Design for an Invertible Water Bottle to Facilitate Cleaning and Promote Sustainable Water Bottle Usage

by

Matthew S. Metlitz

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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Abstract

The goal of this thesis is to explore the design of a reusable water bottle that can be inverted to expose the inside. Being able to directly touch the entire inside of the product could facilitate cleaning and consequently promote sustainable water bottle usage. Existing cleaning solutions and various water bottles were evaluated for benchmarking, and a water bottle usage survey revealed that most respondents clean their reusable bottles on a weekly to monthly basis, with 35.5% of respondents indicating that they had thrown out a bottle since it was clean. Observing volunteers in water bottle cleanliness perception test revealed that being able to physically contact and see the inside of the bottle while cleaning were most important. Two iterations of sketch models were created, demonstrating that a pouch-like design with a drawstring attached between the inside of the pouch and the water bottle top to aid invertibility was the most feasible solution. The final water bottle design, created as a CAD model, consists of three components: a top, a bottom, and an invertible pouch made of a soft plastic. The invertible pouch is held in place and made watertight between the bottom and top components that resemble a standard reusable water bottle design.

Thesis Supervisor: Maria Yang
Title: Associate Professor of Mechanical Engineering and Engineering Systems
Acknowledgements

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Chapter 1
Introduction

Over the past decade, reusable water bottles have become an increasingly accepted and sustainable substitute for the billions of disposable plastic bottles discarded into landfills and incinerators every year [1]. There are dozens, if not hundreds, of companies dedicated to designing and selling reusable water bottles. The design focus for each company can vary greatly, whether the goal is to make a bottle that is more fashionable, more ergonomic, or better insulated. Unfortunately, cleaning continues to be an issue with reusable water bottles. Although companies and designers have explored various solutions to the problem, some people still choose disposable bottles over reusable versions. Even if a person regularly uses a reusable bottle, he or she might have to throw out the bottle earlier than anticipated due to lack of cleanliness.

This thesis explores the design of a water bottle that can be inverted (with the inside being pushed to the outside) for easier cleaning while evaluating water bottle usage habits and perceptions of cleanliness. The idea for an invertible water bottle originated during a brainstorming exercise for the Fall 2013 Product Design Processes class (Course 2.009), an undergraduate capstone product development class at the Massachusetts Institute of Technology. Although the idea did not move past the brainstorming phase for Course 2.009, it is further explored in this thesis through concept sketches, sketch models and Computer Aided Design (CAD) renderings. Initial conversations with potential users revealed that student athletes who typically walk from place to place or travel by bicycle were most interested in a water bottle that was easier to clean. Based on this observation and the results of a water bottle survey, the invertible water bottle design in this thesis targets
student athletes who regularly walk or ride a bicycle and often believe that they have no time to clean their water bottles.

The remainder of Chapter 1 outlines the current state of the bottled water industry and production processes, evaluates existing cleaning solutions, and comments on prior art. Chapter 2 evaluates the results of a water bottle usage survey and a bottle cleanliness perception experiment. Chapter 3 follows the design process of an invertible bottle through preliminary design considerations, two iterations of sketch modeling and a final CAD rendering. Chapter 4 comments on future design considerations for the invertible water bottle.

1.1.0 The Bottled Water Industry

The bottled water industry in the United States is rapidly growing, increasing by 4.7% from 2011 to 2012 alone to reach a valuation of 20.885 billion USD based on sales volumes [2]. Market analysts expect this strong growing trend to continue, with the United States bottled water market reaching a valuation of 26.354 billion USD in 2017, a 26.2% increase from 2012 figures [2]. Of the 37.578 billion liters of bottled water sold in 2012, still unflavored water accounted for 79.9% of the market share, with sparkling flavored water accounting for 9.0% of the market share [2]. Consumers purchased most of their water (73.5%) from supermarkets or hypermarkets such as Costco and Wal-mart [2]. Nestle is the biggest supplier of bottled water with a 33.5% market share, followed by Coca-Cola at 16.9% and PepsiCo at 13.4% [2].

Despite the high production volume, the United States is only the third largest geographic market for bottled water and accounts for 15.1% of the 138.056 billion USD global bottled water market [2]. Europe leads the world in bottled water consumption and comprises 34.8% of the market, with the Asia-Pacific region ranking second with a 21.5% market share [2].
1.2.0 Perceptions of Bottled Water

Several factors contribute to the increasing pervasiveness of bottled water. One study published in the Journal of Exposure Science and Environmental Epidemiology attributes the rise of bottled water popularity to distrust of tap water quality, increasing availability, marketing strategies employed by beverage companies, the fashion of appearing healthy, and the awareness of the benefits of drinking water [3]. The same study explores the validity of the perception that bottled water is safer than municipal water. Bottled water can generally be contaminated from impurities in the aquifer (a shared problem with municipal water supplies), particulates from the manufacturing plant, and chemicals from the packaging leeching into the water over time. Even from this relatively simple analysis, it is interesting to note that bottling water fundamentally increases the number of variables that affect the quality of the water—municipal water does not go through all of the processing that bottled water undergoes. As of 2006, an estimated 56% of bottled water was sourced from protected springs, while most other bottled water was sourced from municipal water that underwent a second purification process at the bottling factory [4]. Whether or not this second purification process is beneficial is a strongly contested subject—consumers can pay a markup for bottled water as high as ten thousand times the value of locally provided municipal water [5]. Municipalities are required to follow purification standards set by the Safe Drinking Water Act, so municipal water is, in theory, perfectly safe to drink from the tap [4].

A survey of members of the Purdue University community also provides insight into perceptions of bottled water usage. Similar to respondents mentioned in the Journal of Exposure Science and Environmental Epidemiology article, members of Purdue University who preferred bottled water over tap water chose to do so due to distrust of tap water and the convenience of buying and then discarding the bottles. Some respondents also indicated that they preferred the taste of bottled water to that of tap water. 28.3% of respondents believed that
bottled water usage contributes to “a lot of environmental damage”, while 47.3% of respondents believed that bottled water results in “some significant environmental damage”. Interestingly, when respondents were told to consider the effects of recycling, only 5.1% of respondents believed that bottled water usage contributes to “a lot of environmental damage”, while 37.0% of respondents believed that bottled water results in “some significant environmental damage” [5]. Perhaps perception that recycling dampens the impact of bottled water reduces the guilt of using bottled water.

1.3.0 Water Bottle Manufacturing

1.3.1 Plastic Bottles

Disposable plastic bottles are almost always made from polyethylene terephthalate (PET), a plastic that is both strong and lightweight. Before manufacturing begins, PET is polymerized into a resin consisting of long molecular chains. If the resin is going to be used for carbonated beverages, it will be tested for carbon dioxide permeability. Manufacturing the bottle consists of two steps. Injection molding is first used to make long, thin tubes called parisons. Stretch blow molding is then used to make the final bottle shape. The parison is inserted into a mold with the final bottle form, and a hollow steel rod called a mandrel is inserted into the parison. Air injected through the mandrel causes the parison to expand and take the shape on the mold, creating the final bottle [6]. Bottle caps are either made of high-density polyethylene (HDPE) or polypropylene (PP) through injection molding or compression molding. Reusable plastic bottles are usually made through injection molding.

Manufacturing disposable plastic bottles requires a significant energy input when accounting for raw material production, manufacturing, further water purification, and transport [4]. Creating the PET resin is the most energy intensive process, with an estimated embodied energy of 70MJ to 83MJ per kilogram of PET resin due to required heating (also note that the recycling rate of
PET bottles is less than 30%, so most PET resin is made from virgin material) [4]. Accounting for all of the stages of the water bottle’s life cycle, approximately 5.6MJ to 10.2MJ of energy are embodied within each liter of bottled water, which is roughly two thousand times the energy required to provide one liter of municipal water [4]. Based on 2007 United States water bottle consumption (approximately 33 billion liters), the energy required to produce all of the disposable water bottles in that year accounted for 0.003% of total energy consumption in the United States, which is not trivial considering that disposable water bottles are only one consumer product of millions, if not billions, produced annually [4]. Although reusable plastic bottles are made through a similar process, it is not difficult to see that using one reusable bottle over a time period equivalent to using several hundred disposable bottles can make a significant difference in one person’s equivalent energy consumption.

1.3.2 Aluminum Bottles

Another essential manufacturing process to mention is the production of aluminum bottles, a popular reusable option. The three hour long process begins with aluminum pucks that are put into a punch press and subjected to a 600 ton force, which stretches the puck into a cylinder with a closed bottom. The bottom is trimmed to the appropriate size, and a series of squeeze and thread the open side until it develops the desired bottleneck. The bottle is then cleaned and coated on the inside with a polymer layer, which is baked onto the aluminum surface. After cooling the bottles, a layer of paint is sometimes applied to the outside, which again needs to be baked onto the bottle surface. Any patterns or decals are silk screened onto the outside surface [7]. Producing aluminum bottles is inherently an energy-intensive process due to the repeated heating and cooling of the product, but since aluminum is highly efficient to recycle (recycling requires only 5% of the energy necessary to process virgin material) and is often recycled, the manufacturing loses are offset by this averaging of the raw material’s embodied energy [8].
1.4.0 Existing Cleaning Methods

The difficulty of cleaning reusable water bottles has always been an inherent problem, so it is not surprising that many methods exist for cleaning. This section describes several cleaning solutions and products, assesses the cost, and evaluates the effectiveness of each. Effectiveness is based on the author’s perception of how clean the bottle becomes and how easy it is to clean (which might correlate to how willing a person is to clean the bottle).

1.4.1 Homemade Cleaning Solutions

There are a number of do-it-yourself methods for cleaning water bottles. Some users rinse out bottles with a little bit of water and decide that the bottle meets some standard of cleanliness. More ambitious users might even add soap to the water and shake the bottle before rinsing it. Even more ambitious users might use a type of cleaning solution such as that proposed on the outdoor living brand REI’s website [9]. REI recommends mixing 1 teaspoon of bleach and one teaspoon of baking soda (or antibacterial mouthwash) into a bottle and then filling the rest of the container with water. The user should leave the solution in the bottle overnight before rinsing it out the next day, putting the bottle through a dishwasher cycle, and letting the bottle air dry. This method is suggested for cleaning bottles that develop a foul odor, but it does not address the possibility of having to remove residue from the bottle. The cost of this method is negligible since the portion of bleach and baking soda used is so small. Overall, this method takes several steps to ensure that the bottle is as sanitized as possible, but the time required doing so makes this process less easy for users.

1.4.2 Bottle Brushes

Bottle brushes, such as the OXO Good Grips Bottle Brush shown in Figure 1-1, provide a method to forcefully and quickly remove residue from the inside of water bottles while also allowing users to reach places that they cannot reach by hand. There may be a slight level of distrust, however, since the bottle brush
does not directly solve the issue of not being able to see inside bottles to confirm that they are clean. Bottle brushes are relatively cheap (the brush in Figure 1-1 costs 4.99 USD on Amazon.com) and can last a long time.

![Figure 1-1: OXO Good Grips Bottle Brush. Image source: Amazon.com](image)

1.4.3 Clean Bottle

Clean Bottle, founded by Dave Mayer in 2008, addresses the issue of cleaning with a product line of bottles that have removable caps on both ends, enabling the user to better reach all areas of the bottle (especially if cleaning is combined with a bottle brush). The openness created by the two removable ends also allows better airflow for quicker drying. Two versions of the Clean Bottle, the Original and the Square, are shown in Figures 1-2 and 1-3, respectively.

![Figure 1-2: Original Clean Bottle made of BPA-free plastic, comprising a main body and two detachable ends. Image source: Clean Bottle](image)
Figure 1-3: Square Clean Bottle, made of stainless steel and shaped as a rectangular prism, comprising a main body and two detachable ends. Image source: Clean Bottle [11]

The Original costs 9.95 USD and is made from BPA-free plastic, while the Square (designed as a rectangular prism so it will not roll away on its side) is made of stainless steel and costs 44.95 USD. The company holds two patents, US 8365941 B2 and US D668913 S1, for the Original and Square designs, respectively.

Although the Clean Bottle solution might be one of the most creative, cheap and effective cleaning solutions, having one more part (i.e. the bottom removable piece) increases the chances of misplacing the part. There is also the potential for the bottle to leak from two sides as well.

1.4.4 Bottle Cleaning Tablets

Water-activated tablets that disinfect (and remove the residue from) the inside of the bottle are also available. As an example, disinfecting tablets made by the Swiss bottle company SIGG, shown in Figure 1-4, require the user to add one tablet into water inside the bottle and wait 30 minutes. These particular tablets cost 14.00 USD for a pack of 20 (tablets are often included with
purchases of more expensive bottle brushes), so they are relatively expensive. Nevertheless, the tablets provide one of the easiest cleaning methods.

![Figure 1-4: Bottle cleaning tablets from SIGG, which will disinfect and remove the residue from the inside of a bottle in 30 minutes. Image source: Amazon.com [12]](image)

### 1.4.5 Steam Sterilization

There are numerous devices available that use steam to disinfect bottles, but the main purpose is often baby bottle sterilization. For example, the Philips AVENT Electric Steam Sterilizer, shown in Figure 1-5, is an electrically powered steamer that Philips claims kills 99.9% of germs in 6 minutes.

![Figure 1-5: Philips AVENT Electric Steam Sterilizer, which kills 99.9% of germs in 6 minutes. Image source: Walmart.com [13]](image)
Another version uses the microwave to steam clean bottles. This method is certainly effective and quick, but it is also expensive (range of 45.00 USD to 75.00 USD) and is targeted toward a specific audience.

1.4.6 Rensa

The Rensa water bottle washer and filler, shown in Figure 1-6, was developed during Fall 2010 in the same MIT class (Product Engineering Processes) from which the original idea for the invertible water bottle originated.

![Figure 1-6: Rensa water bottle washer and filler. Image source: MIT Course 2.009 Website [14]](image)

The Rensa system used water heated to temperatures above 170°F to wash and disinfect a bottle for 30 seconds, which the students working on the project claimed killed 99% of bacteria. The system, which also served as a water refilling station, was targeted at fitness centers. Although this system is a unique solution to the problem, its size and (expected) cost would not make Rensa an easily accessible cleaning method.

1.4.7 Disposable Water Bottles

Disposable water bottles, although an indirect method, can be considered a solution since it completely eliminates the need to clean reusable bottles.
Based on where the bottle was purchased and in what volume, the price for a standard 20-ounce bottle can range from 0.25 USD to 2.00 USD. Although this method is “effective” since the bottle will never become dirty, it is certainly not the most sustainable solution.

1.5.0 Prior Art

A thorough prior art search was conducted to explore the originality and patentability of the invertible water bottle design. A patent application (US 2013/0243909 A1) filed by Dan Joyce on 19 September 2013 details an “Invertible Segmented Consumption Container” that comprises a bottom, flexible section that can be detached from a lid and inverted for easier cleaning [15]. The first claim is the most critical, as it makes a general claim for a container with a bottom and cap that are joined by a collar, with the bottom being flexible and invertible. Several notable sub-claims from the first claim include the fifth, which claims an invertible container with a stiff outer shell for more rigid support, and the eighth, which claims collapsibility for storage. The ninth, eleventh, twelfth and fifteenth sub-claims detail invertibility for easier cleaning, a rigid collar version, a threaded collar version, and the use of an eco-friendly material, respectively. Unfortunately, this patent application has a significant crossover with the idea for an invertible bottle (including the name) and covers a significant space of intellectual property. This could pose a problem if the device designed in this thesis were to be brought to market. Nevertheless, this is still a patent application and not an approved patent, leaving the potential that it will not be approved (although that would leave minimal prospects for a patent from this thesis work). This patent application is also the only piece of prior art found by the author that details anything similar to the invertible water bottle.
Chapter 2
Water Bottle Usage and Cleanliness Studies

To better understand how people use water bottles and perceive the cleanliness of a water bottle, two studies were conducted. The first study consisted of a survey on water bottle usage. The second study involved volunteers cleaning different bottle types with different methods and evaluating the effectiveness of each combination. The data from these experiments helps to define the parameters shaping the design of the invertible water bottle.

2.1.0 Water Bottle Usage Survey
2.1.1 Survey Format and Results

An 18-question survey regarding reusable water bottle usage and purchasing habits was created by the author and sent via email to approximately 70 people, most of whom (approximately 60) are undergraduates at MIT. The survey was also sent to the employees of a small running apparel startup company. 35 people responded for an estimated response rate of 50%, and the average age of a respondent was 22.97±1.35 years. 24 respondents indicated they were male, 10 respondents indicated they were female, and 1 respondent did not indicate a gender. The results of the survey, with the number of respondents indicating each option, are shown in Table 2-1. The majority of questions were multiple choice, with some questions allowing respondents to check multiple answers. A few questions asked the respondents to write in an answer.
<table>
<thead>
<tr>
<th>Do you primarily use a reusable water bottle?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>If no, why not? (Write in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inconvenient to carry around</td>
</tr>
<tr>
<td>Too irresponsible/forgetful</td>
</tr>
<tr>
<td>Do not want to clean</td>
</tr>
<tr>
<td>Afraid of cancer implications</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>If yes, what material is it made from?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic</td>
</tr>
<tr>
<td>Metal</td>
</tr>
<tr>
<td>Have both plastic and metal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Where do you usually get your reusable water bottle? (Can select multiple)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free - random events</td>
</tr>
<tr>
<td>Free - sports team</td>
</tr>
<tr>
<td>Free - gift</td>
</tr>
<tr>
<td>Purchased - online</td>
</tr>
<tr>
<td>Purchased - in store</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How often do you get a new reusable water bottle?</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than once per month</td>
</tr>
<tr>
<td>Once per month</td>
</tr>
<tr>
<td>Every 2 to 3 months</td>
</tr>
<tr>
<td>Every 3 to 6 months</td>
</tr>
<tr>
<td>Every 6 to 12 months</td>
</tr>
<tr>
<td>Yearly or less frequently</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>What is your primary reason for getting a new water bottle?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need clean one</td>
</tr>
<tr>
<td>Lost old one</td>
</tr>
<tr>
<td>Want a new design</td>
</tr>
<tr>
<td>Received a new one for free</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Have you thrown out a reusable water bottle because you thought it was unclean?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Describe how you usually clean your water bottle, and how frequently? (Write in)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Why do you use a reusable water bottle? (Can select multiple)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainability</td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>It's fashionable/cool</td>
</tr>
<tr>
<td>Convenience</td>
</tr>
<tr>
<td>Motivation to be healthy</td>
</tr>
</tbody>
</table>

Table 2-1: Results of water bottle usage survey, with the questions in bold and the frequency of each answer indicated (rank-based questions provide mean and error).
Of the 35 total respondents, 77.1% indicated that they primarily use reusable water bottles. Of the remaining 8 respondents who indicated that they did not primarily use a reusable bottle, 4 mentioned that it was inconvenient to carry around, 3 stated that they were too irresponsible and feared losing the bottle, 2 mentioned that they did not want to clean the bottles, and 1 expressed concern about possible cancer implications from the chemicals in the bottle (users were allowed to list an unlimited number of reasons). Also note that some of the respondents who indicated that they did not primarily use a reusable bottle still answered questions targeted toward those who do primarily use a reusable bottle, an unanticipated error that resulted from less-than-ideal survey wording.

Of the 28 respondents who answered the question regarding the material of their reusable bottles, 60.7% use plastic bottles, 28.6% use metal bottles, and 10.7% use both. Of the 31 people who answered the question “Where do you usually get your reusable bottle?”, the majority (64.5%) indicated that they receive them for free from random events, with purchasing online (38.7%) the second most popular option followed by purchasing in store (19.4%), free from sports teams (16.1%), and free as a gift (6.5%). Note that respondents were allowed to select multiple options for this question.

When asked how often they obtain a new reusable bottle, 6.5% of the 31 respondents who answered indicated once per month, while 9.7% indicated every 2 to 3 months, 22.6% indicated every 3 to 6 months, 19.4% indicated every 6 to 12 months, and the majority (41.9%) indicated yearly or less frequently. Of the 32 respondents who answered when asked the main reason for obtaining a new reusable bottle, most (75.0%) indicated that they had lost their previous bottle. 12.5% indicated that they needed a new clean bottle, 6.3% wanted a new design, and the remaining 6.3% received the new one for free. Of the 31 respondents who answered the question, 35.5% indicated that they had thrown out a reusable bottle since it was unclean. Sustainability (71.0%) and cost (67.7%) are the primary reasons respondents choose to use reusable water bottles (31 answered the question), followed by convenience (16.1%), appearing
fashionable (6.5%) and the motivation to be healthy (3.2%). Note that respondents could select more than one answer or write answers in.

The next set of questions asked users to rank the importance of cost, appearance/shape, material, durability, easiness to clean and brand on a 1 to 5 scale when obtaining a new reusable bottle, with the following metric: (1) Not considered (2) Rarely considered (3) Often considered (4) Strongly considered (5) Highest deciding factor. The average ranking for cost was $3.32 \pm 0.19$, the average ranking for appearance/shape was $3.39 \pm 0.14$, and the average ranking for material was $2.84 \pm 0.22$. The average ranking for durability was $3.65 \pm 0.19$, the average ranking for easiness to clean was $2.68 \pm 0.23$, and the average ranking for brand was $2.06 \pm 0.20$.

When asked if they were on a sports team, the 34 respondents who answered mostly indicated that they are not (55.9%), with only 14.7% on a varsity team. The remaining respondents are either on an intramural team (20.6%), a club team (2.9%), or some other team (5.9%).

The question with the most variability in the answer was the write in question asking respondents to describe how they clean their reusable bottles and how often (29 answered). 41.4% of respondents indicated some form of soap and water being used, while 17.2% of respondents use only water. 20.7% of respondents admitted to never washing their water bottles while 6.9% mentioned using a dishwasher. One respondent mentioned letting the bottle soak with a baking powder and water solution and then scrubbing the inside with a toothbrush, while another used the Clean Bottle described in Section 1.4.3. Only one respondent mentioned using a bottle brush. Of the respondents who answered how often they clean their bottles, 4 indicated weekly while another 4 indicated monthly. 3 indicated that they clean their bottles weekly, while 2 indicated that they do so every two to three months. Only 1 respondent mentioned that he or she cleans his or her bottle every day.
2.1.2 Discussion of Survey Results

There are a few key results from the survey that frame the reusable bottle usage habits of the respondents. First, a surprising number of respondents (77.1%) primarily use a reusable bottle, which may indicate that this survey reached and a more environmentally-conscious population. The majority of respondents have reusable bottles for sustainability and cost reasons, again inferring that the respondents are primarily ecological and economically conscious. The majority of respondents who use reusable water bottles use plastic bottles, which may be related to the fact that the majority of respondents receive water bottles for free at random events (plastic water bottles generally appear to be the free gift of choice at career fairs and other expositions). The fact that a large majority (75.0%) of respondents mainly get new water bottles after losing their previous bottles might also indicate why plastic is more popular, as plastic bottles are generally cheaper than metal versions.

No single variable—cost, shape/appearance, material, durability, easiness to clean, or brand—appears to have a significant influence over users’ choice of reusable water bottle. Durability is the highest ranked, at 3.65±0.19, which indicates that users, on average, often consider or strongly consider this aspect. Appearance/shape and cost are approximately equal at 3.39±0.19 and 3.32±0.19, respectively, indicating that these aspects are often considered. Surprisingly, easiness to clean is the second lowest ranking variable, at 2.68±0.23, indicating that users sometimes consider this aspect. Perhaps easiness to clean is an afterthought that is only realized once cleaning is required.

Nevertheless, with 35.5% of respondents indicating that they had thrown out a reusable bottle since it was unclean, there is a relatively strong case for designing a water bottle that easily encourages cleaning. The various responses regarding the cleaning habits and frequencies amongst users also highlights this issue, with only one user cleaning his or her bottle daily and the majority cleaning their bottles in the range of weekly to monthly. Since it would be difficult to
change users habits, the bottle should be designed to be easily cleaned with soap and water.

From a demographic perspective, there are no strong trends. Although a noticeable majority of respondents are male (68.6%), there are no noticeable differences between the answers given by either gender (or the one person who did not indicate gender). There are also no noticeable trends amongst athletes versus non-athletes, or even varsity athletes versus other respondents. Somewhat unexpectedly, only 2 of the 5 varsity athletes indicated that they receive reusable bottles from their sports teams, and the varsity athletes' cleaning habits ranged from daily to never, with no single habit dominating. These results may challenge the assumption that varsity athletes would be more inclined to purchase a bottle that is easier to clean; however, a more thorough survey that reached more than 5 varsity athletes would be necessary to fully analyze potential trends.

2.2.0 Water Bottle Cleanliness Perception Study

2.2.1 Study Format and Results

To better understand how users perceive the effectiveness of various cleaning methods, a test was conducted that required two volunteers (Volunteers A and B) to clean various bottles using different cleaning methods. The first portion of the test involved volunteers using various cleaning methods on a reusable Gatorade-brand bottle often used by sports team, shown in Figure 2-1.
The two volunteers were asked to use the following cleaning methods on the Gatorade-brand bottle:

I. Water only
II. Water and soap
III. Bottle brush only
IV. Bottle brush, water and soap
V. Bleach and water
VI. Bleach, water, and bottle brush
VII. Water, soap and sponge

After completing the test, the volunteers ranked the effectiveness of each cleaning method on a 1 to 5 scale as follows: (1) Bottle is now dirtier (2) No difference in cleanliness (3) Bottle is slightly cleaner (4) Bottle is significantly cleaner, but could be better (5) Bottle is as clean as possible. Figure 2-2 depicts Volunteer B using the various cleaning methods on the Gatorade-brand bottle. Table 2-2 provides the ranking results of the two volunteers.
Figure 2-2: Volunteer B cleaning a Gatorade-brand bottle with (1) water only (2) water, soap and a bottle brush and (3) water and soap only.

<table>
<thead>
<tr>
<th>Cleaning Method</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volunteer A Ranking</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Volunteer B Ranking</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2-2: Volunteer A's and Volunteer B's rankings of the effectiveness of each cleaning method for reusable Gatorade-brand bottle: (I) Water only (II) Water and soap (III) Bottle brush only (IV) Bottle brush, water and soap (V) Bleach and water (VI) Bleach, water, and bottle brush (VII) Water, soap and sponge. Rankings are on a 1 to 5 scale, based on the following: (1) Bottle is now dirtier (2) No difference in cleanliness (3) Bottle is slightly cleaner (4) Bottle is significantly cleaner, but could be better (5) Bottle is as clean as possible.

The second portion of the test required the two volunteers to perform two cleaning methods, water only and bottle brush with soap and water, on four different bottles, the plastic Gatorade-brand bottle from the first portion, a metal bottle, a Vapur bottle (shown in Figure 2-3), and an Original Clean Bottle (as described in Section 1.4.3). Although the cleaning methods were the same for each, the goal of this test was to see if different designs and different bottle
materials affected how the volunteers perceived the cleanliness of the bottles. Figure 2-4 includes pictures from the test, and Table 2-3 displays each volunteer's ranking results, which use the same metric as the first portion of the test.

**Figure 2-3:** The Vapur bottle, made of BPA-free polyethylene and nylon, is a flexible pouch that can be easily rolled for better storage and portability. Image source: Vapur Bottle [16]

(1)  
(2)  
(3)  

**Figure 2-4:** Pictures from the second portion of the water bottle cleanliness test, including (1) bottle brush with soap and water in the Original Clean Bottle, (2) bottle brush with soap and water in the Vapur pouch, and (3) Volunteer A inspecting the inside of the metal bottle after cleaning.
Table 2-3: Volunteer A’s and Volunteer B’s rankings of the effectiveness of (I) Water only and (IV) Bottle brush, water and soap cleaning methods for 4 different bottles: Plastic Gatorade-brand, Metal, Vapur and Original Clean Bottle. Rankings are on a 1 to 5 scale, based on the following: (1) Bottle is now dirtier (2) No difference in cleanliness (3) Bottle is slightly cleaner (4) Bottle is significantly cleaner, but could be better (5) Bottle is as clean as possible.

### 2.2.2 Discussion of Study Results

Regarding the first portion of the test (various cleaning methods for the plastic Gatorade-brand bottle), the two volunteers were generally in agreement with the effectiveness of each cleaning method, with the exception of the bleach-based methods. Volunteer A ranked bleach alone and bleach with the bottle brush as (4) *bottle is significantly cleaner, but could be better* and (5) *bottle is as clean as possible*, respectively. Volunteer B ranked both bleach processes as (1) *bottle is now dirtier* since he believed that the bleach residue and odor remaining in the bottle negatively affected how he perceived the bottle’s usability.

Both volunteers believed that water only and water with soap and a sponge were either not effective or only slightly effective. Both volunteers explained that the weaker ranking for the sponge was due to the difficulty of reaching the sponge into the bottle to clean. Volunteer A believed that only the bottle brush, water and bleach method cleaned the bottle as thoroughly as possible, while Volunteer B believed that only the bottle brush, soap and water
method cleaned the bottle as thoroughly as possible. In general, methods involving the bottle brush were ranked higher, which could mean that people correlate cleanliness with the ability to physically scrub the surface.

In the second portion of the test, the design of the bottle minimally affected the volunteers' perceptions of the effectiveness of the various cleaning methods. Volunteer A perceived no difference between any of the bottles after rinsing them with water, ranking each as (3) bottle is slightly cleaner, and he perceived no difference between any of the bottles after cleaning them with the bottle brush, water and soap, ranking each as (4) bottle is significantly cleaner, but could be better. Volunteer B gave all of the water rinsing trials a ranking of (3) bottle is slightly cleaner, with the exception of the Original Clean Bottle, which he ranked as (4) bottle is significantly cleaner, but could be better since he believed that running water through the entire open cylinder aided cleaning. Volunteer B ranked all of the bottle brush, water and soap trials as (5) bottle is as clean as possible except for the metal bottle since he claimed that the smaller bottleneck and non-transparent material of the metal bottle made it difficult for him to look inside and confirm that the bottle was clean.

After completing the entire test, both volunteers were asked to choose the most effective cleaning method and water bottle combination across all of the trials between the two portions of the test. Volunteer A believed any bottle combined with the bottle brush, soap and water was the most effective since it could reach all areas of the bottle, and he particularly preferred the plastic Gatorade-brand bottle since it had a wider mouth, allowing him to more easily reach and see inside. Volunteer B believed that the Vapur bottle combined with the bottle brush, soap and water was the most effective since “the brush fit snugly into the bottle and was able to clean the sides effectively and efficiently”. He also mentioned that “since you can see inside [the Vapur bottle], there is no doubt whether it is clean or not”. Volunteer B also noted that the Original Clean Bottle was one of the most effective, but he was concerned that he would lose the bottom cap if he were to actually use the bottle.
The volunteers were also asked to consider which cleaning method and water bottle combined that they considered to be both the most effective and the easiest. Volunteer A believed that the bottle brush alone or just bleach and water in any bottle were the easiest and most effective methods. Volunteer A indicated that having to rinse the soap out of a bottle several times before the residue is noticeably gone reduces the ease of soap-based methods. Volunteer B still believed that the Original Clean Bottle with soap, water and a bottle brush was the most effective and easiest since it was a relatively quick process that provided strong visual feedback.

In general, both volunteers valued being able to thoroughly scrub a surface and being able to observe the surface as the most important factors when determining bottle cleanliness. It is important to note that this study only consisted of two volunteers, and a much larger study would provide more statistically meaningful data. Unfortunately, it is difficult to find people who are willing to clean water bottles for 15 minutes, which only further demonstrates the need for a device that encourages good cleaning practice.

2.3.0 Implications for Invertible Water Bottle Design

Both the water bottle usage survey and the cleanliness perception test provide strong feedback on both the validity of the invertible water bottle concept and the design parameters that need to be considered. The water bottle usage survey demonstrated that a considerable amount of people have discarded a reusable water bottle since they thought it was unclean, and the relatively low frequencies of cleaning bottles might indicate that the inconvenience of cleaning the bottle supersedes the need for a hygienic bottle. A bottle that can be inverted for easier cleaning might be a solution that is easy and fun enough for people to clean regularly. The fact that people value durability and cost most when choosing a water bottle, combined with the fact that most people need a new
bottle since they lose their original bottles, means that the invertible water bottle needs to be both inexpensive and robust as well.

The results of the cleanliness perception test indicate that users (or at least the two volunteers in the study) most value the ability to scrub a surface and observe its cleanliness. This deduction supports the principal behind the invertible bottle since having an invertible container allows both optimal contact with and an unobstructed view of the bottle surface.
Chapter 3
The Design Process

In early September 2013, after discarding a reusable water bottle that had developed a pink slime on the inside with an accompanying foul odor, the author began to contemplate methods to encourage better water bottle cleaning practices. With this issue in mind, the author conceived the idea for a water bottle that can be inverted for easier cleaning during a brainstorming session for the Fall 2013 Product Design Processes class (Course 2.009), an undergraduate capstone product development class at the Massachusetts Institute of Technology. The original sketch is shown in Figure 3-1.

Figure 3-1: Original idea for the Inside-Out Bottle that could be inverted for easier cleaning. The initial design involved a rigid top and a series of rigid rings around a softer bag that could be pushed through the mouth of the water bottle.
The original bottle design consisted of a soft plastic pouch surrounded by harder plastic rings for support. The bag had a hard plastic, threaded collar and a hard top. By pinching the rings and pushing them through the mouth of the bottle, the bottle could be inverted or made “inside-out” to allow for easier, direct cleaning. The Inside-Out Bottle concept was presented as part of a “Three Ideas” pitch in front of the Course 2.009 students and faculty, but it was not pursued further since it was not deemed a suitable design project for a team of 20 mechanical engineers.

After researching design conventions for bottles and evaluating the results of the studies outlined in Chapter 2, preliminary concept sketches were made. Corresponding sketch models were then created, and the lessons from these models were considered in a second round of sketch models. With the knowledge from two iterations of sketch modeling, a digital rendering of the current proposed design was made using the Computer Aided Design (CAD) program SolidWorks.

3.1.0 Design Conventions

3.1.1 Standard Sizes and Handle Design Conventions

Simply designing a water bottle with no background knowledge of industry design standards would be an unwise decision since the bottle needs to be comfortable to hold and needs to fit into standardized interfaces such as bicycle bottle cages. Bottle cages typically have an inside diameter of 2.875 inches, and many reusable water bottles have a corresponding outer diameter, which stems from the fact that the average person can comfortably grasp a sphere up to 2.75 inches in diameter [17]. Bicycle cages also have a lip with a diameter less than 2.875 inches in diameter 5 inches away from the base of the cage, so bottles that are intended for bicycles are generally 5 inches long or have a groove 5 inches above the base of the bottle to accommodate for this gripping feature. Disposable plastic bottles have several standard sizes as well, which are shown in Figure 3-
2. Figure 3-3 shows the dimensions of various SIGG metallic bottles. All of these conventions were considered throughout the design of the invertible bottle.

![Figure 3-2: Standard volumes and shapes for disposable plastic water bottles. Image Source: Emerald Valley H2O](image)

![Figure 3-3: Standard dimensions for SIGG metallic reusable water bottles. Image Source: Sigg.com](image)

A guide for surgical handle design published by Michael Patkin of The Royal Adelaide Hospital in South Australia outlines several important design considerations—size, shape, surface, and security against slip—that can be useful for bottle design as well [20]. Patkin mentions that size not only accounts for the physical dimensions but for other, not-as-obvious scenarios such as someone wearing gloves while gripping the product. Regarding shape, Patkin explains that thickening a handle at its center prevents slipping, as does providing the ability to flatten one’s thumb in line with the central axis of the handle in a “power grip”. The surface of a handle should also be made to prevent...
slipping, but over roughening or knurling a surface can also make the handle uncomfortable to hold. Patkin also mentions that gentle finger grooving on a handle provides further prevention against slip, while creating a "pommel", an enlargement of the top end of the handle, can prevent the object from being dropped. Although some of these design considerations appear to be obvious, they are still aspects that can lead to a better user experience.

3.1.2 Specifications for the Invertible Water Bottle Design

Based on the design standards for water bottles and handles and the observations from the water bottle usage and cleanliness perception studies, a few engineering specifications can be derived to define the design process of the invertible water bottle. Namely, the bottle should be able to fit into a bicycle cage if it is to be targeted to a sporting and on-the-go market, and it should be designed with features that prevent slipping when being used. Since people prefer bottles that are durable, the invertible feature needs to be robust, and must sustain several hundred inversions until failure. Since people more strongly consider cost and often lose their bottles, the bottle should cost under a reasonable price limit such as 15.00 USD. Table 3-1 outlines these design requirements. Although there are only a few specifications, they are critical to the design of the water bottle.

<table>
<thead>
<tr>
<th>Customer Need</th>
<th>Product Attribute</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to fit in bicycle cage</td>
<td>Diameter and height of groove</td>
<td>$D = 2.875$ inches $H($groove$) = 5$ inches</td>
</tr>
<tr>
<td>No slippage</td>
<td>Finger groove diameter</td>
<td>$&lt; 2.875$ inches</td>
</tr>
<tr>
<td>Robustness</td>
<td>Inversions to failure</td>
<td>600 inversions</td>
</tr>
<tr>
<td>Inexpensive</td>
<td>Cost</td>
<td>$&lt; 15.00$ USD</td>
</tr>
</tbody>
</table>

Table 3-1: Preliminary specifications for invertible water bottle design.
3.2.0 Concept Sketches

With the preliminary specifications in mind, several concept sketches were generated to explore possibilities for the design of an invertible water bottle.

3.2.1 Segmented Design

The first concept sketch details the original Inside-Out Bottle design. The bottle consists of a soft, plastic pouch with rigid collar that a hard top can be attached to. The rigid support ribs made of a harder plastic surround the softer plastic pouch to provide support. Pinching the ribs and pushing them through the mouth of the bottle inverts the bottle. The ribbed design enables the bottle to be easily collapsible and storable, but it also makes it less vertically stable. The preliminary concept sketch is shown in Figure 3-4.

![Segmented Design Sketch](image)

**Figure 3-4:** Segmented design for an invertible water bottle, consisting of hard plastic ribs surrounding a softer plastic pouch that comprises the main body.

3.2.2 Vertical Support Design

The second set of concept sketches details a bottle similar to the segmented design but with vertical, hard plastic supports along the outside of a softer plastic pouch instead. This design also has a rigid base that can be
pushed from the bottom up through the mouth of the bottle to invert the product. This design eliminates the need to individually push the ribs through as is the case with the segmented design, and the vertical supports make this bottle more stable. The concept sketch is shown in Figure 3-5.

**Figure 3-5:** Design for an invertible bottle with rigid vertical supports surrounding a softer plastic pouch that comprises the main body.

This concept sketch also acknowledges the issue of base design considerations and attempts to address the best way to stress at the junction between the base and the main walls of the bottle. This junction, when inverted, will experience a moment that will attempt to force the wall to pivot 180 degrees. By making the base as thin as possible, there will be less resistance to the bending moment after inversion. Figure 3-6 details this issue.

**Figure 3-6:** Detail of the base design for the bottle. A flatter bottom will allow the wall to pivot around the circled critical point more easily.
3.2.3 Spiral Design

As a more experimental idea, this concept sketch explores a variation of the vertical support design, with the harder plastic vertical supports spiraling around the softer plastic pouch. If possible, it might be a fun and exciting experience for users to twist the bottle and then have the body pop through the mouth of the bottle to be inverted. Figure 3-7 depicts this concept sketch.

![Concept sketch of spiral vertical support design](image)

**Figure 3-7**: Concept sketch detailing a spiral vertical support design, with harder plastic ribs spiraling around a softer plastic pouch body. If possible, a user would twist the body to have the bottle invert itself.

3.2.4 Clamshell Design

In another exploration of methods to allow maximum contact with the inside of the bottle, a clamshell design would consist of a main body (most likely made of metal for rigidity) that would open via a hinge at the base. A middle collar that snap fits to the main body would hold the two halves together, and the lid would fit over this middle collar to seal the bottle. Although this design allows for as much contact within the bottle as possible, there would probably be issues with leaking. Figure 3-8 depicts this concept.
Figure 3-8: Clamshell concept sketch detailing a bottle that opens at a hinge to allow access to the inside. A middle collar holds the two halves together, with the lid fitting over the middle collar to seal the bottle.

3.2.5 Splitting and Stacking Design

Following the inspiration of the clamshell design but providing a more robust solution, a splitting and stacking design would enable easier access to the inside of a metal bottle. These bottles could be made of 2 to 4 segments that fit together through either press fits or threaded collars. Users would be able to customize their bottles by adjusting the heights or even interchanging parts from different bottles to change the colors or patterns of the bottle. Similar to a thermos, the bottom and top portions could be detached to form cups. Figure 3-9 details this concept.

Figure 3-9: Splitting and stacking design for a water bottle that allows for easier access to the inside for cleaning. The segments fit together.
through either press fits or threaded collars, and the height can be adjusted with interchangeable middle segments.

### 3.2.6 Pull String Design

To better assist users with the inversion of the water bottle, a pull string could be attached to the base of the bottle. Pulling on the string guides the soft plastic body of the bottle through the bottle’s mouth to be inverted. The string could be attached to the top piece so it could act as a sturdy handle from which to pull the bottom through, as shown in Figure 3-10. The string would be longer than the overall length of the bottle so the bottom would not be immediately pulled when removing the top, which would be an issue when refilling. By attaching the top piece to the rest of this bottle in this manner, the potential to lose the top is eliminated as well.

![Figure 3-10](image_url)

**Figure 3-10:** Design for a bottle with a soft plastic body than can be inverted by pulling on a string attached to the top of the bottle. Note that the string has slack to prevent the bottle from being immediately inverted when removing the top.
3.3.0 First Iteration of Sketch Models

After completing the concept sketches for the invertible water bottle, various sketch models were made to test how easy it was to invert a bottle based on the proposed designs. Sketch models were made using reusable plastic Gatorade-brand bottles and other household items including plastic wrap and string.

3.3.1 Segmented Design

To test the segmented design, a Gatorade-brand bottle was cut into rings that were then held together with a plastic thread, as shown in Figure 3-11. The plastic thread served to imitate the restrictions the bottle would experience if the entire soft plastic body were included in the design.

Figure 3-11: Sketch model of segmented design with hard plastic support ribs made from a sliced Gatorade-brand bottle.

This sketch model was tested by observing the feasibility of pinching the ribs and pushing them through the bottle mouth, as shown in Figure 3-12.
Figure 3-12: Testing the feasibility of pushing the plastic ribs through the bottle mouth with (1) one rib through and (2) all ribs attempting to go through. Unfortunately, the design would not physically work with the soft plastic pouch included.

This sketch model demonstrated that it was not feasible to have a segmented design that relied on pushing the ribbed sections through the bottle mouth. All of the ribs had to be passed through the bottle mouth at once in order to avoid breaking the strings that connected them (one of the strings broke anyway), and this would not be physically possible if a soft plastic pouch was introduced since the pouch would not stretch enough to accommodate the strain required.

3.3.2 Vertical Support Design

The next set of sketch models explored the feasibility of inverting a bottle with harder, vertical plastic supports. For the first model, a Gatorade-brand bottle was cut so that it had 4 vertical supports, as shown in Figure 3-13. Unfortunately, inverting this bottle was difficult, and the end result did not resemble the inverted form originally conceived. The bottle was twisted and deformed, and it would probably not be easy to clean, either. The results of this test are shown in Figure 3-14.
To further explore the concept of using vertical supports, another sketch model with three vertical supports was created and tested for its ability to be inverted. Figure 3-15 shows this model. This bottle did not invert well (results shown in Figure 3-16), either, although the form was better than that of the four vertical support version.

To further test the ability to invert the model with three vertical supports, plastic wrap was glued to the inside of the bottle to simulate the soft plastic pouch that
the final design would have (shown in Figure 3-17). Inverting this model was especially difficult, and the inverted form did not look like it could be easily cleaned (shown in Figure 3-18). Overall, the vertical support design did not appear to be a feasible option for the invertible water bottle.

Figure 3-17 (left): Sketch model with three vertical supports and plastic wrap glued to the inside to simulate a soft plastic pouch.

Figure 3-18 (right): Inverted form of the bottle with three vertical supports and plastic wrap pouch.

3.3.3 PVC Soft Pouch Design

With the vertical support design eliminated, a design with just a semi-rigid soft pouch for a body was explored. PVC plastic was cut from a collapsible water jug and glued around the inside rim of a threaded collar cut from a Gatorade-brand bottle, as shown in Figure 3-19. The PVC pouch was then pushed through the mouth of the bottle to test the ability to be inverted, which was not easy. Figure 3-20 shows the final form of the inverted PVC sketch model. Like the segmented and vertical support designs, the PVC soft pouch model was not an ideal design for inverting.
3.3.4 Pull String Pouch Design

The final sketch model made in the first iteration of testing was fabricated from a plastic sandwich bag glued to the threaded collar of a Gatorade-brand bottle. A plastic thread was attached from the bottom inside of the bag to the bottle top to simulate the design of pulling the pouch through with a string, as shown in Figure 3-21. This sketch model proved to be successful in demonstrating that a very flexible, thin bag could be pulled through the mouth of a bottle with a string attached to the top. Figure 3-22 shows the inverted form of this sketch model. With the success of this last sketch model, the focus of the invertible water bottle design shifted toward creating a robust pouch and pull string design.
3.4.0 Second Iteration of Sketch Models

Although most of the first iteration sketch models demonstrated that a rigid structure would be difficult to invert, the plastic pouch and pull string design proved to be effective. The second iteration of sketch modeling focused on the design of the pouch itself using woven polypropylene (WPP) and a thin packaging plastic as test materials. Woven polypropylene was originally chosen since it a durable material (the weave provides strength in two dimensions), is thin, and is made of a material (polypropylene) commonly used in water bottles. Unfortunately, the woven strands of the WPP made it difficult to cut since the material would unravel and fall apart. This was partially solved by heat-sealing the frayed ends with a hot piece of metal, but the last pouch sketch model was made with the thin plastic the WPP was shipped in.

3.4.1 Rectangular Woven Polypropylene Pouch

The first WPP pouch used two rectangular pieces of WPP stitched together with plastic thread, as shown in Figure 3-23. A plastic thread was attached to the bottom of the inside of the pouch and was used to try to pull and invert the pouch. This shape was not invertible, and Figure 3-24 shows the result.

Figure 3-23 (left): Sketch model of rectangular WPP pouch with pull string.

Figure 3-24 (right): Failed attempt to invert rectangular WPP pouch.
3.4.2 Triangular Woven Polypropylene Pouch

After the failed attempt to invert the rectangular WPP pouch, a version with two triangular WPP pieces stitched together was fabricated (Figure 3-25) with the idea that the cone shape might be easier to invert. Although pulling the string alone was not able to invert the triangular pouch, the pouch was invertible by hand, as shown in Figure 3-26. The point at the end of the triangular pouch prevented the string from being able to pull the pouch through.

![Sketch model of triangular WPP pouch with pull string.](image1)

![Inverted triangular WPP pouch.](image2)

Figure 3-25 (left): Sketch model of triangular WPP pouch with pull string.

Figure 3-26 (right): Inverted triangular WPP pouch.

3.4.3 Curved Thin Plastic Pouch

Since WPP was difficult to work with, the final pouch sketch model was made from a thin plastic used for shipping packaging. This pouch had a slight taper inward from the opening and curved around a half-circle on the bottom, shown in Figure 3-27. A strip of plastic attached to the inside of the pouch was able to invert the pouch relatively easily when pulled (Figure 3-28), demonstrating a more effective pouch design than the previous WPP versions. After this test, it was determined that the prototype would have a shape similar to a tapered test pouch.
3.5.0 Proposed Design

After completing two rounds of sketch modeling and compiling data from user studies and water bottle design conventions, a full, invertible water bottle design was created. The proposed design, shown in Figure 3-29 as a SolidWorks assembly, in Figure 3-30 as a section view, and in Figure 3-31 as an exploded view, consists of a bottom section, a top section, and an invertible pouch that is secured between the bottom and top pieces. The overall height of the bottle is approximately 7.5 inches, and the largest outside diameter is 2.875 inches.
3.5.1 Bottom Section

The bottom section of the water bottle, shown in Figure 3-32, is made of a harder and more rigid plastic material. This shell provides an outside support for the pouch that can fit into a bicycle water bottle cage while also enabling the bottle to still stand vertically and be firmly grasped by the user. The large open areas in the bottom section allow the user to squeeze the pouch, and the reduction in plastic reduces the cost and weight of the bottle.

Figure 3-32: SolidWorks rendering of bottom section of the invertible water bottle. The large gaps in the bottle reduce the amount of plastic needed for the bottle while allowing the user to squeeze the liquid out of the pouch within.
The largest outside diameter of the bottle is 2.875 inches, and the groove is located 5 inches above the base so the bottle can fit in a bicycle water bottle cage and be comfortably held by the user. The collar of the bottom is threaded so the top can be fastened to securely hold the pouch in between the bottom and top pieces, as shown in Figure 3-33.

Figure 3-33: Section view of invertible water bottle showing the press fit of the pouch between the bottom and top sections.

3.5.2 Top Section

The top section, shown in Figure 3-34, of the water bottle consists of a nozzle to drink from and a threaded base that can be secured onto the bottom section. Small fingertip size grooves along the circumference of the top section base allow the user to more easily twist the section on and off of the bottom section.

Figure 3-34: SolidWorks rendering of the top section of the invertible water bottle. Grooves along the circumference allow for easier attachment and removal of the piece.
Although the resolution of the SolidWorks rendering does not show the feature, the nozzle keeps the bottle sealed when pushed down and unseals the bottle when pulled upward.

3.5.3 Pouch Section

The final section of the water bottle consists of a translucent plastic pouch attached to a rubber ring. The rubber ring creates a watertight seal when the pouch is placed between the top and bottom components, and it also prevents the pouch from slipping and detaching from the assembly. The plastic pouch can be inverted by either pushing it by hand or pulling a string attached to the bottom of the inside of the pouch (not depicted in the renderings). The curved shape of the pouch is based off of the results from the sketch modeling exercises, and the choice of translucent plastic stems from users’ desire to clearly see that the bottle is clean. Figure 3-35 depicts a rendering of the pouch.

![Figure 3-35: SolidWorks rendering of the translucent plastic pouch and rubber ring around the opening. Note that the plastic string that allows the user to pull and invert the pouch through the rubber ring opening is not shown.](image-url)
Chapter 4
Future Considerations

Although the work in this thesis explored water bottle usage, perceptions of cleanliness, and the feasibility of numerous invertible water bottle designs, there is still further research necessary outside the scope and time permitted for what has been a semester-long project.

4.1.0 Overall Design

The current proposed design of the invertible water bottle has been carefully planned, but there are certainly design improvements to be made. The shape of the proposed design uses a lot of first derivative curvatures (called C1), which give the impression of a manufactured and unnatural product. Going forward, a design with a more natural appearance (i.e. second derivative curvatures, or C2) should be explored. The ergonomic factors of the water bottle (and whether or not they are truly important) should be explored as well. An increasing number of products are being designed to be ergonomic, and consumers might prefer their water bottles to be ergonomic as well. Finally, design for manufacturing was somewhat considered in the proposed design, but having an actual vendor provide a quote on the cost to manufacture the product would significantly affect the direction of the design process.

4.2.0 Material Choice

Material choice for the water bottle was lightly explored, but not to the extent of definitively determining which plastics should be used for the first prototype. Given how many variations of plastics are available, the right materials for this product must certainly exist, but it will require a substantial amount of time
to determine the best materials, from the flexible pouch membrane to the plastics used for the top section and nozzle.

4.3.0 Failure Testing

Since the design of the invertible bottle requires an often-repeated deformation of the interior pouch, failure analyses need to be conducted. First, a finite element simulation of the pouch undergoing the expected inversion deformation should be performed to identify stress concentrations and other weak points in the design. After being used to gather user feedback data, the pouch on the first prototype should be inverted until failure to determine the expected life span of the product.

4.4.0 Prototyping and User Feedback

The most important next step is creating prototypes and getting them in the hands of users. All of the feedback observed from users other than the author in this thesis relates to existing water bottle designs and cleaning methods. There are plenty of questions regarding the proposed design that need to be answered: Will people want a bottle with three pieces? Will people like the idea of an invertible water bottle once they can use one? Will people like the idea of the pull string in the pouch? Is the outer shell comfortable to hold? Does the bottle actually fit well in a bicycle water bottle cage? By answering these questions and many others regarding the proposed design, a concrete design direction can be pursued for the invertible water bottle prototypes.
References


