ENGS 21: Introduction to Engineering Winter 2019

Reusable Drinkware Cleaner

Final Report

Group 2

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I. Problem

50 billion plastic-lined disposable paper cups are thrown away in the US per year.[1] In line with US trends, Dartmouth generated 3,664 tons of waste in 2018 of which 68% was not recycled or composted.[2] Out of the various waste contributors, we intend to address address a specific constituent, single-use non-recyclable drinkware, which are frequently used by the Dartmouth undergraduate population. A survey of 40 Dartmouth students revealed that 58% use more than 4-7 disposable cups per week and 38% use more than 10 disposable cups per week.

There is a solution to disposable cup waste: reusable drinkware. Despite this longstanding solution, the problem still persists. Dartmouth's waste has grown since 2015, with more waste being sent to the landfill despite 83% of students expressing interest in reducing their use of disposable products. Therefore, this solution is inadequate as seen by the discrepancy between the students' desire to reduce waste and their actual use of disposables.

Through initial user surveys, we found that the failure to consider the user prevented reusable drinkware from being an effective solution. In a survey of 55 Dartmouth students, more than 50% reported that they continued to use disposables because of the inconvenience of cleaning. This drawback forestalls the widespread adoption of reusable drinkware as both users and non-users of reusables claim that cleaning is one of the largest inconveniences of reusable cup use. Our user research revealed that the user inconveniences of cleaning included cleaning time, physical

[1] https://wasteadvantagemag.com/new-infographic-reveals-the-waste-mountain-of-coffee-cups-we-produce-per-year/
[2] https://docs.wixstatic.com/ugd/06a39f_9fb2ff77a5794108987abad273603bef.pdf

effort, and location inconveniences. Our solution aims to address the root of Dartmouth’s disposable cup waste problem allowing eco-friendly Dartmouth students to efficiently clean reusable drinkware on-the-go and reduce disposable waste.

II. Background and State of the Art

The focus on the problem of disposable waste at Dartmouth stems from the variety of dining options that offer disposable drinkware across campus. The problem extends to the Class of ’53 Commons, where ironically the “Green2Go” program includes large paper and plastic cups. A Dartmouth student that wishes to eliminate disposable drinkware waste would have to carry a reusable cup or mug with them and clean it after use. With these inconveniences in mind, it is difficult for many Dartmouth students to avoid disposable drinkware. With the implementation of easy washing stations throughout campus, the inconveniences of the user will be eliminated while the guarantee of a quick, efficient cleaning will both encourage students to invest in reusable drinkware and eliminate disposable drinkware waste.

While our problem involves the inconvenience of quickly cleaning reusable drinkware specifically in public spaces, the patents we discovered address only the difficulties of cleaning the drinkware. These solutions aim to clean drinkware more thoroughly, but none fully solve the problem of making that process accessible and convenient to individuals in public areas. Some patents show mechanisms for bottle rinsers in an industrial setting, where a plethora of the same type of bottle is washed and dried with pressurized streams of water (Appendix XII Fig. 1-3). We noted a variety of limitations: they are unable to accommodate a wide range of drinkware; they are not meant for individual use; many are outdated (ranging from 1902-1978).

On the other hand, there are individual manual bottle cleaners that make the process easier with rinsing systems using jets of water or solution aimed at the container. One example is the Glass Mug Washer with Drain Hose (Appendix XII Fig. 3). This product is on the market and is meant to be used at bars for bar-type glass mugs and cups. It is made from plastic and features a drain hose for dirty water and a nylon brush with bristles for scrubbing. However, limitations exist here as well. The product is not designed for public installation as there is a risk of public cross-contamination, bacteria buildup, and mess. Additionally, the product requires direct input from users to clean their drinkware which does not mitigate the issue of inconvenience well.

Another product is a simple stainless steel spray nozzle. It is a closed-valved push operating mechanism that sprays water vertically up into the desired container. Used in the Rapid Rinser (Appendix XII Fig. 4), it claims to be effective for containers 8” or smaller. Here the limitations are: again, designed for commercial/business rather than public spaces; expensive at $250-$495; only rises; and lacks a long-term drainage system.

There are more traditional solutions such as the manual bottle brush that cleans hard-to-reach areas, and a piecewise bottle that comes apart for an easier clean. However, these do not solve the root of the problem itself i.e. the inconvenience and inaccessibility of cleaning the drinkware on the go. The reusable drinkware cleaner addresses the limitations of the current state of the art as an easily implementable public product that caters to a wide range of drinkware, considers cross-contamination issues, and addresses user conveniences.

In order to explore the drying component of the reusable drinkware cleaner, we explored some current state of the art drying mechanisms. We explored various state of the art including: compressed air in a can that is designed to clean small crevices; car air pump, designed for keeping tires properly inflated; blow dryer, set at a high heat setting; shop vac vacuum on its blower setting; air tunnel, from the fluids lab on full power with the cup inside; mini fan, directed into the cup; iPower Blower, directed into the cup. We found the shop vac vacuum to be most effective for drying drinkware but found limitations in size and cost.

III. Potential Purchaser and User

The reusable drinkware cleaner is designed for Dartmouth undergraduates, particularly those who desire to decrease reduce disposable drinkware waste, but struggle with the inconveniences of reusable drinkware cleaning. The target consumer demographic encapsulates the majority of Dartmouth students generally between 18 and 23 years of age and of all genders, as 83% of the 40 disposable cup users surveyed also reported a desire to decrease their disposable cup use. One target consumer stated, “I hate washing my thermos, but if I could wash it without hassle, I would use it more.” Further consumer research defined the “hassle” of cleaning to be cleaning time, physical effort, and location inconveniences.

In order to better understand consumer behavior, we looked at Baker-Berry Library King Arthur Flour Cafe (KAF) patrons as a microcosm of the Dartmouth undergraduate population’s relationship with reusable and disposable drinkware. We contacted John Tunnicliffe, Director of King Arthur Flour to obtain data about the successes of KAF’s Bring-Your-Own-Mug (BYOM) policy. We surveyed a random sample of 16 users about the BYOM policy to gauge the ratio of avid reusable drinkware users, and conducted interviews with our 10 specified testers (Jenna Musco, Assistant Director of Sustainability; Andrew Heo ‘19; Kaitlyn Hahn ‘19; Theresa Alvarado ‘19; Bridger Holly ‘21; Chirag Malkani UG; Prosper Onungwa UG; Sarah Oh GRAD; Jae Hong ‘20; Thomas Kim ‘19;) to pinpoint the user pain points in drinkware cleaning.

The potential purchaser for the reusable drinkware cleaner is Dartmouth College. We intend to install our product at various locations across campus, specifically alongside the water-bottle refill stations. The Sustainability Office at Dartmouth specifically requested a solution of this nature in order to decrease the use of disposable drinkware, and were willing to support our solution if it successfully encouraged users to utilize reusable drinkware. Furthermore, we expect that our product could easily extend to other campuses across the country. While we do not have qualitative or quantitative data surrounding different student bodies, we can assume that the sentiments expressed by purchasers and consumers at Dartmouth extend to other schools. Therefore, a successful implementation at Dartmouth could potentially be replicated with success to other college campuses.

Out of 7 users who tested our final prototype, 6 said they would use it for various drinks due to the easier cleaning process our device introduces. A user feedback noted, “I really like how I don’t have to do anything other than put my bottle in and push a button. I also think it’s cool that I can see how my bottle is being cleaned through the transparent door. It’s kind of fun.” The purchaser gave positive feedback on the implementation of the concept. Marcus Welker, the Sustainability Program Manager commented, “I love the implementation of this concept. If installation was easy, the

Sustainability Office would be on board with adopting this."

IV. Specifications

In order to evaluate the success of the potential solutions, 14 specifications were determined (Appendix I). The weights for each specification ranged from 1-5, five being the highest. The key specifications for a successful solution originally included Time Required to Use, Effectiveness in Cleaning, and Ease of Use. Time Required to Use measured the amount of seconds to clean drinkware by with the goal of cleaning within 10 seconds, and was weighed at 4 as user research indicated that the ideal cleaning wait time was 30 seconds. Effectiveness in Cleaning measured the absorbance of residue after cleaning by testing the level of light absorbance which indicated dirtiness. We saw an user need to clean drinkware completely, and weighed the Effectiveness in Cleaning at 5. Ease of Use measured the number of required user interactions to operate device, and was weighed at 5 as a critical user pain point of cleaning was the required physical effort.

From user interviews, the additional performance specifications were determined to be Mess Level, and Aesthetic Attractivity. Mess Level qualitatively measures the amount of mess the users must deal with. Users indicated a need for mess elimination from cleaning, and influenced the Mess Level weight at 4. The qualitative specification of Aesthetic Attractivity measured the perception of attractiveness through user surveys ranking the attractiveness of the device. As the attractiveness of the device has an impact on encouraging consumer use, Aesthetic Attractivity was weighed at 3.

The purchaser specifications included Ease of Implementation, Space Intrusivity, Life Cycle, Energy Efficiency, and Cost. Ease of Implementation measured the cost of installation and compared cost of installation to similar products in order to calculate the feasibility of implementing the solution. As the feasibility of implementation would be crucial to the success of the solution, Ease of Implementation was weighed at 3. The qualitative specification of Space Intrusivity measured the perception of intrusiveness by surveying consumers on the device's level of intrusivity in the public space. The purchaser noted concerns about space intrusivity, influencing the specification of Space Intrusivity to be weighed at 4. Life Cycle was measured by calculating and comparing the life-cycle of the solution to similar products on the market. Energy Efficiency measured the joules of energy used by measuring the amount of water and energy use per cup washed. We determined that both Life Cycle and Energy Efficiency were crucial as sustainability goals were the main appeal to use our device for both purchaser and user, and were weighed at 4. Cost measured the cost of production, and compared the price to similar products. Cost weighed 4 as we determined that the solution must be at a price feasible for the purchaser.

Other specifications consisted of Safety, Impact, Ethics, and Legality. Safety considered the number of potential safety risks for the user, and was weighed at 5 as user safety is a prerequisite in marketability of the device. The qualitative specification of Impact measured the likelihood of increasing reusable drinkware usage through gathering user feedback. Impact was weighed at 5, as in order for the device to be effective, it must have a significant impact in promoting use of reusable drinkware. Ethics measured the adherence to the code of ethics and Legality measured the adherence to the law. Both were weighed at 5 as adherence to the law and code of ethics is a given requirement in production of any device.

V. Problem Solving and Methodology

After specifications were delineated, we brainstormed solutions centering around the current inconveniences of drinkware cleaning methods (Appendix II). One solution was to create a reusable drinkware cleaner that would enable students to take dirty drinkware for quick cleaning and reuse, and eliminate the inconveniences of carrying around a used container. The cleaner could be placed around campus for increased accessibility. Another alternative solution was a cup vending machine that would exchange a user's dirty drinkware with clean drinkware. The user may exchange used drinkware with a carabiner or placeholder that could be exchanged at a later time, similar to the existing Green2Go program at Dartmouth. Other alternative solutions included potential improvements on existing drinkware to propel an easier clean. We proposed a self-cleaning mug with build-in features that would clean itself, a "puzzle bottle" that disassembles and allows hard-to-reach areas to be cleaned, and a non-stick mug coated with a hydrophobic interior allowing liquids to be cleaned out with a quick rinse. A cup with removable and reusable lining was considered as the lining would allow for new beverages without immediate cleaning. Two of our alternatives also approached a change in the cleaning mechanism. The electric 'super' brush would be designed to give a quicker clean than a manual brush, and the 'vacuum cleaner' would operate similarly to a traditional vacuum, but specifically to suck liquids.

Out of the nine alternatives proposed, the best viable alternative was selected by implementing a decision matrix (Appendix II) using the aforementioned specifications and weighting. Highlighted in red, the highest ranked alternative was the reusable drinkware cleaner. The reusable drinkware cleaner seemed the most effective when considering the needs of the user through our specifications. Components of the reusable drinkware cleaner would be housed in a stand-alone enclosure with pipe attachments for water and draining, and a drying system. We considered the aspects of water source, sanitation, drying, nozzle type, on/off mechanism, and stabilizer for the reusable drinkware cleaner to create a decision matrix (Appendix III).

The implementation of the water source had specifications of Feasibility, Low Maintenance Cost, Safety, Ethics, and Legality. The specification of Feasibility, weighed at 5, qualitatively considered the feasibility of each mechanism. The Low Maintenance Cost, measured by the cost of maintenance, was weighed at 3. The specifications of Safety, Ethics, and Legality were weighed at 5 as they were critical to consider. Safety considered the number of potential safety risks for the user, Ethics measured the adherence to the code of ethics and Legality measured the adherence to the law. With these specifications, the implementation matrix indicated that the pipe would be a better alternative water source than a water jug (Appendix III).

Sanitation and drying implementations considered additional specifications of Effectiveness and Speed. Effectiveness, weighed at 5, measured the effectiveness of sanitation and drying. Speed, weighed at 4, measured seconds to desired outcome. By analyzing the sanitation decision matrix, we decided to proceed with the UV light over the soap, bleach, hot steam, hot water, and no sanitation options. For the drying mechanism, the cold air jet was deemed to be the best over the hot air jet, paper towel, sponge, and not drying (Appendix III). Nozzle type implementation considered specifications of Target Range and Velocity of Flow. Target Range, weighed at 5, evaluated the range of water from the nozzle. Velocity of Flow, weighed at 4, assessed the velocity of water flow of the nozzle type. Out of the alternatives of slit, single hole, multiple holes, rotating slit, and rotating hole, the decision matrix indicated that the rotating slit would be best for the nozzle type (Appendix III).

The on/off mechanism included specifications of Low Room for Error, weighed at 5, and User Effort, weighed at 4. Low Room for Error measured the potential malfunctioning of the on/off mechanism. User Effort gauged the number of required user interactions to operate device. For the on/off mechanism, the user button was best suited over the alternatives of proximity sensor, door weight sensor, and manual on/off Switch (Appendix III). Additional specifications of Stability of Cup, Long Lasting, and Potential Misuse were added for the stabilizer implementation. Stability of Cup and Potential Misuse were weighed at 5. Stability of Cup examined the ability of the stabilizer to stabilize the cup during the operation of the device to ensure that the cup can withstand the water pressure, and Potential Misuse accounted for the potential of the stabilizing mechanism to be misused. Long Lasting, weighed at 4, evaluated the time of operation without a replacement. For the stabilizer, the decision matrix revealed that the ceiling weight clamp would be a better option than the side clamp, users hold in place, no clamp, and ceiling spring clamps (Appendix III).

VI. State of the Art Testing

We conducted state-of-the-art testing on the Beer Glass Cleaner, the Rapid Rinser Nozzle, and hand-washing. We also tested our first nozzle prototype to evaluate their effectiveness in terms of time and cleanliness. This test was conducted using a reusable, collapsible drinkware called the Stojo, which eliminated user frustrations with structural composition of the drinkware, such as portability and leaking. Out of the state-of-the-art, we found that hand-washing had the quickest and cleanest results. However, our initial prototype was quicker and cleaner than hand-washing.

We quantified ‘effectiveness’ by using a spectrophotometer to measure the amount of residue that remained after several seconds of cleaning. The spectrophotometer gives an absorbance value of the tested solution via Beer's law which states that the concentration of the tested solution is proportional to its absorbance. A higher absorbance value indicates a higher concentration of coffee residue.

For each test, 30 ml of coffee with a concentration of 28g of instant coffee per liter was placed in the cup and shaken. For all flow-based methods, the flow rate was set to 0.176 liters/ second. Following each cleaning method, the cups were rinsed with 4 ml of water and collected into individual cuvettes. This process was repeated for 3 secs, 6 secs and 9 secs of cleaning. We included a rinse of an unwashed cup as our control and a blank cuvette with water as our baselines for comparison. The absorbance of the liquid in each cuvette was measured at 600 nm.

Since coffee has multiple compounds in it, it is difficult to establish a clear calibration curve for concentration. Therefore, we defined pure water as 0% “dirtiness” and the cuvette using an unclean mug as 100% “dirtiness”. Using the equation below, we quantified “% dirtiness” for each state-of-the-art.

$$\% \text{□□□□□□□□□□} = \frac{\text{□□□□□□□□□□□}(\text{□□□□□□□}) - \text{□□□□□□□□□□□}(\text{□□□□□□})}{\text{□□□□□□□□□□□}(\text{□□□□□□□□})-\text{□□□□□□□□□□□}(\text{□□□□□□})}(100) = \frac{\text{□□□□□□□□□□□}(\text{□□□□□□□}) - 0.040}{0.796}(100).$$

This allowed us to compare cleaning methods. The results indicate that our prototype nozzle cleans more quickly and more completely than the state of the art mechanisms. This can be visualized in the data fitting graphs below. When testing our fourth prototype, we found that it matched the performance of our first prototype, as expected. (See Figure XII.)

The review board raised concerns on whether our prototype could clean heavier residues such as lattes, milk, or dried coffee. Therefore we performed tests on the effectiveness of the state-of-the-art and our prototypes in cleaning oil residue when using hot water. We used oil as a proxy for heavy residue since it is one of the more difficult substances to remove. We measured the time it took for the each device/method to clean a cup coated with a mixture of oil and blue dye. As this test is more qualitative than quantitative, dye was added to the oil to make the residue more visible for inspection. The results are illustrated in Appendix V Plot I. As expected, we found that our fourth prototype performed the best, cleaning in 5.7 secs. The bar mug cleaner had an indefinite cleaning time because the water used to clean remains in the vessel; thus, the oil indefinitely coats itself back on the cup. Cleaning dried coffee a bit more time and thus, more water. The volume of water used per method is outlined in Appendix V Plot II. But our prototype again performed best. To consider the cases with more difficult residue, we decided that it would be best to use hot water as our water source rather than cold water.

We conducted “state-of-the-art” for drying as well. While the devices/methods can not be directly considered as state-of-the-art devices, the basic manner in which they dry have potential to be useful. The methods we tested is listed on Appendix VI.

We found that a majority of the state-of-the art did not dry effectively, taking more than 60 seconds. However, hot air from a blow dryer and a Shop Vac vacuum on its blower setting was most promising with 33 secs and 5.3 secs to dry, respectively. The vacuum blower takes less energy since it requires no heating of the air, and it was 6 times as fast to dry. Rather than evaporating the water from the cup, the vacuum blows the water off in a more physical manner and increases the surface area of the water to promote evaporation. Therefore, we attempted to emulate this state-of-the-art.

To address the user concerns of sanitization of their bottles, as rinsing alone does not kill bacteria, we looked into the state of the art for using UV light. According to the American Ultraviolet, "the average bacterium will be killed in ten seconds at a distance of six inches from the [germicidal ultraviolet" lamp." and they kill up to 99.9% of most viruses, airborne bacteria, and mold spores.[3] Given this literature, we decided to pursue these germicidal ultraviolet lamps in our design methodology.

VII. Design and Development of the Final Prototype

With the implementation decision matrices in mind, the reusable drinkware cleaner design features include a rotating slit nozzle, a cold air jet, sanitizing UV-C lights, electronics, and a stabilizing ceiling weight clamp. Each major feature of the prototype underwent several iterations, each attempting to improve upon the previous design. We used Solidworks to plan out our design and illustrate how to integrate the components of the device and into its final assembly (Appendix VII).

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[3] https://www.americanultraviolet.com/uv-germicidal-solutions/faq-germicidal.cfml

Our rotating nozzle was modified five times (Appendix VIII). The first was designed primarily to investigate the effectiveness of a slit nozzle (VIII.a.), and the second, to examine the effectiveness of the use of arms to spray water to rotate the nozzle around a joint (VIII.b). The 360* rotating fitting we purchased proved to be too stiff for the torque from arms to spin it. This led us to our third and fourth design which incorporated the rotating mechanism from a sprinkler with a slit nozzle attachment (VIII.c,d). Due to the successes of the fourth prototype in spinning and spraying, we created our fifth and final nozzle prototype in aluminum, drawing from the sprinkler mechanism to create our own rotating joint and arms (VIII.e). Aluminum was chosen because it is lightweight, sanitary, and doesn’t rust.

The initial prototype of the ceiling weight clamp is raised by a ledge attached to the door that catches on the bottom of the clamp as it moves upward, and lowers naturally via gravity (Appendix IX.A). However, the door failed to completely close, creating a gap from which water sprayed out from the bottom of the enclosure (Appendix IX.B). Water also exited from a gap between the top of the door and enclosure. Thus, we made sure that the door slid below the opening and attached a squeegee to the top. Because we are using UV-C lights, the door should block UV-C light from exiting, protecting the user from potential harm. The initial clamp was also unbalanced, would easily get stuck, and the rod protruded 14 inches above the machine when the door was completely open. Users disliked this consequence of the clamp mechanism. Based on feedback, we thus attempted to create a telescoping clamp that limits the protrusion to 5 inches. However, after many trial and errors, we found that our design could not be carried out in the machine shop due to a lack of proper tools and time. Therefore, we were left to resort to our first design, but would like to implement a telescoping clamp in a subsequent development of the device.

A shop vac vacuum on its blower setting proved to most effective drying method in our state-of-the-art testing; therefore we decided to utilize a blower with similar features with a minimum airflow of 157 CFM. We started with an Air Duct fan with higher air flow rate at 442 CFM. However we found that it was not capable of tolerating high pressures within the fan due to its axial design; we were not able to narrow the opening flow and direct the air with high velocity due to a lot of backflow. We decided to try a centrifugal fan with 115 CFM. We could not afford a fan with higher air flow due to limitations to our budget at the time. However, it did perform better than the initial axial fan. The fan attaches to the back of the device, and connects to tubing that directs the air towards the cup (Appendix VIII.F).

To initiate the several steps in the cleaning process, we incorporated several electronic components to streamline the stages and follow automatically one after one another (VIII.G). The final prototype included a microcontroller arduino in which we programmed commands into to set outputs into the various electrical components. Once such component was an electronic check valve which was inserted between the input and the nozzle. Since the water source will be connected to the main water line, we needed a valve that could start and stop the inflow of water to the nozzle within the span of seconds. We also programmed LED lights to turn on/off for specific durations of time. We used regular LEDs as a proxy for the intended sanitizing UV-C LEDs (VIII.H) A magnetic switch was incorporated into the door to eliminate safety concerns by preventing the machine from running when the door is open. To provide visual feedback to the user when using the device, we used a start button with an LED build in to alert the user when the cleaning was in progress, and completed when the LED is turned off. Ideally, the drying stage would also be incorporated into the arduino, however, we found that the fan we purchased was not appropriate for use near water. Thus, we were unable to integrate this system in the final prototype.

The reusable drinkware cleaner is designed to be a two-step solution to the problem of cleaning reusable drinkware. First, the user places their dirty drinkware into the cleaner by opening the door, which simultaneously lifts the clamping mechanism. When the door is closed, the ceiling weight follows and drops onto the drinkware, securing the cup inside in one smooth motion. The closed door also completes an electrical circuit via a magnetic switch which enables an automatic cleaning, drying, and sanitation process to begin with the press of a blue LED light button. When pressed, the button lights up to signal that the device has started and the cleaning process begins with the influx of water as it drives the washing mechanism; the spinning nozzle with arm attachments allows high velocity hot water to simultaneously clean the interior and exterior of the drinkware for 5 seconds. Next, the drying mechanism is automatically activated which utilizes the centrifugal blower with a smaller mouth attachment that narrows the airflow and allows the high velocity air to dry off the drinkware more effectively. To avoid water entering the air mouth attachment, a future design will include a flap or check valve that prevents water flow from entering the blower. Lastly, to sanitize, UV-C LED lights are activated for 10 seconds. The germicidal UV-C lights address the cross-contamination concerns from the purchaser and users. According to the American Ultraviolet, “the average bacterium will be killed in ten seconds at a distance of six inches from the [germicidal ultraviolet] lamp."[4] Once the sanitization process concludes, the blue light from the button turns off, signaling to the users that the cleaning cycle is completed. The user is then able to open the door, and take out their ready-for-use drinkware.

The enclosure of the reusable drinkware cleaner was designed to be small and compact which would allow for ease of installation and flexible integration into spaces (Appendix VIII.I). The initial prototype was made of steel which only held the space for cleaning and drying. The second and final prototype of the enclosure is made of aluminum which is much lighter, sanitary, and does not rust. It comprises of a rectangular interior compartment for cleaning and drying, and an exterior shell (VIII.J). We housed the electronics between the interior and exterior sheets to protect them against water. However, higher precautions and safety measures that follow certain standards when incorporating electronics and water should be taken for future iterations.

Once all components were fabricated separately and the electronics tested, we assembled our final prototype (VIII.K). We had many setbacks and difficulties assembling the pieces due to the required precision in placement of many of the pieces. However, we were able to improve and make changes as we went so that we could evaluate the performance of our final prototype.

VIII. Performance of Final Prototype

The final prototype performed as anticipated: a five second wash of a dried coffee stained mug with cold water resulted in a clean cup (Appendix IX.C).

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[4] https://www.americanultraviolet.com/uv-germicidal-solutions/faq-germicidal.cfml#top

Unfortunately, we were not able to tap into our normal hot water line during the testing phase. Even so, if cold water cleaned the cup in 5 secs, from our previous testing we can infer that using hot water will result in a better clean in less time. The electronics worked perfectly, running through a seamless sequence of the cleaning process. We were not able to mount the electronics on the interior as we wished because they are borrowed materials from the Thayer Instrument Room. Therefore, they are mounted on the outside. Evidently, this did make it easier for us to wire the components and plug into the outlet/power supply.

The drying component was not effective due to the limitations of the fan we purchased. We were not able to incorporate it into the arduino because it was a 120V AC fan--too high for the microcontroller to handle. But we also noted that the angle/mounting of the tubing attachment that directed the air is not optimal. As a result, our final prototype was not able to effectively dry the cups. Water also falls into the attachment which poses some safety hazards. But we feel that this can be improved upon with more research and iterations of the drying mechanism. Similarly, because we used LED lights as a proxy to UV sanitation lights, we were not able to evaluate the effectiveness of UV to sanitize. However, qualitatively, the lights do reach the interior of the cup, and seem to be in a good position for sanitation.

Out of 7 users who tested our final prototype, 6 said they would use it for various drinks due to the easier cleaning process our device introduces. A user feedback noted, "I really like how I don't have to do anything other than put my bottle in and push a button. I also think it's cool that I can see how my bottle is being cleaned through the transparent door."

Marcus Welker from the Sustainability Office commented: “I think my only feedback would be to find a way that users would be more incentivized to use it, like informing them how they are making an impact by using this [device].” We hope that we could incorporate features that Welker delineated and provide more positive feedback for the users.

IX. Other Aspects

Ethical Issues

After our user testers ran through our final prototype, we conducted follow-up interviews to source any ethical concerns that they saw. Our users conveyed that they had no ethical concerns with the use and purpose of the drinkware cleaning device.

Evaluation of Sustainability

A full LCA analysis that includes environmental factors such as greenhouse gas emissions, smog, acidification, eutrophication, is out of our scope. However, we performed a basis analysis of our prototype’s energy consumption, following the method outlined in *Reusable and Disposable Cups: An Energy-Based Evaluation* (Appendix XI).

Disposable cups require much less energy to manufacture compared to reusable cups. Therefore, a reusable cup must have multiple uses in order to reach a break-even point and prove to be less demanding of energy in manufacture and cleaning. The energy consumption for the manufacture of reusable and disposable cups varies on its material, and for cleaning, on its model. For the sake of simplicity, we evaluated the impact of reusable cups with the highest and lowest energy demand to give the upper and lower limits to break-even with a paper cup, commonly used for hot beverages at

Dartmouth. And for energy in cleaning, we used the energy consumption of our reusable drinkware cleaner prototype.

The highest energy demand from our prototype comes from the use of hot water. The energy required to heat water from 55*F to 120*F s 150.7kJ/L. With a flow rate of .176L/s, for a 5 sec wash, 132.616 kJ of energy is used. If we factor in the inefficiency in energy generation around 38% in the United States, the required energy for one wash is 350 kJ. Comparatively, the electronics and drying components use significantly lower amounts of energy rendering them negligible, and thus were not considered in the total energy consumption.

The total energy used to manufacture ceramic, reusable plastic, and paper cups is 14088kJ/cup, 6,300 kJ/cup and 589 kJ/cup, respectively. Using the break-even equation: $X = A/(C-B)$, where X is the break-even number of uses for the reusable cup, A is energy required for manufacturing the reusable cup, C is the energy required for the disposable cup, and B is the energy used in washing. For a ceramic cup, the break-even number is 59 uses; for a reusable plastic cup, the break even number is 27. Considering 58% of Dartmouth students use 3-7 cups per week, the time to break even will range from 4-20 weeks. The time to break even will depend on the individual, however, still reasonable. However, since our first prototype was able to clean under 1 sec quite effectively, if we perfect our prototype, it is quite possible for the numbers to grow smaller. Furthermore, reducing reusable cups lowers the output of trash decreasing landfill volume.

Liability Concerns and Minimizing Them

Main liability issues arise from the potential safety hazards from the use of hot water, and the combination of electronics and water. To prevent injury from hot water, we incorporated a magnetic switch such that when the door is open, cleaning can not begin. If the door is opened during the clean, the routine is automatically stopped and the water is shut off. There are standards that are mandated for devices that pose potential injury from electric shocks and burns. For our prototype, we made sure to separate the electronics from the main cleaning compartment with their own housing, and protect any electronic devices from water. Ideally, they would be enclosed in waterproof housing with a GFCI wiring. Lastly, with our UV light component, the potential dangers of the UV light to the eye is a potential liability but we would make sure that the door, which is the only transparent portion, would be of a material that blocks/absorbs the UV light, such as window film which is known to block UV light or borosilicate glass compositions which can absorb UV light (Appendix XI).

X. Economics and Business Plan

Our primary purchaser is the Dartmouth Sustainability Office. However, we aim to broaden the market to other colleges/universities, cafes, and other public spaces, specifically targeting places that primarily utilize disposable drinkware. In our analysis of the cost of production and cash flow, we limited our market to colleges/universities as they would be our first market base. Because the Sustainability office is willing to apply for grants to fund this project, we estimate that we will need to borrow $15,000 in loans to cover initial costs but will open up to investors. Our variable costs total to $494/unit which include Aluminum, Plexiglass, Stainless Steel Grating, HDPE Pipe, UV light, Blower, Electronics, and Labor; fixed costs total to $2,745/month. However, we expect that our variable costs to decrease if we upscale production and buy material in bulk. Our total costs are outlined in Appendix X.

For the first 3 years, we plan to sell to colleges, estimating at 20 per college on average with 5300 colleges in the U.S. We also see opportunity to sell to high schools and middle schools and we plan to sell 108,000 potential units, estimating at 2 per school with 54,000 schools in the U.S. Lastly, cafes/coffee shops/drink shops would also be a large market since the drinkware cleaner should be directly in the user's path of obtaining a new drink. We estimate 31,000 potential units sold, at 1 per shop with 31,000 shops in the U.S. We also hope to gain political support with our sustainability agenda, and a sponsorship is likely possible after gaining enough traction with colleges and other schools.

Our cost decision for this drinkware cleaning device considers the fact that the common Elkay LZWSSM Surface Mount EZH20 Filling Station (X.D) is priced at $830. As we envision the installation to be next to these Water Filling Stations in order to tap into the same water and draining system, we priced the reusable drinkware to be competitive. In particular, we found that installation costs for the purchaser is estimated to be $3,000. And thus we need prices to be as low as possible to encourage the purchase of our device. We want to sell at $500 per device and hope to sell 100 devices per month with a 20% growth rate for the first three years. We expect to break even during April of the second year (Appendix X.C)

XI. Conclusions and Recommendations

In conclusion, we were successfully able to create a working spinning nozzle prototype that effectively cleans both the interior of a used drinkware and hits the exterior rims to perform a thorough clean. We successfully engineered all the parts from scratch (grate, drain, clamping mechanism connected to the sliding door, interior casing for cleaning, exterior shell to contain the device and mount on a wall, electronics and arduino to activate the check valve and LED lights to simulate UV lights). The user and purchaser specs were met with our design methodology (see CAD model Figure V.) and we were able to gain interest and approval from our pitch to the Dartmouth Sustainability Office (our target purchaser). All in all, we strongly encourage the DCEF to pursue our concept and prototype based on the enthusiastic user feedback from final testings and the expected disposable cup waste that would be reduced as a result.

Further research and implementation in our next steps include how to integrate a nozzle for the power fan that would dry the drinkware after rinsing and setting up real UV lights in a safe manner. We also hope to incorporate feedback from the Sustainability Office on adding positive feedback that encourages behavioral change, such as a "# of cups saved" counter. This would be an easy addition with the electronics we have in place currently. One limitation that we hope to iterate on in the future is the protruding shape of our wall-mounted device, which can seem intrusive in some smaller spaces. Our recommendation for this would be to include a paved out space within a wall that our device can fit neatly into and factor this into our installation cost.

Appendix

I. Specification Table

	Specification	Justification	Weight 1 - 5 (High)	Quantification	Test
1	Time to Use	Must meet ideal wait time of <30 seconds, based on user interviews	4	Time to clean in seconds (Goal: 10 seconds per stage of cleaning)	Measure amount of time to clean drinkware
2	Mess Level	Must have no mess for users	4	Time to dry user hands after operation	Measure amount of time for users to dry hands
3	Energy Efficiency	Must appeal to sustainable users	4	Joules of energy used (Goal: Less than half of dishwasher efficiency)	Measure amount of water and energy use per cup washed
4	Effectiveness in Cleaning	Must clean drinkware completely	5	Measurement of residue after cleaning	Measure absorbance of residue after cleaning
5	Safety	Must be safe for users	5	Measure number of potential risks	Count number of potential safety hazards
6	Ease of Use	Must not be a very involved process for user for user retention	5	Measure number of actions to operate device	Count number of user steps for operation
7	Ease of Installation	Must be feasible to implement for purchaser	3	Measure time and cost of installation or implementation process	Compare cost of installation or implementation process to similar products
9	Ethics	Must adhere to the code of ethics	5	Measure number of ethical violations	Count number of ethical violations with insight from user/purchaser interviews
10	Impact	Must promote use of reusable drinkware	5	Qualitative: Likelihood of increasing reusable drinkware usage	Survey user feedback on likelihood of increasing reusable drinkware usage
11	Cost	Product must have feasible price for purchaser	4	Measure cost of production	Compare prices to similar products
12	Legality	Must adhere to the law	5	Measure number of law violations	Count number of law violations

II. Alternatives Matrix:

Specs	Mess Level	Time to Use	Energy Efficiency	Effectiveness in Cleaning	Ease of Use	Ease of Implementation	Aesthetic Attractivity	Impact		Ethics	Legality	Safety	Cost	Total
Weight (1-5, 5 highest)	4	4	4	5	5	3	3	5		5	5	5	4	
Drinkware Cleaning Station	20	20	12	25	25	9	15	25		25	25	25	8	258
Cup Vending Machine	20	20	4	25	25	9	15	25		25	25	25	8	242
Self Cleaning Mug	12	16	12	25	25	12	15	25		25	25	25	12	257
Puzzle Bottle	4	8	8	20	5	12	15	20		25	25	25	12	207
Portable Dishwasher	4	4	8	25	25	9	12	25		25	25	25	8	211
Non-stick Cup	4	8	4	20	5	12	15	25		25	25	25	12	208
Electric "Super" Brush	4	8	8	20	5	12	3	15		25	25	25	16	178
Vacuum Cleaner	12	12	8	15	25	15	15	25		25	25	25	12	230
Reusable Cup liner	4	4	4	25	5	15	6	20		25	25	25	16	194

III. Implementation Specification Table**

	Specification	Justification	Weight 1 - 5 (High)	Quantification	Test
1	Feasibility	Must be feasible to implement for the part to function	5	Measure feasibility of implementation	Implement and check if the mechanism works
2	Low Maintenance Cost	Must have low maintenance cost	3	Measure total cost of maintenance	Compare cost of maintenance between implementations
3	Room for Error	Must have low room for error	5	Measure the potential malfunctioning of the on/off mechanism	Count number of potential errors
4	Effectiveness	Must clean/dry drinkware completely	5	Measurement of residue after cleaning/drying	Use spectrophotometer to measure residue
5	Safety	Must be safe for users	5	Measure number of potential risks	Count number of potential safety hazards
6	User Effort	Must require low effort to use	4	Measure number of actions to operate device	Count number of user steps for operation
7	Potential Misuse	Must have low potential misuse	5	Measure the potential of the stabilizing mechanism to be misused	Count number of potential misuses
8	Speed	Must be quick to achieve desired outcome	4	Measure seconds to desired outcome	Count seconds up to desired outcome
9	Ethics	Must adhere to the code of ethics	5	Measure number of ethical violations	Count number of ethical violations
10	Long Lasting	Must	4	Measure the time of operation without a replacement in seconds.	Measure the time of operation without a replacement.
11	Stability of Cup	Must stabilize the drinkware	5	Examine the ability of the stabilizer to stabilize drinkware during operation	Implement and check if drinkware maintains stability
12	Velocity of Flow	Must have a high velocity that can clean drinkware	4	Measure the velocity of water flow of the nozzle type	Measure and calculate velocity
13	Target Range	Must	5	Measure the range of water from the nozzle	Measure range of water
14	Legality	Must adhere to the law	5	Measure number of law violations	Count number of law violations

** Because our list of specifications did not apply to each implementation, we decided to list specifications that were important for users tailored to each implementation, as described in the table above.

IV: Matrix of Implementation Alternatives

	Specs (1-5)	Feasibility	Low Maintenance Cost	Effectiveness	Speed	Safe	Ethical	Legal	Total
	Weight	**5**	**3**	**5**	**4**	**5**	**5**	**5**	
Sanitation	UV Sanitation Light	16	15	20	20	25	25	25	146
	Soap	20	12	12	16	25	25	25	135
	Bleach	20	12	20	20	20	25	25	142
	Hot Steam	10	12	25	16	20	25	25	133
	Hot Water	20	12	25	16	20	25	25	143
	No Sanitation	25	15	5	20	25	25	25	140
Drying	Hot Air Jet	20	12	25	20	20	25	25	147
	Paper Towel	25	12	10	8	25	25	25	130
	Cold Air Jet	25	15	20	20	25	25	25	155
	Sponge	15	12	5	4	10	25	25	96
	No Drying	25	15	5	4	25	25	25	124
Water Source	Pipe	20	15	--	--	25	25	25	110
	Water Jug	25	9	--	--	25	25	25	109

	Specs (1-5)	Feasibility	Target Range	Effectiveness	Velocity of flow	Safe	Ethical	Legal	Total
Nozzle Type	**Weight**	**5**	**5**	**5**	**4**	**5**	**5**	**5**	
	Slit	25	10	5	25	25	25	25	140
	Single Hole	25	10	5	8	25	25	25	123
	Multiple Holes	25	20	15	12	25	25	25	147
	Rotating Slit	25	25	25	25	25	25	25	175
	Rotating Hole	25	15	15	8	25	25	25	138

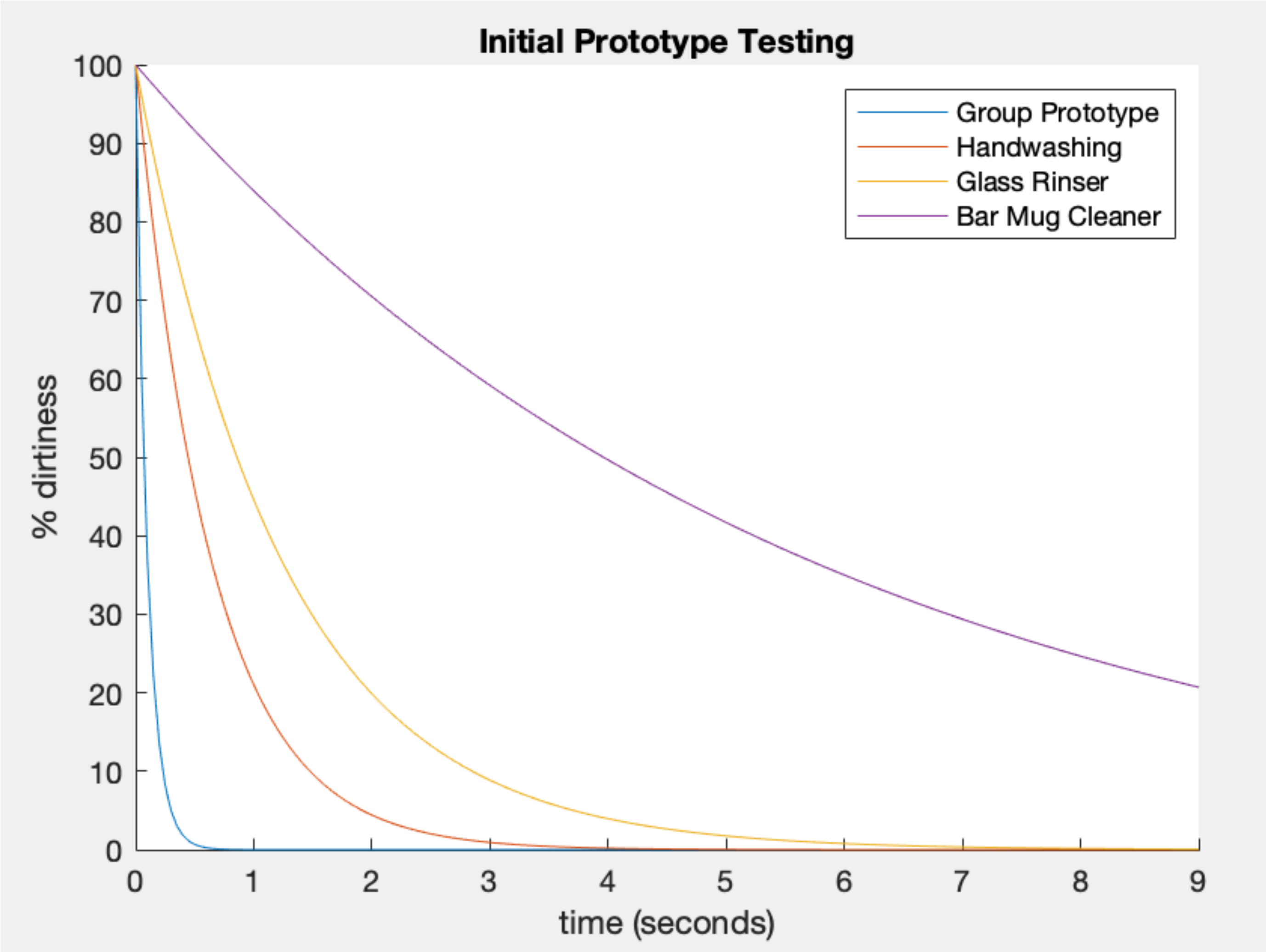
	Specs (1-5)	Feasibility	Low Room for Error	User Effort	Safe	Ethical	Legal	Total
	Weight	**5**	**5**	**4**	**5**	**5**	**5**	
On/Off Mechanism	Proximity Sensor	20	10	20	15	25	25	115
	Door Weight Sensor	25	25	20	25	25	25	145
	User Button	15	20	20	15	25	25	120
	Manual On/Off Switc	15	25	16	15	25	25	121

*We decided to implement a combination of the door weight sensor as a way to close the circuit so the user could start the process when he/she was ready with the push of a user button.

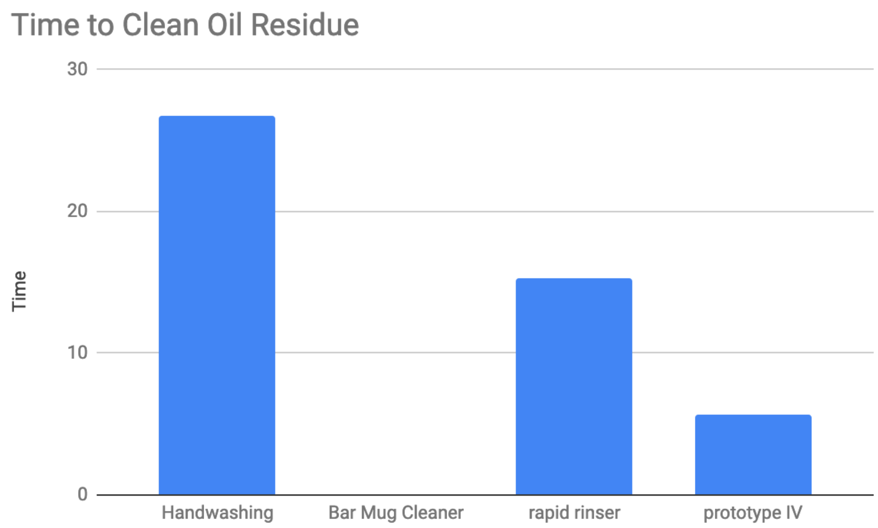
	Specs (1-5)	Feasibility	Stability of Cup	Long-lasting	Potential Misuse	User Effort	Safe	Ethical	Legal	Total
	Weight	**5**	**5**	**4**	**5**	**4**	**5**	**5**	**5**	
Stabilizer	Side Clamp	25	25	20	25	16	25	25	25	186
	User holds in place	25	25	20	5	4	15	25	25	144
	Ceiling weight	25	25	20	25	20	25	25	25	190
	No clamp	25	5	20	5	20	5	15	25	120
	Ceiling spring clamp	25	25	16	25	20	25	25	25	186

V: State of the Art Testing

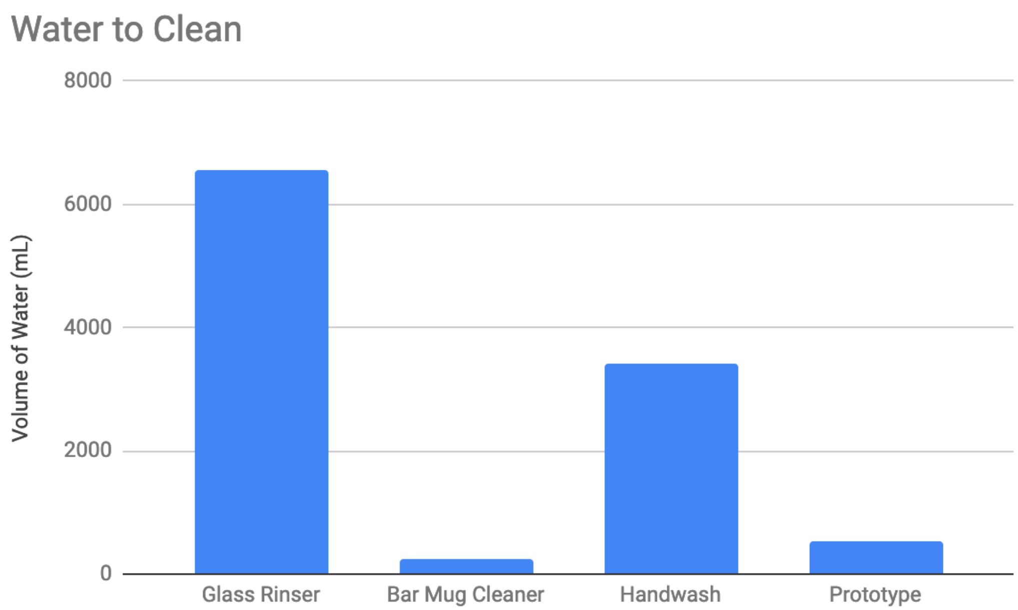
A. % Dirtiness



B. Time to Clean Oil Residue



C. Amount of Water used to Clean

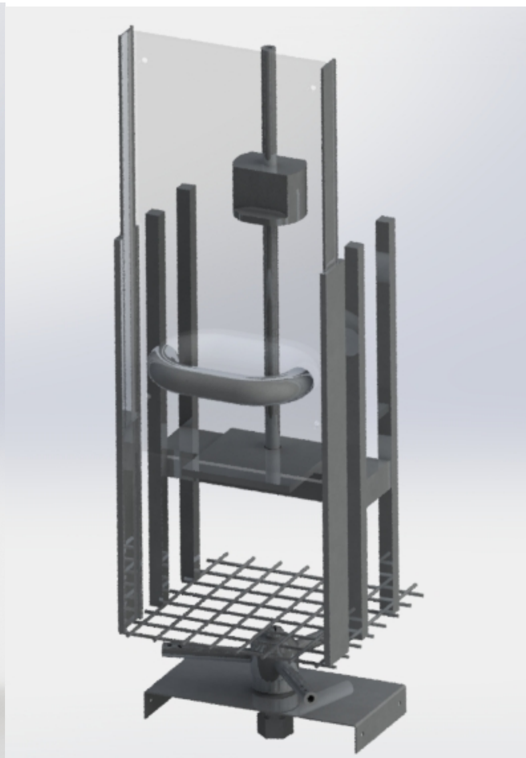


D. Drying Methods and Results

Method	Time (s)

Compressed Air	60+
Air Car Pump	60+
Air Tunnel	60+
High Hot Blowdryer	**33**
High Cold Blowdryer	60+
Vacuum Blower with rounded nozzle	**5.72**
Vacuum with Prototype I Nozzle	**31.87**
Mini Fan	60+
iPower Blower	60+
Centrifugal Fan	51

VII. CAD Models



VIII. Development of Final Prototype

A.

B*.

B.

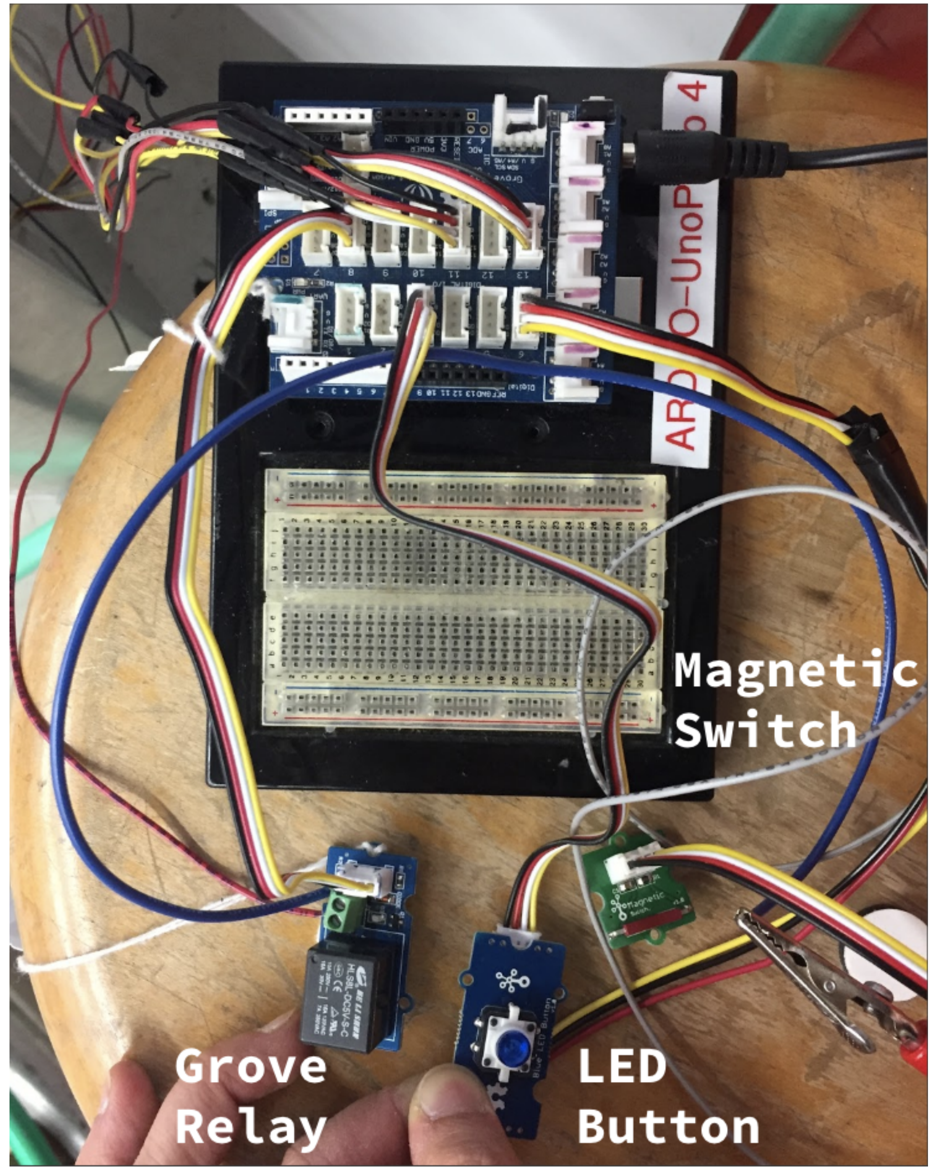
D.

E.

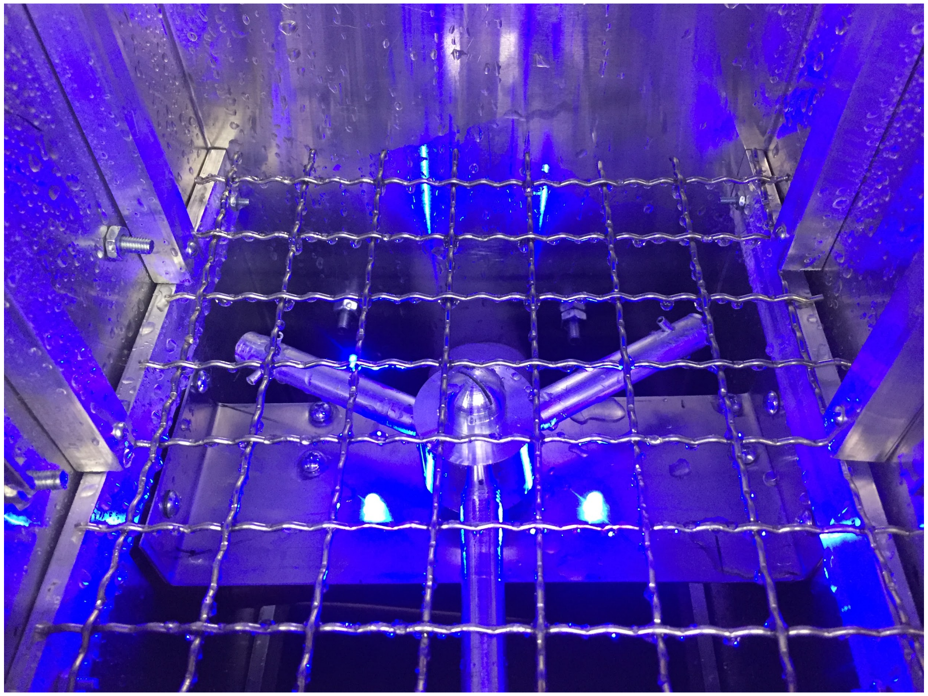
*Brass Arms yet not attached (could not find an image of the prototype with arms attached)

F. Fan attached to the back of device

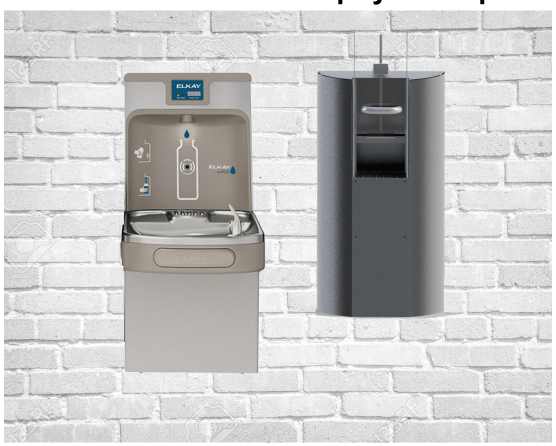
G. Electronics



H. Blue LED lights simulating our UV lights

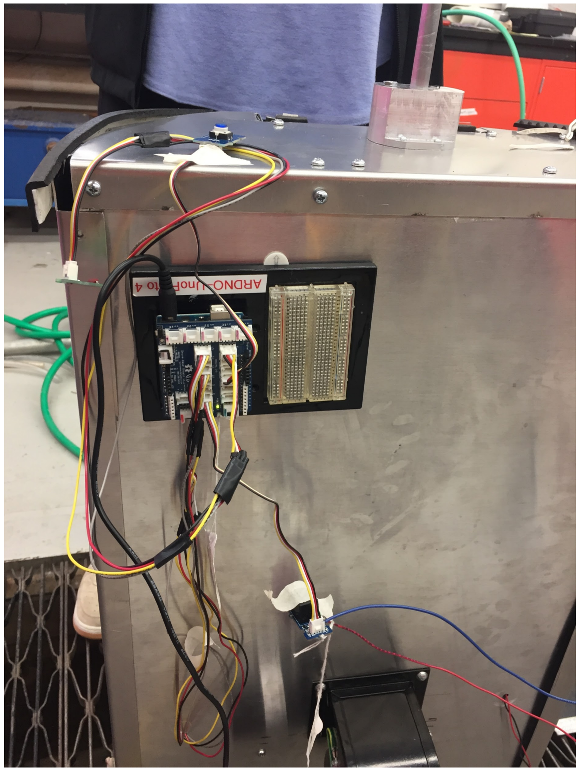


I. “Looks like” model in physical space mockup



J. Progress Shots

K. Final Assembly of Device



IX. Media

A. Demonstration of First Clamp Prototype:
https://youtu.be/Oy3YKUsTwLE

B. Demonstration of Initial prototype:
https://youtu.be/67fbX8CFmC0

C. **Demonstration of Final prototype:**
https://www.youtube.com/watch?v=a9NrEX2J2k0

X. Business Plans

A. Variable and Fixed Costs

Reusable Drinkware Cleaner

Part I: Variable Costs

Aluminum	$100.00
Plexiglass	$20.00
Stainless Steel Grating	$2.00
HDPE Pipe	$2.00
UV light	$20.00
Labor	$150.00
Blower	$150.00
Electronics	$50.00
Total Variable Costs	$494.00

Part II: Annual Fixed Costs

Rent (factory and warehouse)	$12,000		
Leasing of computers, etc	$0		
Heat	$0		
Electricity	$1,200		
Marketing/Advertising	$1,500		
Trade Shows	$0		
Insurance	$3,000		
Salesmen (3 @ $20K/yr)	$0		
Executive Salaries (2 @ $24K/yr)	$12,000		
Total Fixed Costs	$29,700	or per mon:	$2,475.00

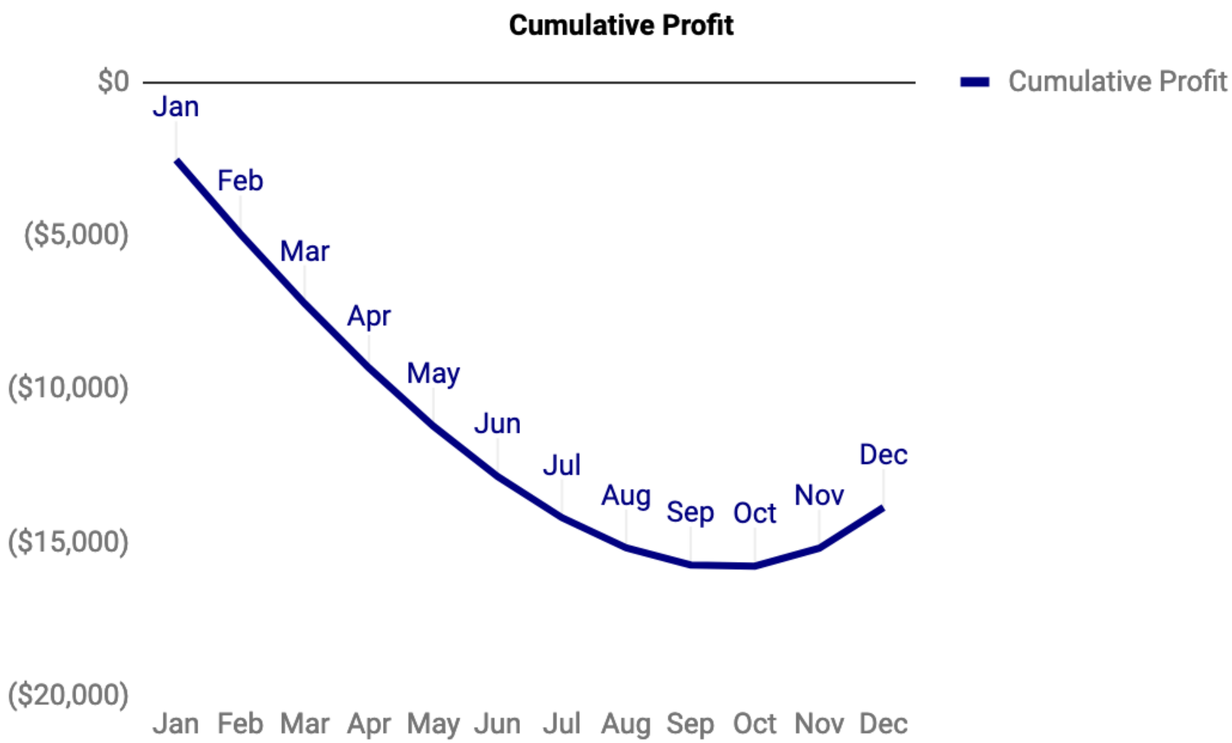
B. Breakeven and Loan Info

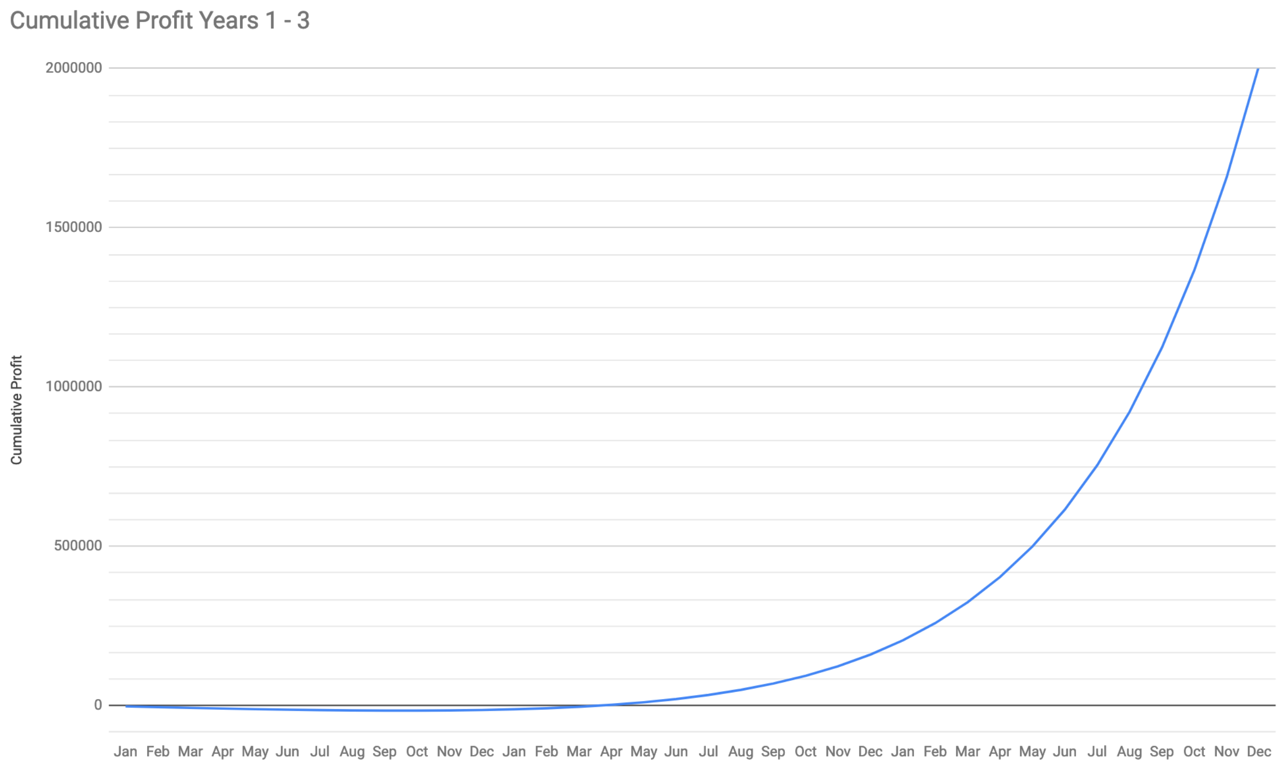
Part III: Breakeven Sales Volume

Total Market Size	100,000	(from market research)	
Price per Unit	Contribution	Breakeven	Percent
Price		Volume	Market
$500.00	$6.00	4950	5.0%
$600.00	$106.00	280	0.3%
$700.00	$206.00	144	0.1%
$800.00	$306.00	97	0.1%

Loan Information	
Required loan amount	$15,000
Annual Interest Rate	5%
Length of loan (mos)	24

C. Plots of Cumulative Profit for Year 1 and 1-3





D. Elkay LZWSSM Surface Mount EZH2O Bottle Filling Station

XI. Research Links:

Patents and SoA:
https://patents.google.com/patent/US4104081
https://patents.google.com/patent/US950885A/en
https://www.blendtec.com/products/rapid-rinse-station
http://www.waterbusiness.com/products/commercial/bottle-rinse/
https://www.barproducts.com/glass-mug-washer-with-drain-hose-self-contained

UV Light Research
http://www.koppglass.com/blog/transparent-material-comparison/

Reusable and Disposable Cups: An Energy-Based Evaluation
https://www.design4x.com/misc/bus183/handouts/Hocking.SpringerVerlag.Energy%20Use%20of%205%20Different%20Cups.pdf

XII. State of the Art

Fig. 1 Inline Bottle Rinser: US4104081A

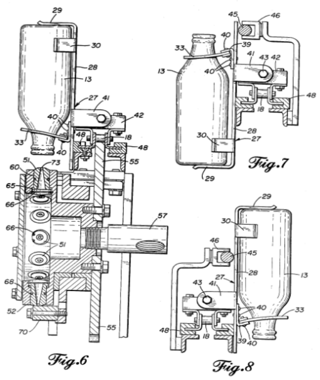


Fig. 2 Bottle Rinser and Sterilizer: US950885A

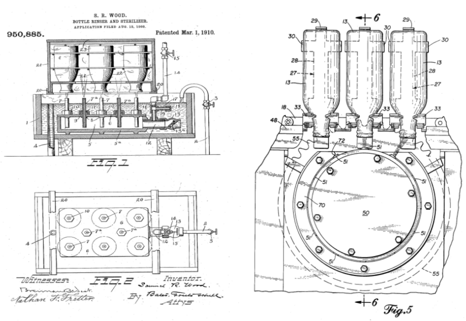


Fig. 3 Glass Mug Washer with Drain Hose

Fig. 4 Rapid Rinser

Fig. 5 Bottle Brush