SILENTBRUSH SUSTAINABLE ELECTRIC TOOTHBRUSH - FINAL REPORT

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Abstract
The objective of this project was to design a more environmentally friendly and innovative electric toothbrush that would remedy the flaws that consumers identify in the current market offerings. The most important factors that were considered were ease of use, quality of cleaning, and the sustainability of the materials utilized. Sustainability is a particularly important consideration because toothbrushes are used often and have to be replaced frequently. The plastic that is commonly used cannot be recycled and thus pollutes landfills. The standard electric toothbrush has a myriad of issues, including that it cannot clean hard-to-reach places thoroughly, it wastes excessive amounts of water and toothpaste, and it has relatively short bristle life. After Team ZZZ brainstormed ideas, the use of structured charts and matrixes allowed the team to compare ideas and settle on a new design. It was found that functionality and sustainability issues could be enhanced by implementing a durable mouth-guard like shape and using ultrasound as the means of cleaning. This unique design satisfied the most criteria from the customer needs survey and vastly improved upon the sustainability problems that were inherent in the standard electric brush.

1.0 Introduction

Team ZZZ was charged with the task of reimagining the standard electric toothbrush so that it was more sustainable than the average electric toothbrush. Electric toothbrushes, and the brushing process in general, are very wasteful. There are large amounts of clean water wasted during brushing, and close to 50 million pounds of plastic toothbrushes are simply discarded once they reach the end of their life (West, 2005). As a result, Team ZZZ underwent a rigorous design process to ensure that the product being designed would satisfy what the consumers desired in a toothbrush, to narrow down a large list of ideas to a more manageable list of plausible designs, and to eventually bring these ideas to fruition as a single final product. The design team began by defining their initial design problem. The team then conducted a customer needs survey to better understand the target market. The group then researched other toothbrushes on the market and compared them to the standard electric toothbrush. The electric toothbrush was dissected to better understand the mechanisms inside, as well as understand the limitations of conventional brushing. A large list of ideas for the energy source, signal and material of the toothbrush were brainstormed and organized into a morphological chart, which was then narrowed down using a Pugh chart. A final model was then created which fit the design team's original goals and vision.

1.1 Initial Problem Statement

The goal of this project was to produce an innovative and sustainable electric toothbrush that satisfies the needs of Team ZZZ's target customers. The focus was on creating a product that is environmentally friendly.

2.0Customer Needs Assessment

When attempting to redesign an established product, understanding what features and functions must be improved upon is a pivotal part of the design process. In order to identify these needs, Team ZZZ interviewed twenty fellow classmates using the questions in Appendix A. These questions were devised to provide the design team a better picture of the issues that consumers face with the electric toothbrushes that are in use today. The questions enabled the group to focus their efforts into tailoring a new product to the customers' needs. These needs were listed in Table 1 and then organized into overarching categories and subcategories in Table 2. These categories were arranged in order of importance to the customer as stated in the surveys.

Table 1. Initial Customer Needs List Obtained from Focus Group and Individual Interviews

- Looks good
- Good grip
- Quick charging
- Durable
- Affordable
- Lasts a long time
- Size – not too big and bulky
- Light
- Easy to operate
- Less than $20
- Simple – not too many unnecessary features
- New/different
- Dispenses toothpaste
- Adjusts to customer's brushing style
- Cleans teeth, tongue, and cheeks
- Reduced cleaning time
- Easy maintenance
- Eco-friendly
- Doesn't hurt my gums
- Whitens teeth

Table 2. Hierarchal Customer Needs List Obtained from Focus Group and Individual Interviews

1. Functionality
    - 1.1 Quick-charging
    - 1.2 Easy to operate
    - 1.3 Easy maintenance
    - 1.4 Simple
    - 1.5 New/different
        - 1.5.1 Dispenses toothpaste
        - 1.5.2 Adjusts to customer's brushing style
        - 1.5.3 Whitens teeth
    - 1.6 Cleans teeth tongue and cheeks
    - 1.7 Reduced cleaning time
2. Cost
    - 2.1 Affordable
    - 2.2 Less than $20
3. Structure
    - 3.1 Good grip
    - 3.2 Durable
    - 3.3 Lasts a long time
    - 3.4 Size
    - 3.5 Light
    - 3.6 Smaller brush head
4. Aesthetics
    - 4.1 Looks good
    - 4.2 Relatively maintenance free
5. Safety
    - 5.1 Doesn't hurt your gums
6. Sustainability
    - 6.1 Lasts a long time
    - 6.2 Eco-friendly

2.1 Weighting of Customer Needs

Fully understanding how customers use a product and what aspects they most value is an essential component to the design process. Beginning with a list of customer needs gathered from a market survey, a more precise and meaningful weighted list of customer was derived and constructed from the initial list of customer feedback. A weighted list of customer needs provides important insight into what the customer values as a consumer in comparison to other components of the design. This insight, in return, guided Team ZZZ through the design process as it provided information on which components were more important to the consumer. AHPs were constructed for each main objective and its sub-objectives, and the scores of each objective were compared against each other and organized hierarchically (an AHP was not made for safety because it only has one sub-objective under it and thus does not have anything to compare to). This information allowed Team ZZZ to better meet the desires and needs of the customer.

Figure 1. Pairwise Comparison Chart to Determine Weighting for Main Objective Categories

	Functionality	Cost	Structure	Aesthetics	Safety	Sustainability	Total
Functionality		1	1	1	1	1	5
Cost	-1		1	1	1	1	4
Structure	-1	-1		1	1	1	1
Aesthetics	-1	-1	-1		1	1	-1
Safety	-1	-1	-1	-1		0	-4
Sustainability	-1	-1	-1	-1	0		-4

Figure 2. AHP Pairwise Comparison Chart to Determine Weighting of Main Objectives

	Functionality	Cost	Structure	Aesthetics	Safety	Sustainability	Total	Weight
Functionality	1.00	1.33	2.00	5.00	7.00	9.00	25.33	0.336
Cost	0.75	1.00	2.00	5.00	5.00	6.00	19.75	0.262
Structure	0.50	0.50	1.00	2.00	5.00	6.00	15.00	0.199
Aesthetics	0.20	0.20	0.50	1.00	4.00	4.00	9.90	0.131
Safety	0.14	0.20	0.20	0.25	1.00	1.00	2.79	0.037
Sustainability	0.11	0.14	0.17	0.25	1.00	1.00	2.67	0.035

Figure 3. AHP Pairwise Comparison Chart to Determine Weighting of Functionality Sub-Objective

	Quick Charging	Easy to operate	Easy maintanence	Simple	New/different	Cleans teeth and cheeks	Reduced cleaning time	Total	Weight
Quick Charging	1	0.2	0.4	0.4	0.5	0.33	0.4	3.23	0.054
Easy to operate	5	1	2	2	2.5	1.667	2	16.167	0.27
Easy maintainence	2.5	0.5	1	1	1.25	0.833	1	8.083	0.135
Simple	2.5	0.5	1	1	1.25	0.833	1	8.083	0.135
New/different	2	0.4	0.8	0.8	1	0.667	0.8	6.467	0.1081
Cleans tongue/cheeks	3	0.6	1.2	1.2	1.5	1	1.2	9.7	0.1621
Reduced cleaning time	2.5	0.5	1	1	1.25	0.833	1	8.083	0.135

Figure 4. AHP Pairwise Comparison Chart to Determine Weighting of Cost Sub-Objective

	Affordable	Less than $20	Total	Weight
Affordable	1	0.5	1.5	0.33
Less than $20	2	1	3	0.67

Figure 5. AHP Pairwise Comparison Chart to Determine Weighting of Structure Sub-Objective

	Good grip	Durable	Lasts a long time	Size	Light	Smaller brush head	Total	Weight
Good grip	1	0.8	0.8	1	1	0.8	5.4	0.1481
Durable	1.25	1	1	1.25	1.25	1	6.75	0.1852
Lasts a long time	1.25	1	1	1.25	1.25	1	6.75	0.1852
Size	1	0.8	0.8	1	1	0.8	5.4	0.1481
Light	1	0.8	0.8	1	1	0.8	5.4	0.1481
Smaller brush head	1.25	1	1	1.25	1.25	1	6.75	0.1852

Figure 6. AHP Pairwise Comparison Chart to Determine Weighting of Aesthetics Sub-Objective

	Looks good	Relatively maintenance free	Total	Weight
Looks good	1	0.5	1.5	0.33
Relatively maintenance free	2	1	3	0.67

Figure 7. AHP Pairwise Comparison Chart to Determine Weighting of Sustainability Sub-Objective

	Lasts a long time	Eco-friendly	Total	Weight
Lasts a long time	1	0.5	1.5	0.33
Eco-friendly	2	1	3	0.67

Table 3. Weighted Hierarchical Customer Needs List Obtained from Market Survey

1. Functionality (.336)
    - 1.1 Quick-charging (.054)
    - 1.2 Easy to operate (.270)
    - 1.3 Easy maintenance (.135)
    - 1.4 Simple (.135)
    - 1.5 New/different (.1081)
        - 1.5.1 Dispenses toothpaste
        - 1.5.2 Adjusts to customer's brushing style
        - 1.5.3 Whitens teeth
    - 1.6 Cleans teeth tongue and cheeks (.1621)
    - 1.7 Reduced cleaning time (.135)
2. Cost (.262)
    - 2.1 Affordable (.33)
    - 2.2 Less than $20 (.67)
3. Structure (.199)
    - 3.1 Good grip (.1481)
    - 3.2 Durable (.1852)
    - 3.3 Lasts a long time (.1852)
    - 3.4 Size (.1481)
    - 3.5 Light (.1481)
    - 3.6 Smaller brush head (.1852)
4. Aesthetics (.131)
    - 4.1 Looks good (.33)
    - 4.2 Relatively maintenance free (.67)
5. Safety (.037)
    - 5.1 Doesn't hurt your gums (1.0)
6. Sustainability (.035)
    - 6.1 Lasts a long time (.33)
    - 6.2 Eco-friendly (.67)

3.0 Revised Problem Statement

The information gathered from the customer needs, in conjunction with Team ZZZ's original design goals, allowed the team to revise their initial problem statement. The revised problem is to produce a functional device that effectively cleans teeth, while taking into account the financial needs of the consumers, and ensuring that the product is both innovative and sustainable. The customer needs provided Team ZZZ with much insight on which products consumers were most interested in purchasing and which issues they were experiencing most with their current toothbrushes. For most, cleaning ability was the single most important factor when assessing toothbrushes. Team ZZZ decided that a concentrated effort must go into designing a toothbrush with enhanced cleaning capability and features that set it apart from other toothbrushes that are currently on the market. Another important aspect of the toothbrush is its cost. Many customers voiced concerns over the high prices they face when purchasing toothbrushes. Team ZZZ decided that its toothbrush must be financially affordable without sacrificing the quality of teeth cleanliness. Though sustainability was not as highly prioritized as functionality and cost, many customers still valued sustainability, and seeing as environmental consciousness is a pivotal part of Team ZZZ's values, it remained both a challenge and a goal of the team to ensure that the material used would not harm the environment.

4.0 External Search

An external search was conducted by Team ZZZ in order for them to better comprehend the issues of functionality, cost, and sustainability, and other considerations found in the customer needs survey. Similar products on the market were examined, and assessments were made based on how these other toothbrushes fit the design criteria. Further, research was done in order to determine the aspects of toothbrushes that pose the greatest issues for sustainability, and all of this research was compiled.

4.1 Literature Review

The modern toothbrush, in its familiar form, originated in the late 1930s. However, toothbrushes have been used since ancient times, more than 5,000 years ago. These ancient toothbrushes were sticks that people rubbed against their teeth. Throughout the course of history, many different types of bristles have been used, including the hairs from hogs and boars. Nylon bristles were first introduced at the end of the 1930s, and continue to be the primary bristle material used today. (The Library of Congress, 2010). Electric toothbrushes with oscillating bristles were first introduced in America in the 1960s and have continued to improve in safety and functionality since then (Colgate, 2006). Recently ultrasonic toothbrushes have been introduced into the electric toothbrush market and use ultrasonic waves to clean teeth, allowing for less gum irritation and a deeper clean (Emmi-Dent, 2013).

There are many hurdles to overcome in achieving a sustainable toothbrush. The toothpaste industry is a giant multibillion dollar industry that is projected to reach a net worth of $12.6 billion dollars by 2015 (Global Industry Analysts, Inc., 2010). The scale of this particular market not only has economic impacts but ecological ones as well. Triclosan and potassium nitrate are both common toothpaste ingredients that have been shown to increase bacterial resistance in the human mouth. These chemicals also pose a risk to marine environments when washed down the drain (Murielle, 2011). In addition, large-scale toothpaste production and distribution have dire environmental repercussions. In 2006, over 356 million kilograms of toothpaste were traded globally. Carbon emissions and pollution released during production and distribution cause harm to humans as well as the environment as a whole (Block, 2006). Another concern for toothbrush sustainability is the excessive waste of water. According to research done by the American Dental Association, the average American brushes their teeth for 46 seconds. ("Many 'too Busy for a Proper Brush' of Their Teeth.", 2010). If just one average American does not turn off the faucet while brushing their teeth, he or she will waste around 684 gallons in one year (Bussell, 2009). Beyond the water waste, the materials that make up a toothbrush are not very sustainable. Toothbrushes are designed to last for 3-4 months and because of this America alone discards over 50 million pounds of toothbrush waste every year (West, 2005). This is incredibly detrimental to the environment and is a main guiding point as the design team creates its product.

4.2 Patent Search

In order to ensure that the design was not infringing on preexisting products, Team ZZZ conducted research on preexisting patents related to electric toothbrushes. An Art-Function Matrix was created to compile the patents collected in this search. It relates the part to the function it performs.

Table 4. Art-Function Matrix for Electric Toothbrush

	ART			
FUNCTION	Bristles	Back of brush head	Motor	Brush head
Teeth cleaning	DE 3334841 A1			
Tongue and gum cleaning		US 8359693 US 3254356		
Oscillation			WO 2003082049 A1	
Ultrasonic cleaning				DE 102012021262 WO 2009108262 A4

4.3 Benchmarking

In deciding that innovation was one of the team's goals, Team ZZZ compared three other toothbrush designs that are currently on the market. The other toothbrushes were the Colgate 360° Optic White, the Blizzident, and the Emmi-Dent Ultrasonic Toothbrush. The Colgate toothbrush was chosen as a template for the standard electric toothbrush that could be readily identified as such by a consumer. The Blizzident, although it is not an electric toothbrush, was chosen because its design shape was vastly different from the standard. The Emmi-Dent toothbrush was selected because its utilization of alternate technology. Team ZZZ explored aspects of each of these various toothbrushes in order to augment the functionality of the team's toothbrush to suit its customer's needs. By choosing these three distinct toothbrushes, Team ZZZ was able to construct a comprehensive view of how its product would eventually compare to innovative products on the market. To quantify the comparison, a benchmarking table broke down each product based on different features. Each product was ranked on a five point scale as follows: 1- strongly disagree, 2- disagree, 3- neutral 4- agree, 5- strongly agree.

Table 5. Benchmarking of Four Products

Feature	Emmi-Dent Ultrasonic 	Blizzident 	Colgate 
Packaging	2	N/A	3
Aesthetics	4	2	4
Ease to clean	5	4	3
Convenience of on/off switch	5	N/A	5
Safety	4	3	5
Cleaning Effectiveness	5	5	4
Cost	3	3	5

4.4 Product Dissection

In order to get a better idea of the electric toothbrushes that are already on the market, Team ZZZ took apart a Colgate 360° Optic White Electric Toothbrush. Energy consumption levels were measured in order to see how energy efficient the benchmark toothbrush is. These measurements gave the team perspective on how energy is currently used and how it could be better used in a different design.

The pictures in Figure 8 show each individual piece of the toothbrush. The parts include the battery casing, the brush head, the motor, the rotating metal rod, the oscillating bristles, the non-oscillating bristles, the spring, and the battery.The motor supplies rotational motion to the mechanisms within the brush head, which is converted to translational motion that allows the bristles to oscillate rapidly. The battery casing is sufficiently waterproof to allow the user to run water through the handle to clean the build-up of dirt from daily use.

General Product Information:

How many detachable pieces does the product have? 3

Part number:Part name:

1. Head of toothbrush
2. Body
3. Battery case

Part number:	Material & Functional Description:
1.	Top circle of nylon bristles that swivels back and forth; lower set of U-shaped nylon bristles that remains stationary; back of head includes rough surfaced tongue and cheek cleaner made of rubber-like material; the head includes an elongated neck that is attached to the body.
2.	Plastic body that encloses on DC motor with external on and off switch.
3.	Plastic bottom of toothbrush that holds two AAA batteriesthat attach to the motor inside the body

Is it easy to detach each part?

Part number:Detachment (Easy, difficult, use of force etc.):

1. Easy
2. Easy
3. More difficult – requires a force both backwards and downwards

Describe the packaging. Is it easily opened? Describe the opening procedure.

Easy-to-open packaging. Packaging back had thin perforated plastic that allowed it to be easily torn to gain access to the tooth brush. The whole packaging was clear plastic that allowed for top of toothbrush to be easily viewed. Packaging included red paper that showcased the features of the toothbrush.

Table 6: Product Features

Product: Colgate 360 Optic White Electric Toothbrush	
Packaging	● Packaging successfully highlights the features of the toothbrush, presenting the features in a fashionable way. ● Unnecessary amount of plastic
Aesthetics	● Blue and green bristles stand out against white and silver handle and brush head; very modern looking
Cleaning	● Swiveling brush head provides more thorough clean ● User can pour water into casing to clean brush
On/off switch location	● Naturally placed location for thumb use
Power location	● Practically placed farthest away from the location of toothbrush that is most likely to come in contact with water
Ease of switch use	● Moderate; on button is pressed with ease but off button requires a moderate to significant amount of pressure to turn completely off
Handle (Ergonomics)	● Sufficient amount of grip, ergonomic shape ● On/off switch at convenient location
Quality	● Reasonably good quality; made of durable plastic ● Nylon bristles seem to be able to last the expected three months
Safety	● The fact that you can pour water into the casing may or may not be unsafe. There doesn't seem to be enough of a separation between the handle and the battery casing to prevent water damage and a possible short circuiting that could pose a safety hazard.
Versatility, attachments	● Probably isn't versatile. Mostly just brushes your teeth. ● Could be used for other household cleaning applications.
Weight with components	● Not much heavier than a normal toothbrush, even with all components ● Not overly bulky ● Weight distribution allows the toothbrush to stand up on its own.
Environmental Friendliness	● Excess plastic in packaging; only needs to cover toothbrush ● Disposable batteries are not as environmentally friendly over; more waste; should consider rechargeable batteries
Other features	● Can replace brush head. Can rinse inside body of brush.

Table 7: Background Research

Cost	• Unit:
	  ○ Amazon: $3.05
	  ○ Target: $5.99
	  ○ eBay: $9.99
	  ○ Drugstore.com: $8.49
	• Cost of replacing brush head:
	  ○ Amazon: $3.50 (approx.)
	  ○ Drugstore.com: $3.98
	• Cost of replacing batteries:
	  ○ Various sources: $1 (approx.)

How long has the product been on the market?	• Approximately 3 years based on the patent date
Target population	• Anyone who brushes their teeth • People above the age of 6, with parental supervision if younger
Product Versions	• Most other versions of the product are not electrically powered • Some are rechargeable
Improvements between versions of product	• Rechargeable toothbrush improves cist efficiency of toothbrush for consumer • Offers better clean because of moving and stationary bristle • Less expensive over time because of replaceable heads
How is it sold?	• Drug stores and department stores • Online
Patented Features	• Oct. 21st, 2010: Colgate patented toothbrush with power head • Feb. 7th, 2013: Colgate patented powered toothbrush with rotating sections

Table 8: Noise Measurement

Location:	Noise Level:
Brush head 4 in. away from decibel meter	77.8 dB
Brush head 3 in. away from the decibel meter	79.4 dB
Brush head 2 in. away from decibel meter	81.5 dB
Brush head 1 in. away from the decibel meter	82.8 dB
DC motor 4 in. away from decibel meter	45.1 dB
DC motor 3 in. away from the decibel meter	48.7 dB
DC motor 2 in. away from the decibel meter	51.5 dB
DC motor 1 in. away from the decibel meter	54.5 dB

Approximate duration of brushing per day: 4 minutes/day
Average noise level during brushing: 80.7 dB

2. Power Measurement:

Voltage supplied to the circuit:

	Battery Type	**Volts (V):**
Battery 1	AAA	1.587
Battery 2	AAA	1.585

Total Voltage:

	Connection Type	**Volts (V):**
Battery 1 and Battery 2	Series	3.173

Current Measurements	**Averaged Current Value**
No load condition	4.62

Load condition(s)

1. 4.50
2. 4.00
3. 3.26
4. 3.92

Mean current 'under load': 3.92 A

	Voltage		**Current**		
Power (no load) =	3.172 V	X	4.62 mA	=	14.655 x 10^-3 Watts

	Voltage		**Current**		
Power (under load) =	3.172 V	X	3.92 mA	=	12.434 x 10^-3 Watts

3. Battery Life

1. Number of hours available per single battery 'under load' conditions: -3.26 Hours
2. Estimate duration for each brushing: .073 Hours
3. Number of days before battery replacement: 49.9 Days

Table 9: Bill of Materials

Product Manufacturer/Model Number: Colgate 360 Optic White Electric Toothbrush

Date: February 3rd, 2014

Disassembly method: hand, hacksaw, pliers
Subtract and Operate Procedure (SOP): Yes, No
Diagram: Yes, No

Part #	Part Name	QTY	SOP Effect	Function	Mass (lbs)	Material	Manuf. Process	Dimensions	Cost
1.	Package	1	Yes	Holds toothbrush during shipping and marketing	0.020	Plastic, paper	Blow molded	9” x 2” x 1¼”	$0.10
2	Brush Head (without bristles)	1	No	Extending the bristles into the mouth	0.022	Plastic, rubber, aluminum	Injection molded	3 5/8” x 3/8” diameter	$0.20
3	Handle	1	Yes	Used to hold toothbrush while in use	0.032	Plastic, rubber	Injection molded	4” x 1” diameter tapers to ½” diameter	$0.40
4	Battery Casing	1	Yes	Keep the battery in place and allow for battery replacement	0.018	Plastic	Injection molded	1¾” x 1” (average) diameter	$0.20
5	Oscillating Bristles	1	Yes	To clean teeth	.0002	Nylon, plastic	Polymerized and spun, injection molded	½” diameter x ½” bristles	$0.20
6	Center Non-Oscillating Bristles	1	Yes	Conventional Brushing	0.001	Nylon, plastic	Polymerized and spun, injection molded	¼” diameter x ½” bristles	$0.15
7	Non-Oscillating Bristles	1	Yes	Conventional Brushing	0.003	Nylon, plastic	Polymerized and spun, injection molded	½”x ½”x⅝” bristles	$0.20
8	AAA Battery	2	Yes	Power source	0.026	Potassium hydroxide and zinc	Mixing electrode materials, coating, sealing	1 ¾”x ⅜” diameter	$0.50
9	Motor	1	Yes	Transform chemical energy into mechanical energy	0.080	Steel, copper, plastic, rubber	Casted, coiled wires, injection molded	2 ⅞” x ⅞”x ¾"	$1.50
10	Rotating Metal Rod	1	Yes	Extending the mechanical energy in the motor to the head of the brush	0.008	Aluminum, plastic	Casted, injection molded	3 ¼”x 1/16” diameter	$0.15
11	Spring	1	Yes	Connecting the batteries	0.001	Steel	Casted, coiled	¼” x ¾”	$0.01

Figure 8: Visuals of the Dissected Toothbrush

 Figure 8.1: Package	 Figure 8.2: Brush Head	 Figure 8.3: Brush head (2)	 Figure 8.4: Handle
 Figure 8.5: Battery Casing	 Figure 8.6: Oscillating bristles	 Figure 8.7: Center non-oscillating bristles (1)	 Figure 8.8: Non-oscillating bristles (2)
 Figure 8.9: Battery	 Figure 8.10: Springs	 Figure 8.11: Motor	 Figure 8.12: Rotating metal rod

4.5 Design Target

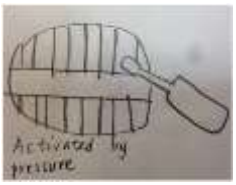
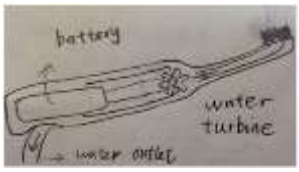
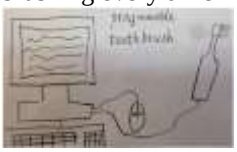
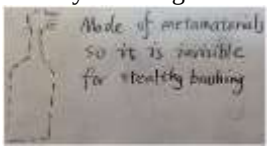
After examining patents and comparing them to the customer needs, Team ZZZ found many interesting and useful facts about toothbrushes. The patent search revealed that the electric toothbrush has been around for a very long time, but has not fundamentally changed in structure or functionality since its conception. However, when other similar products in the market were examined, a few revolutionary new designs were uncovered. The Blizzident reimagined the shape of the toothbrush, making it more retainer-shaped and with an emphasis on the number of bristles to improve cleaning rather than the electric functions. The Emmi-Dent revamped the normal toothbrush's

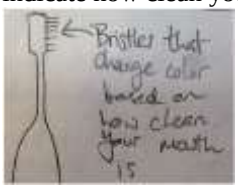
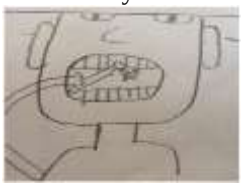
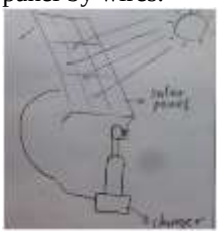
cleaning style, using ultrasound rather than bristles and toothpaste to clean teeth. These other products gave Team ZZZ ideas on how to see beyond the familiar toothbrush design and hopefully create a product that can revolutionize the way people maintain good oral hygiene.

5.0 Concept Generation

After analyzing other products on the market, Team ZZZ began to brainstorm ideas for a new concept. Each team member individually filled out a morphological chart for possible signals, materials, and forms of power for the brush, which was then compiled into the comprehensive morphological chart below. From the chart, the design team discussed which ideas were most plausible and discarded the ideas that could not be utilized. A blackbox model, as shown in Figure 9, was used during this process to simplify the process. A black box model shows what inputs are put into the system and what outputs result, while ignoring the mechanisms of the system that convert the inputs to the outputs. This type of model simplifies the design process for a design team because it allows the team to concentrate its energy on deciding what should go in and what should come out of the system without getting confused by the more complicated technical detail in between. These techniques helped Team ZZZ to narrow down their large list of concepts to a more manageable number.

Table 10: Morphological Chart

Signal(input to the system)	Material	Power Generation
Activated when saliva is detected 	Recycled plastics	Rechargeable batteries 
Activated when a pressure is applied on the bristle 	The body of the brush is a mirror	Thermal energy from water and water turbine 
Connected by WiFi to the computer, this allows you to customize your brushing every time 	Body made by memory foam which can adjust for user to enable comfortable handling 	Hand crank 
Standard on/off switch 	Body made by starch and bristle made by tissue/fiber 	Shaking powered - electromagnetic induction/Faraday coil 
Turn on/off with your mind 	Made with metamaterials for stealthy brushing 	Squeezing sides to produce power 

Timer to avoid overbrushing 	Color-changing bristles to indicate how clean your mouth is 	Utilize natural electricity present in human body 
Switch on/off by verbal command 	Use of ultrasound to kill bacteria, transmitter attached to palm 	Solar-powered and connected to the panel by wires. 
Use of piezoelectric material to generate ultrasonic wave to clean teeth. When used, put the retainer into your mouth and then immerse your teeth with water.	Handle made with leather	
Detector that automatically adjusts speed, vibrating amplitude to achieve better cleaning		
Use of operational amplifier to accurately adjust the motion of the bristle.	Copper flecks in bristles to kill bacteria	
Switch on/off when the handle is touched	Nylon bristles	
Scent detector located on bristle to give suggestion for the amount of toothpaste used, the type of toothpaste used and the time taken for brushing	Aluminum casing	

*Cells without drawings are better explained in words

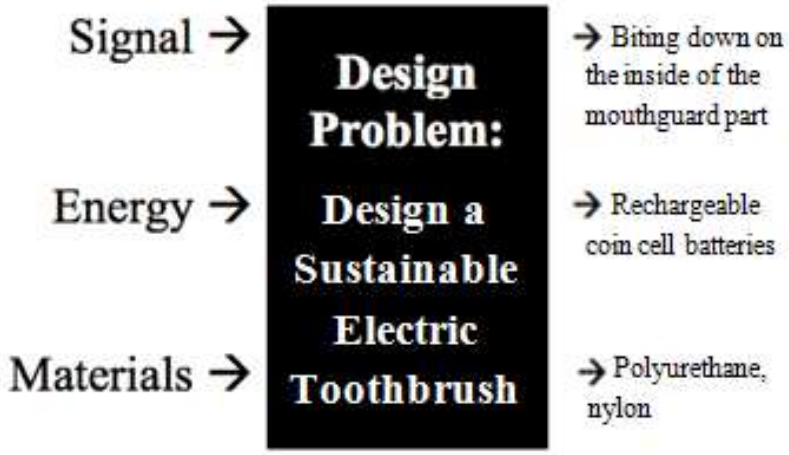


Figure 9. Black Box Model

6.0 Concept Selection

Team ZZZ used established concept selection methods and diagrams to reduce the vast list of generated concepts down to the most plausible ideas. Following careful deliberation, the design team decided on 3 concepts that would improve upon problems that were discussed in the customer needs survey, particularly in sustainability. The Pugh chart is the chart below that compares the newly generated concepts to the standard electric toothbrush design, which is called the datum. Plusses are placed in each criteria where the concept design exceeds the datum, zeroes where the concept and the datum are approximately equal, and minuses where the datum design exceeds the concept. The final scores are calculated by multiplying the number of plusses and minuses by the weight of the category (which were taken from the AHP above) and then adding them together to provide a net score. The 3 included designs were:

Concept 1:Brush with biodegradable starch head, on/off button, Faraday coil for power generation from shaking, andcolor-changing bristles to indicate when brush must be disposed

Concept 2:Brush with copper flecks in bristles to kill bacteria, activated by touching to teeth using a spring to complete a circuit,powered by temperature differentialof water running over thehandle

Concept 3: Mouth guard like shape that utilizes ultrasound to kill bacteria, turned on by biting down, minimal toothpaste and water, and rechargeable batteries

Concept 3 was the clear choice once the net scores were calculated, since it has the only positive score of the three.

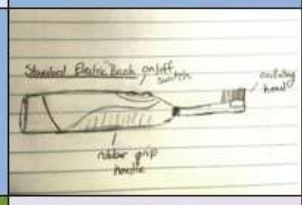
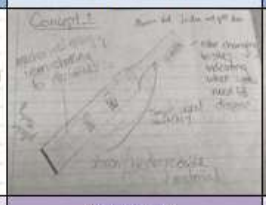
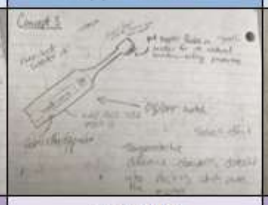
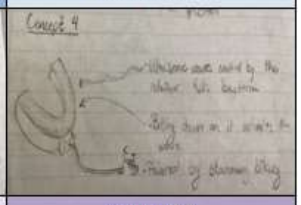
Description		Standard Elec. Brush	Starch Head	Copper Bristles	Mouth Guard
Sketch					
Criteria	Weight	Datum	Concept 1	Concept 2	Concept 3
Functionality	0.336	0	0	+	++
Cost	0.262	0	-	-	--
Structure	0.199	0	-	0	+
Aesthetics	0.131	0	0	-	+
Safety	0.037	0	+	--	-
Sustainability	0.035	0	++	+	++
+		0	0.107	0.371	1.072
0		6	2	1	0
-		0	0.461	0.467	0.561
Net Score		0	-0.354	-0.096	0.511

Figure 10. Pugh chart

7.0 Final Design

Team ZZZ's final design, named SilentBrush, employs ultrasonic technology for the cleaning process. The structure of the final design resembles a mouth guard with small protrusions in the inner lining. Made of recycled polyurethane, this design is more sustainable than the standard electric toothbrush. Powered by a battery, the design uses a piezoelectric technology. This reduces the need for toothpaste and decrease the amount of waste from toothpaste as well. The SilentBrush, would be sold in reusable case as to avoid unnecessary packaging. Drawings of the final design are included in Appendix B. Seeing that cost was one of the most important customer needs, creating a product that would be a less of a financial burden to the customer was one of Team ZZZ's goals. Due to the longevity of the design and the lowered use of toothpaste, the long term costs of the SilentBrush would be less than the average toothbrush. This is modeled by the two Net Present Value timelines (5 years) below, which takes into the account a customer would spend on a product over a period of time relative to current prices and inflation.

Figure 11. SilentBrush Net Present Value

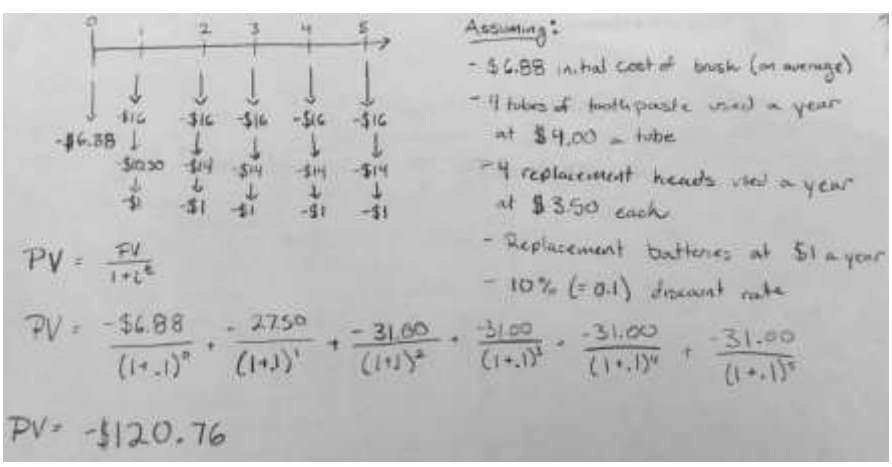
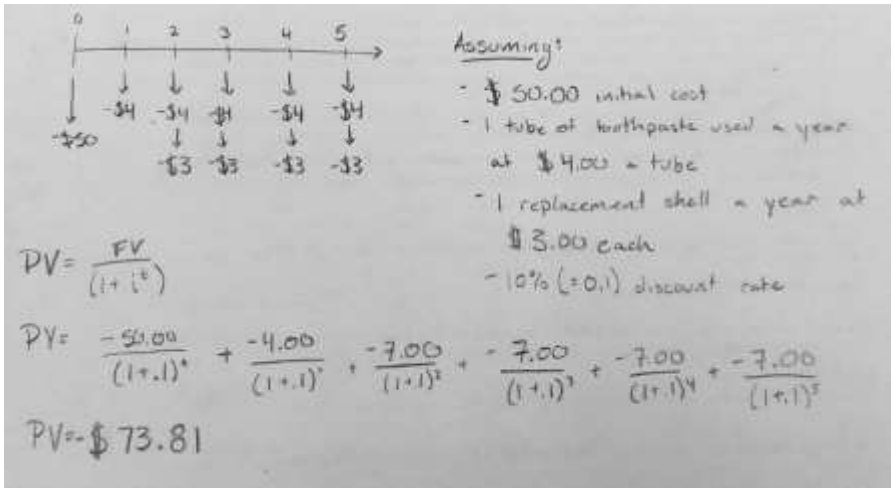


Figure 12. SilentBrush Net Present Value



7.1 Design Drawings, Parts List and Bill of Materials

Table 11: Bill of Materials

Product Manufacturer/Model Number: SilentBrush									
Date: March 7th, 2014									
Disassembly method: hand **Subtract and Operate Procedure (SOP):** Yes, No **Diagram:** Yes, No									
Part #	**Part Name**	**qty**	**SOP Effect**	**Function**	**Mass (lbs)**	**Material**	**Manuf. Process**	**Dimensions**	**Cost**
1.	Outer Shell	1	No	Hold the form and contain the transducer and wire	0.05	Recycled Polyurethane Elastomers	Polymerization, molding	Varying depending on sizing (Adult small 2.25”x 2.5”x 0.75”)	$0.25
2.	Inner Lining	1	No	Translates ultrasonic waves from transducer to medium/teeth	0.03	Nylon	Polymerization, molding	Varying depending on sizing (Adult small 2.10”x 2.35”x 0.70”)	$0.25
3.	Wires	10	No	Transfer electricity	0.020	Wire	Coil	Varying lengths	$0.10
4.	Recharge-able Lithium Ion Coin Cell Battery	2	No	Power the transducer during use	0.024	Lithium	Assembly	0.67” diameter x 0.12”	$1.00
5.	Power Cord	1	Yes	Bring electricity from outlet to battery	0.034	Rubber with wires	Coating	30”	$0.15
6.	Case	1	Yes	To protect the SilentBrush when not in use and for sale	0.033	Recycled Polyurethane	Injection Mold	2.75” x 3” x 1”	$0.10
7.	11W Piezo-electric Transducer	2	No	Creating ultrasonic sound waves	0.330	Lead zirconate titanate	Assembly	3”x 0.15”x 0.25”	$7.00
8.	Gel Battery Casing	1	Yes	Prevent battery leakage	0.027	Baking soda mixture surrounded by plastic	Blown plastic and filled	.75” diameter x 0.30”	$0.20

7.2 How does it work?

The SilentBrush works through the use of ultrasonic technology. Other products on the market that employ this technology share the appearance of the standard, commonplace toothbrush. They include the standard handle, the standard brush head, and the standard bristles. However, instead of being used to brush your teeth, the bristles vibrate rapidly, creating millions of oscillations per minutes that create the ultrasound that dislodges the bacteria and plaque from the teeth (Emmi-Dent, 2013). Although these ultrasonic toothbrushes have solved many problems that are present in a standard toothbrush (reaching behind braces or wiring, cleaning tongue and gums), the shape and structure of these oral cleaners have failed to evolve alongside the technology. Team ZZZ reimagined the way that a toothbrush could be utilized. The hands-free approach that the team envisioned combined with the ultrasonic technology already on the market creates a revolutionary new way to brush teeth. The product is hands-free because it incorporates a design akin to a mouth guard. An advantage of this design is that it allows ultrasonic waves to be directed at teeth and gums from two distinct directions simultaneously, rather than from the typical one direction. This design will drastically cut down on cleaning time and is estimated to take less than 15 seconds. The design will also provide a better clean and will produce healthier gums.

The SilentBrush contains three rechargeable lithium-ion coin cell batteries. The significant amount of power generated and the small size of these batteries make them an ideal energy source to power the ultrasonic toothbrush. The batteries can be recharged using a power cable that can attach to and detach from the SilentBrush and be plugged into any standard electrical outlet. The SilentBrush takes advantage of piezoelectric technology to produce the ultrasound that is used to clean teeth. Found within the center of the mouthguard-like structure are piezoelectric transducers. A piezoelectric transducer converts the electrical energy from the coin cell batteries into sound energy in the form of ultrasonic waves. The power used to convert the electrical energy into sound energy must remain below 50 Watts as ultrasound has only been found to be safe in the human body up at or below this power level (Emmi-Dent, 2013). Inside a piezoelectric transducer is some form of piezoelectric material. Whenever alternating current is passed through this certain type of material(like lead zirconate titanate), it deforms and reforms at very high frequencies and produces ultrasonic waves. (Beiking Ultrasonic, 2012). These waves are transmitted to the nylon texture that lines the inside walls of the SilentBrush. A fluid is required to act as a medium between the ultrasound of the nylon bristles and the teeth and gums. The ultrasound causes the fluid to form microscopic bubbles which surround both teeth and gums. These bubbles eventually implode due to the high frequency of the ultrasound and provide a thoroughly clean the surfaces they implode on by breaking down bacterial cells and removing stains (Emmi-Dent, 2013). Ordinary tap water works as a fluid, but is not as effective as a gel or toothpaste so it is recommended to use a cleaning gel or paste once every four uses.

8.0 Conclusions

Team ZZZ undertook an extensive design process before the final product was generated. The process began by identifying the problem statement. The team then thoroughly researched toothbrushes, with an emphasis on electric models and designs. By doing so, the team gained a better understanding of how the mechanisms of an electric toothbrush work. With this knowledge in mind, the team searched for patents on current technology and explored electric toothbrushes on the market, which guided the team's brainstorming process as potential concepts were generated. Various ideas for energy, signal and material of the toothbrush were expressed, the whole list of which was eventually whittled down to three main concepts that were comprised of different combinations from the main list of energy, signal and materials. After comparing the costs and benefits of each design, Team ZZZ chose the SilentBrush as the final design product to move forward with. This design was successful because it satisfied the requirements of functionality and sustainability that were put forth in the problem statement. The innovative design and the incorporation of ultrasound were the main improvements in functionality. The truly unique features include the hands-free mouthguard design, the use of ultrasound, and the lessened need for toothpaste. These features are a step above what is currently on the market, or at least combine the ideas behind multiple products in order to create the most versatile brush for any consumer. The drastic reduction in water and toothpaste use due to the use of ultrasound make the toothbrush more sustainable than the industry standard. The rechargeable batteries also mean that the batteries do not have to replaced as often, which adds to the sustainability. The durable polyurethane material prolongs the life of the toothbrush, which means that despite its technological complexity, will last longer than most toothbrushes, thus justifying the higher price.

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Appendix A: Customer Needs Survey

Market Survey

1.) What is the most important aspect of a toothbrush to you?

2.) How much would you be willing to pay for an electric toothbrush?

3.) What do you consider to be the perfect size for a toothbrush?

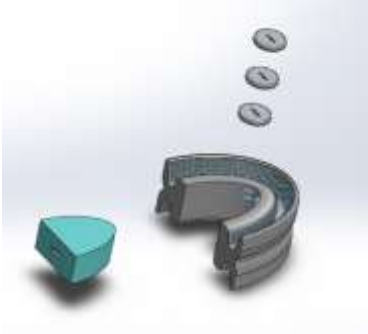
4.) What features do you think would improve an electric toothbrush?

5.) Does your current toothbrush hurt/irritate your gums or any other part of your mouth?

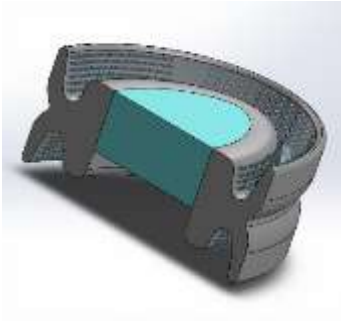
6.) How important is sustainability to you in your toothbrush choice?

Appendix B: Final Design Drawings

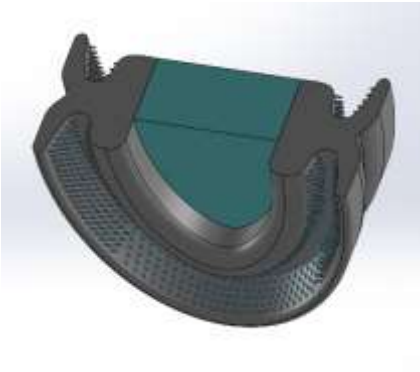
B1. Figure 13



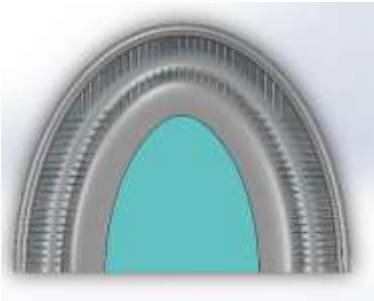
B2. Figure 14



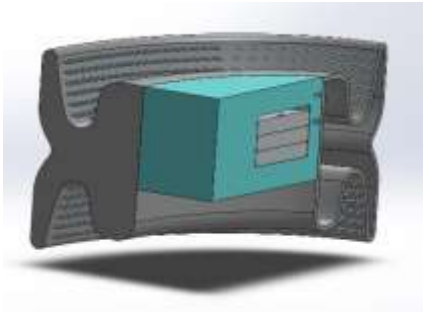
B3. Figure 15



B4. Figure 16



B5. Figure 17



B6. Figure 18