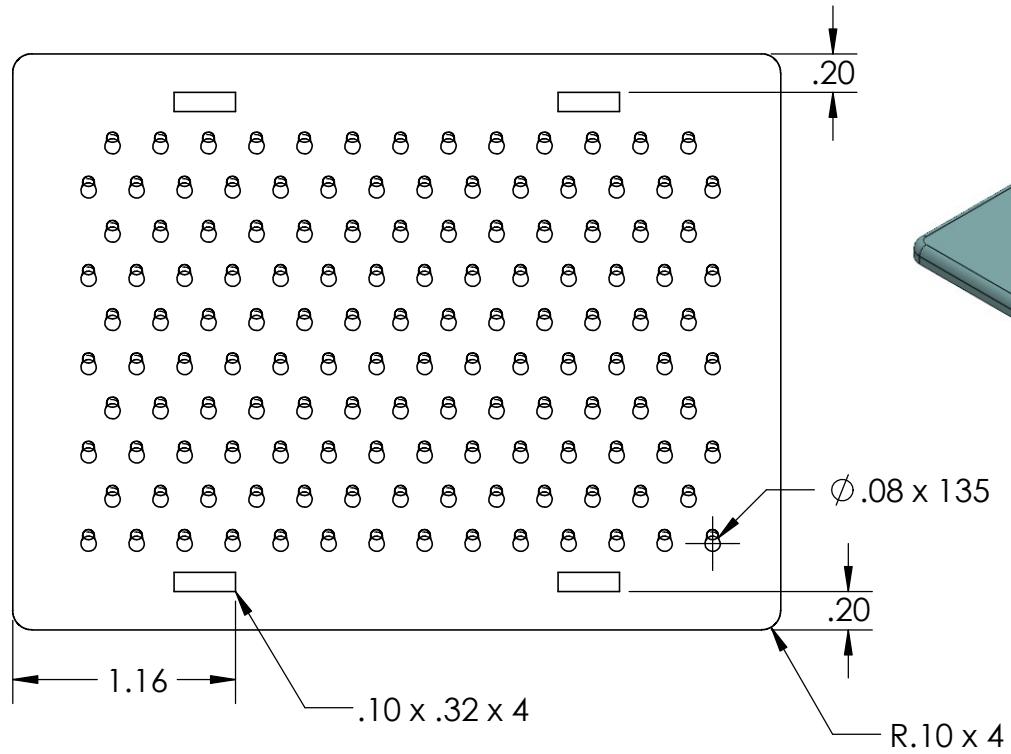


The part is symmetrical from front to back.

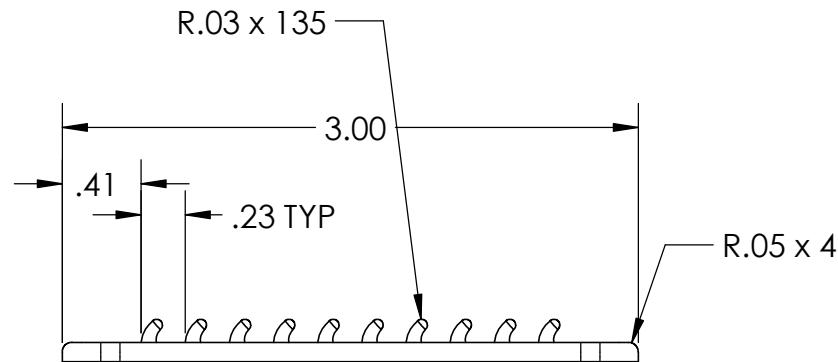
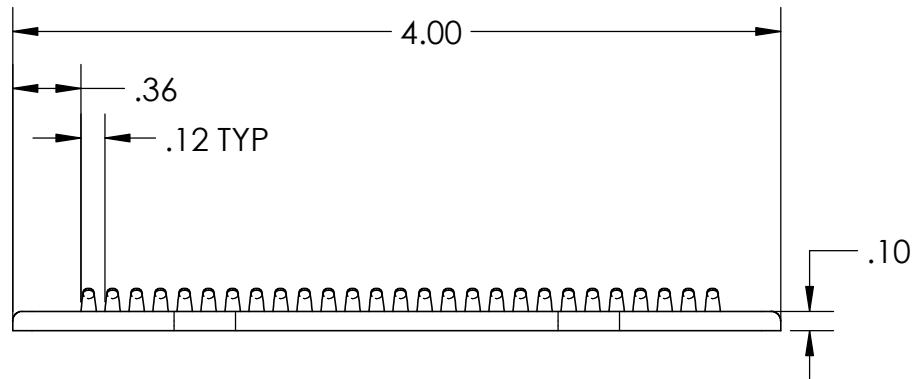
The Ohio State University First Year Engineering	Dwg. Title: Vertical Support Drawn By: Mira Faizul	Scale: 3:1 Mass: 0.0011 lbs	Section: 26469 Volume: 0.0551 cu in	Units: IPS Seat: C	Dwg. No.:5 Date: 4/19/22
SOLIDWORKS Educational Product. For Instructional Use Only.					



The Ohio State University First Year Engineering	Dwg. Title: Spring Holder Drawn By: Dan Haikal	Scale: 4:1 Mass: 0.0007 lbs	Section: 26469 Volume: 0.0352 cu in	Units: IPS Seat: C	Dwg. No.:6 Date: 4/19/22
SOLIDWORKS Educational Product. For Instructional Use Only.					



The object is symetrical from left to right
All bristles are uniform



The Ohio State University First Year Engineering	Dwg. Title: Bristles Drawn By: Angelina Barone	Scale: 1:1 Mass: 0.05 lbs	Section: 26469 Volume: 1.24 cu in	Units: IPS Seat: C	Dwg. No.:07 Date: 4/19/22
SOLIDWORKS Educational Product. For Instructional Use Only.					

Appendix L: Images

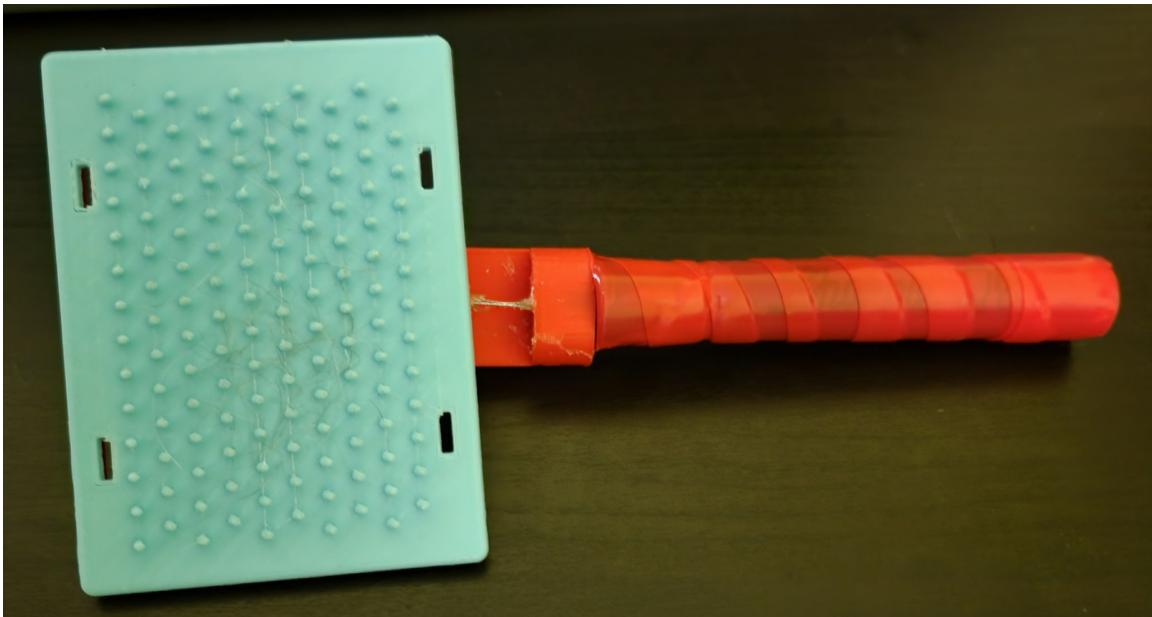


Figure L1: Final Prototype

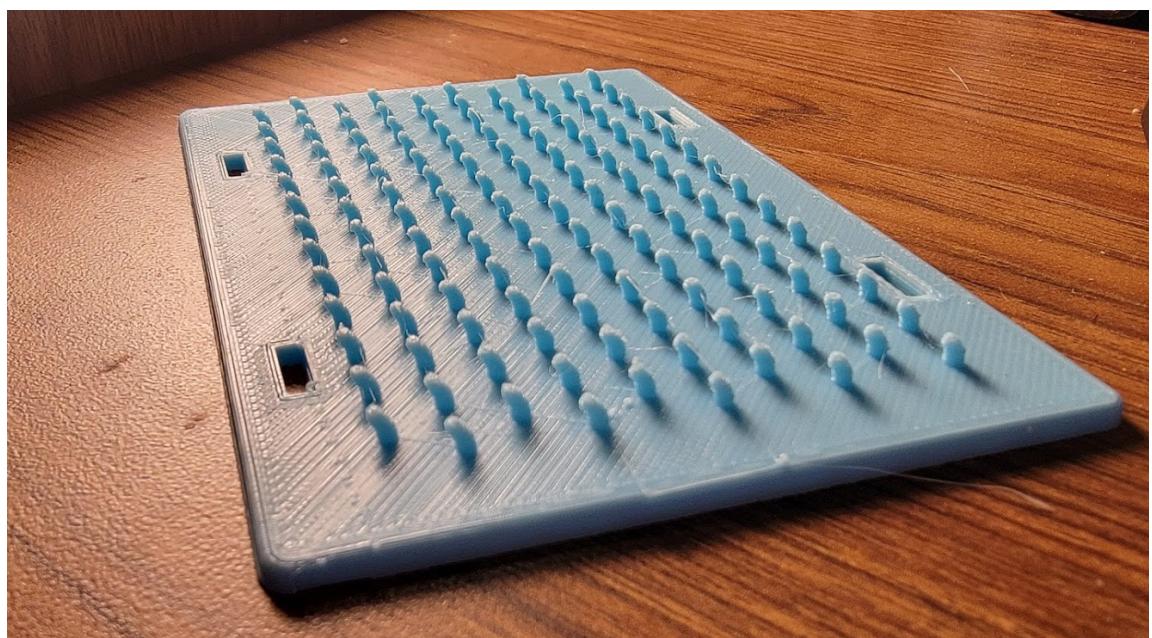


Figure L2: Final Bristles



Figure L3: First Bristle Prototype

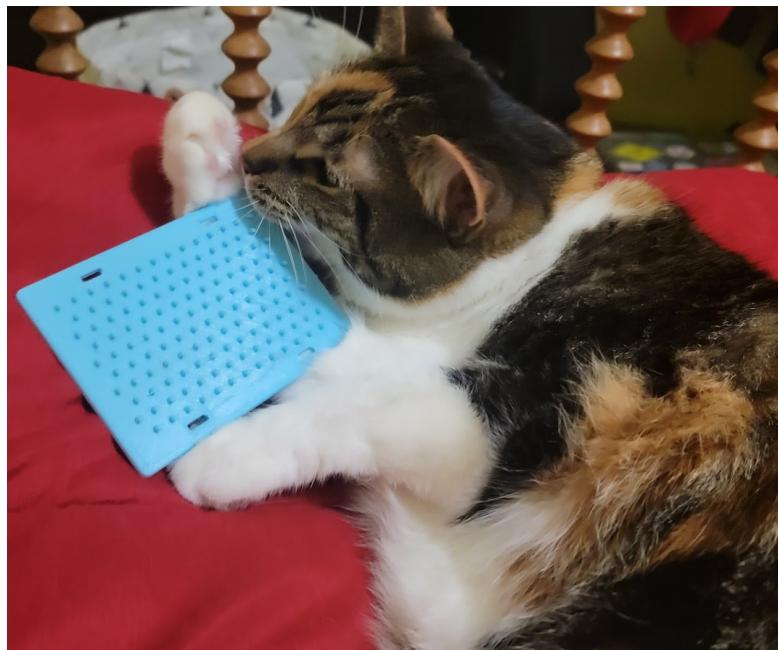


Figure L4: Confused user during testing

Appendix M: Final Testing Scorecard

Table A1: Final Scorecard

Requirement	Range	Score Rubric (Total Score: 18/28)									Final Score
		8	7	6	5	4	3	2	1	0	
Time to clean hair out of brush (5 pts)	0 - 120 seconds				≤ 80 s	≤ 90 s	≤ 100 s	≤ 110 s	≤ 120 s	> 120 s	5
Total brush mass (1pt)	0 - 500 g								< 250 g	> 250 g	1
Brush material cost (1pt)	\$0-20								$< \$10$	$> \$10$	1
Force to break one bristle (3pts)	0-3 lbs of force						≥ 3 lbs	≥ 2 lbs	≥ 1 lb	< 1 lb	3
Brush strokes to adequately clean pet (8pts)	1-10	1	2	3	4	5	6	7	8	≥ 9	4
Pet opinion (7pts)	1-10		10	9	8	7	6	5	4	< 3	4

Appendix N: Project Budget

The project had a fixed budget of \$50 for prototype development.

Due to technical limitations of the Makerbot 3D printers, the two bristle prototypes were printed (with approval from Dr. Casale) through the Ohio State University Innovation Studio at Pomerene Hall, 1760 Neil Avenue Building 067, Columbus OH 43210. The Innovation Studio offers free 3D printing and laser cutting to OSU students. For the purposes of the prototyping budget, these prints will be counted using the same prices specified by the FE Prototyping Store: \$5 plus \$0.40 per cubic inch for 3D-printed items and \$3.50 plus \$0.07 per square inch for laser cut items [19].

The volume and area measurements are obtained from the SOLIDWORKS models created of the brush [16].

Table N1: Custom part budget

Part No.	Description	Source	Manufacture	Volume/Area	Price
7	Bristle Proto 1	Innovation Studio	3D Print	1.24 cu in	\$5.50
7 rev 1	Bristle Proto 2	Innovation Studio	3D Print	1.24 cu in	\$5.50
4,5,6	Backplate and supports	FE Store	Laser cut	12.98 sq in combined	\$4.41
1	Hinge linkage	FE Store	3D Print	0.34 cu in	\$5.14
2	Horizontal pivot	FE Store	3D Print	0.54 cu in	\$5.22
Total					\$25.77

Any additional parts, such as bolts, zip ties, springs, and the handle, were sourced independently or fabricated using existing materials, and are of negligible cost.

Appendix O: Group Responsibilities

Problem Definition (PD)

PD1: Problem Definition & Task Analysis			
Project Manager for Assignment	Angelina Barone		
Deputy Manager for Assignment	Mira Faizul		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Dan Haikal	Created Tables	Ranga Rutiser Sundar
Other Contributions			
N/A			
Problems Overcome			
The group was able to decide on a final task to examine for the design project. Several possibilities were discussed before pet care was decided on.			

PD2: Research Plan			
Project Manager for Assignment	Ranga Rutiser Sundar		
Deputy Manager for Assignment	Dan Haikal		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Mira Faizul	Created Tables	Angelina Barone
Other Contributions			
N/A			
Problems Overcome			
The group was able to gain more knowledge and better defined the task through research.			

PD3: End User Needs			
Project Manager for Assignment	Ranga Rutiser Sundar		
Deputy Manager for Assignment	Mira Faizul		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Angelina Barone	Created Tables	Mira Faizul
Other Contributions			
N/A			
Problems Overcome			
The group better defined the needs of the user audience and created a persona for an example user.			

PD4: Market Character			
Project Manager for Assignment	Dan Haikal		
Deputy Manager for Assignment	Angelina Barone		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Ranga Rutiser Sundar	Created Tables	Mira Faizul
Other Contributions			
N/A			
Problems Overcome			
The group was able to learn about the individual users to understand the potential impact related to the pet project.			

PD5: Research Results and Value Proposition			
Project Manager for Assignment	Ranga Rutiser Sundar		
Deputy Manager for Assignment	Angelina Barone		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Mira Faizul	Created Tables	Dan Haikal
Other Contributions			
N/A			
Problems Overcome			
The group managed to summarize the research results as well as come up with a value proposition.			

Conceptual Design (CD)

CD1: Individual Concept Brainstorming & Ideation			
Project Manager for Assignment	Angelina Barone		
Deputy Manager for Assignment	Mira Faizul		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Dan Haikal	Created Tables	Ranga Rutiser Sundar
Other Contributions			
N/A			
Problems Overcome			
Each team member was able to brainstorm ideas and come out with few conceptual solutions to solve the problem with pet cleaning.			

CD2: Group Concept Brainstorming & Ideation			
Project Manager for Assignment	Angelina Barone		
Deputy Manager for Assignment	Mira Faizul		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Dan Haikal	Created Tables	Ranga Rutiser Sundar
Other Contributions			
N/A			
Problems Overcome			
The group was able to brainstorm ideas and come out with few conceptual solutions to solve the problem with pet cleaning.			

CD3: Concept Selection			
Project Manager for Assignment	Mira Faizul		
Deputy Manager for Assignment	Dan Haikal		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Angelina Barone	Created Tables	Ranga Rutiser Sundar
Other Contributions			
N/A			
Problems Overcome			
The group managed to select the best design concepts that met the weighted user needs based on both end-user feedback and the Pugh Scoring Matrix.			

CD4: Grand Concept & Prototyping Plan			
Project Manager for Assignment	Angelina Barone		
Deputy Manager for Assignment	Dan Haikal		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Ranga Rutiser Sundar	Created Tables	Mira Faizul
Other Contributions			
N/A			
Problems Overcome			
The group was able to develop the final design concept and created a plan for the prototype.			

CD5: Prototype Design Requirements & Verification Plan			
Project Manager for Assignment	Mira Faizul		
Deputy Manager for Assignment	Ranga Rutiser Sundar		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Angelina Barone	Created Tables	Dan Haikal
Other Contributions			
N/A			
Problems Overcome			
The group managed to develop a Grand Concept Design to solve the issues with pet hair brushes and identify a plan to create a prototype for that concept.			

Detailed Design (DD)

DD1: Project Management			
Project Manager for Assignment	Angelina Barone		
Deputy Manager for Assignment	Mira Faizul		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Dan Haikal	Created Tables	Ranga Rutiser Sundar
Other Contributions			
N/A			
Problems Overcome			
The group was able to make a complete schedule to finish the prototype and testing phase on time.			

DD2: User Validation Plan			
Project Manager for Assignment	Mira Faizul		
Deputy Manager for Assignment	Dan Haikal		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Angelina Barone	Created Tables	Ranga Rutiser Sundar
Other Contributions			
N/A			
Problems Overcome			
The group created a plan to validate the prototype and evaluate how well it meets user needs.			

DD3: Social and Economic Value			
Project Manager for Assignment	Ranga Rutiser Sundar		
Deputy Manager for Assignment	Mira Faizul		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Angelina Barone	Created Tables	Dan Haikal
Other Contributions			
N/A			
Problems Overcome			
The group defined the values the product delivers for various stakeholders and addressed the impacts of the group's solutions.			

DD4: Detailed Design			
Project Manager for Assignment	Dan Haikal		
Deputy Manager for Assignment	Angelina Barone		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Mira Faizul	Created Tables	Ranga Rutiser Sundar
Other Contributions			
N/A			
Problems Overcome			
The group described the full process of prototyping including the testing and verification.			

Final Design (FD)

FD1: Prototype Working Drawings Packet			
Project Manager for Assignment	Ranga Rutiser Sundar		
Deputy Manager for Assignment	Angelina Barone		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	Ranga Rutiser Sundar	Proofread Assignment	All group members
Created Figures	All group members	Created Tables	N/A
Other Contributions			
N/A			
Problems Overcome			
The group created a working drawings packet for the prototype.			

FD2: Final Verification Testing			
Project Manager for Assignment	Mira Faizul		
Deputy Manager for Assignment	Dan Haikal		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Angelina Barone	Created Tables	Ranga Rutiser Sundar
Other Contributions			
N/A			
Problems Overcome			
The group presented the results of the verification conducted.			

FD3: Final Pitch			
Project Manager for Assignment	Angelina Barone		
Deputy Manager for Assignment	Dan Haikal		
Drafted Assignment	All group members	Revised Assignment	All group members
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Mira Faizul	Created Tables	Dan Haikal
Other Contributions			
N/A			
Problems Overcome			
The group created a pitch presentation for the Fundamentals of Engineering Showcase.			

FD4: Technical Design Review			
Project Manager for Assignment	Dan Haikal		
Deputy Manager for Assignment	Angelina Barone		
Drafted Assignment	All group members	Revised Assignment	Ranga Rutiser Sundar
Reviewed Assignment	All group members	Proofread Assignment	All group members
Created Figures	Ranga Rutiser Sundar	Created Tables	Mira Faizul
Other Contributions			
N/A			
Problems Overcome			
The group assembled the previous reports into one document.			