Smart Electric Toothbrush

with Basal Body Temperature Project

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Background of the market

The smart electric toothbrush can be defined as a toothbrush with an electric engine and different types of sensors. The sensors in the electric toothbrush can measure pressure on the teeth, map the position and the angle of the mouth where the brushing is operated. They always include a timer of two minutes, the recommended brushing time from dentists, and also different functionalities and multiple cleaning modes.
Many smart toothbrushes keep track of the brushing history and performance, to give a better sense of how to improve the brushing. Furthermore, the apps that pair with many of these toothbrushes also feature games, coaching, and rewards to appeal to kids and adults alike. These goals and rewards offer additional motivation to brush properly. When you reach a goal, you may get a virtual trophy or achievement like in video games. For kids, the games turn the chore of brushing into an activity that they can enjoy. Overall, the results equal better oral health. {1}

The smart electric toothbrush market is growing at a very fast rate and is estimated to be worth 4,7 Billion dollars by the year 2025. This growth is owned by the awareness of oral diseases, that directly impacts the awareness on how important oral hygiene is. Also the technological changes are increasing and this is another factor for the growth of the electric toothbrush diffusion.
Even governments and dental institutions try to wake up the awareness for the electric toothbrush, they take initiative to convince people that the smart version is much better than manually brushing. {2, 3}
The sector of the electric toothbrush is innovative and companies try to match customer preferences and the dentist recommendation for toothbrushing. It's estimated that the demand for this industry will rise higher than expected, because of the increased oral diseases. The CAGR growth for the industry is around 7,76% and it is forecasted for the year between 2019-2025. {2}
The smart electric toothbrush market is the biggest in Europe with 66% of the market shares. In North America they have 13,9% of the market shares and the remaining market shares are divided between Asia between China and Japan, with 6,06% and 6,2% of the total market. This data was collected in the year 2016.
The smart toothbrush market is dominated in Europe and in the USA. The main reason for this domination is the high affordability for a smart toothbrush in those continents and consumers' preferences for premium dental care. Another reason is that in the USA and Europe there's a coordinated effort to develop smart toothbrushes that use high technology to saturate the consumers preferences, and it's mainly driven by countries like Germany, France, Italy, Netherlands and Sweden. {4}

Basal Body Temperature

BBT is the temperature of the body at rest and is defined from the word *basal* that means rest. There are many articles that point out that BBT data collected can chart up menstruation cycles for women in an effective way. The main reason for this is that BBT is influenced by reproductive hormones, like progesterone, so when a woman has ovulation there is a small increase of temperature.

Therefore, the BBT hardware can help in making a prediction and map up the menstrual cycle for feminine consumers, but also to detect other diseases that cause a hormonal variation, because fertility isn't the only thing that may influence the BBT. These factors can also have an impact:

- stress;
- sleep cycles that are interrupted, or getting too much sleep;
- shift work;
- illness, like hypothyroidism;
- travel and changes in time zones;
- alcohol;
- gynecological disorders;
- some kinds of medications. {5, 6}

To measure the BBT is necessary to follow some basic rules:

- Every morning before getting out of bed, take your temperature using the same method each time, it can be an oral, vaginal, or rectal reading.
- Take the temperature as close to the same time every day, trying to stay within 30 minutes of an average time.
- Have a minimum of six hours of sleep before measuring.
- Plot the thermometer number on a chart. Over time, a pattern may begin to emerge. {6}

Objective of the research

The point objective in this research is to analyze the market for smart toothbrushes and design a smart solution which is able to measure, record and transmit the BBT through a temperature sensor integrated in the hardware.

The goal of the new product will be not to be just a toothbrush, but also to allow us to easily collect data on body temperature to detect diseases and understand the metabolic changes for a person.

<u>Cost-Benefit Matrix</u>

The current market of smart toothbrush is mainly made up of three established companies, Colgate, Oral-B and Philips Sonicare, which started from the oral hygiene market of manual toothbrushes, then moved to the electrics and now to the smart version of them.
In 2019, the French start-up Y-Brush joined the competition with an intelligent toothbrush innovative in shape and material.
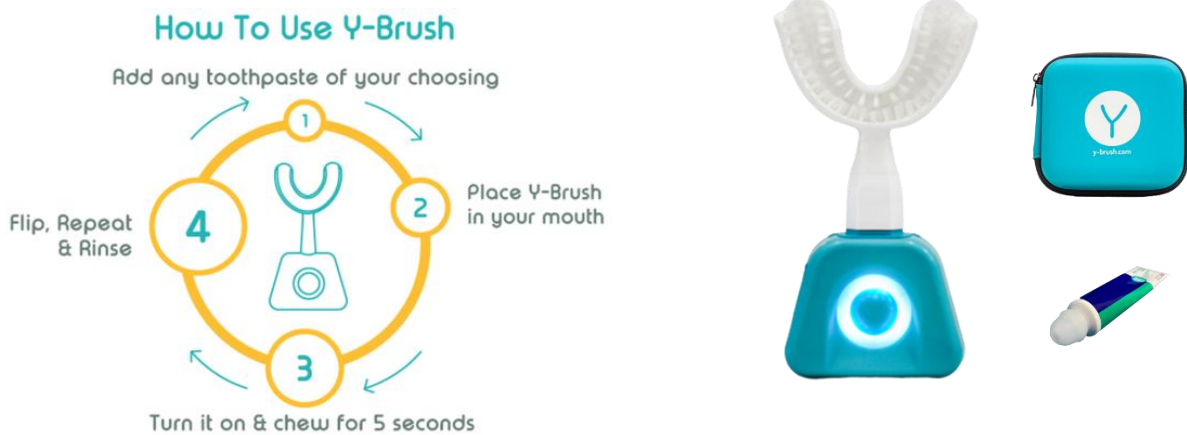

Figure 1: Y-Brush

It resembles a sports mouthguard packed with nylon bristles. Y-Brush technology reproduces the correct gestures (the Bass method of toothbrushing) and uses sonic vibrations. These vibrations allow the 35,000 nylon filaments lining the brush to remove the dental plaque. So, it does a simultaneous in-depth cleaning of all your teeth in 10 seconds only.

Through the analysis of the market we found eleven models of smart toothbrush considered the best currently on sale on the market:
- Colgate Connect E1 Smart Toothbrush;
- Colgate Plaqless Pro;
- Oral-B 7000 Series with Bluetooth & App;
- Oral-B Genius 8000;
- Oral-B iO;
- Oral-B White Pro 1000;
- Philips Sonicare DiamondClean Smart Toothbrush;
- Philips Sonicare FlexCare Platinum Smart Toothbrush;
- Philips Sonicare HX6321/02 Kids Connected Toothbrush;
- Philips Sonicare ProtectiveClean 4100;
- Y-Brush.

Therefore, we have built the advanced Cost-Benefit matrix, using the features and functionalities of smart toothbrushes as indicators of benefit, including also innovative functions such as the Plaque-detecting mechanism, and prices and brushing time for the cost part.
In particular, the benefit rating is composed of seven indicators, with a weight of 15% each, except for the presence of a timer, to which we have assigned only 10%, since all models are equipped with a timer and this indicator does not really affect the final result.

The indicators are:

- Timer (that make a sound after two minutes, the time recommended by dentists for brushing teeth);
- Mouth mapping sensors (able to recognize which area of the mouth or which tooth is being brushed);
- Pressure sensors (that recognize how much pressure you are putting, too much pressure damages the gums and too little pressure means not brushing well);
- Plaque-detecting mechanism (works via a light on the underside of the brush head, which makes plaque look blue; the sensor detects those blue areas and when you've successfully removed the plaque, the light turns white and you can move on);
- Multiple cleaning modes (the possibility to choose the mode to brush your teeth, such as daily clean, gum care, sensitive, whitening, intense, etc.);
- Coaching app (the toothbrush connects to a dedicated app on the phone through Bluetooth connection; the app is a digital coach to help you brush teeth correctly in real-time, to ensures that you cover all areas of the mouth and surfaces of the teeth, then it pulls up the data summary after each brushing session; you can also view high-pressure dentition maps to learn where you need to apply less pressure and view trends based on your recorded brushing history);
- Kids friendly structure (if the shape of the toothbrush is suitable for children, or there is a special head just for them).

The cost rating is composed of two prices, the toothbrush one and the refills, and the time required to brush, because every toothbrush requires 2 minutes, except for the Y-Brush that requires only 10 seconds, so this difference had to be highlighted positively.

Regarding the price, we decided to report both the price of the first purchase of the toothbrush, and the price of the single refill, because it is recommended to change the head of the brush every 3-4 months, so it is an expense to be incurred at least 3 times a year.

The price of the toothbrush always includes at least one brush head, the body, the charging station and sometimes even a travel pack; while the price of the refill refers to a single new head, even if they are usually sold in packs of 4, to have the stock for a whole year.

The resulting Cost-Benefit matrix is shown below. In particular we have highlighted the most important areas, in gray the death zone, in red the red ocean and in blue the blue ocean.

It is evident that there are no toothbrushes in the death zone, with high cost and low benefit.

Instead we see some models in the area of low cost and low benefit, including the innovative Y-Brush, because it is not equipped with mouth mapping and pressure sensors, plaque-detecting mechanism or a coaching app.

The center is a competition area, populated by five toothbrushes from the three main brands, with two models each from Colgate and Philips Sonicare, competing with each other. Actually, Colgate toothbrushes are located far enough apart, at least in terms of price, but the two Philips Sonicare toothbrushes are relatively close to each other in cost and benefit.

Then there is the Blue Ocean area, where only Oral-B 7000 Series with Bluetooth & App is able to position, thanks to a benefit of 1.45 for a cost of 79.3.

Finally, another model of the same brand, Oral-B iO, boasted as the best on sale by the manufacturer, is located in the lower right area, with a high benefit for a high cost. The high cost and benefit values actually reflect the brand's intention to make it the top of the range, but outside the competition zone.
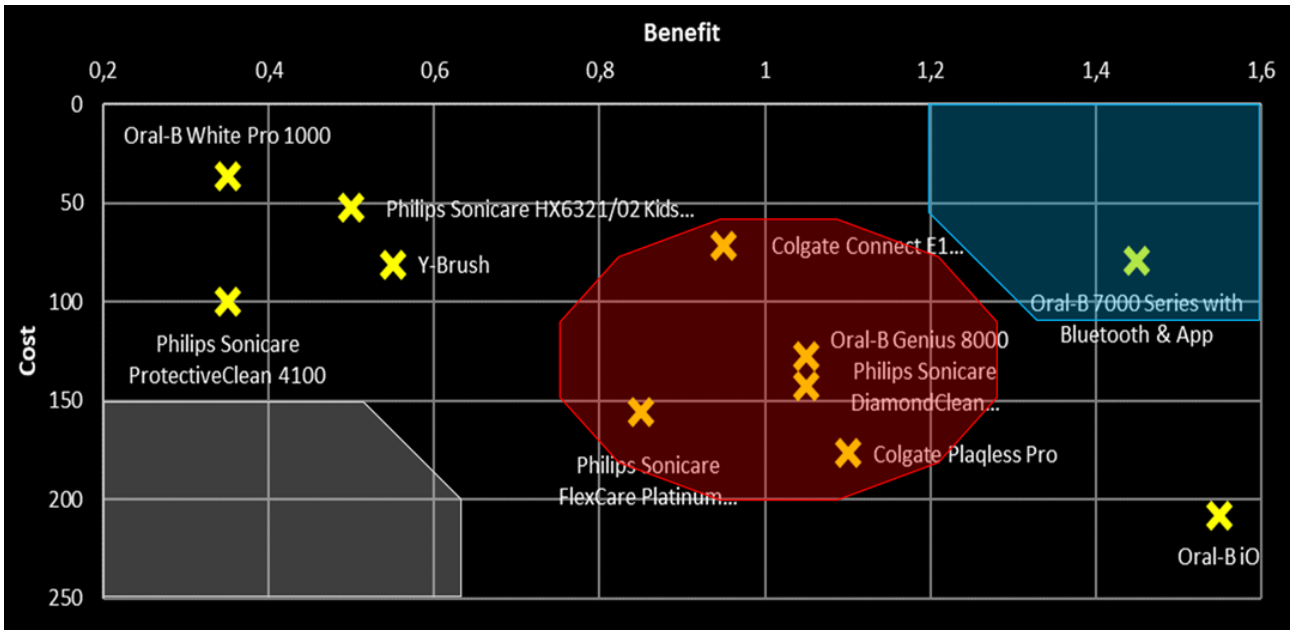
Figure 2: Cost-Benefit matrix

Value Strategy Canvas

We then carried out a second, more in-depth, analysis of the same eleven best models on the market, the Value Strategy Canvas.

As typical characteristics of the market, we have chosen nine factors, some already used in the Cost-Benefit matrix (timer, mouth mapping sensors, pressure sensor, multiple cleaning modes and coaching app) and some new ones, such as:

- Quiet motor (to evaluate the noiselessness of the engine, on a quiet/medium noisy/noisy scale);
- Kids friendly (to study both the kid-friendly structure and the presence of interactive apps dedicated to improving their oral hygiene);
- Duration (intended as the duration of a single toothbrush battery charge, which varies between 7 days of the Oral-B White Pro 1000 and 30 days of the Y-Brush);
- ADA accepted (the ADA Seal of Acceptance is to this day recognized by dentists and consumers as the gold standard for evaluating safety and efficacy of dental products).

For the new value proposition we have focused on technological innovations applied or related to the market under analysis.

The first characteristic is the Extra features that the various toothbrush models are equipped with, such as Vibrating Sonic Technology or 3D Teeth Tracking and AI Recognition. In this section we have given importance to the innovative nylon filaments structure and shape of the Y-Brush.

In second position we find the sale through E-commerce, which for each brand can be done directly through their e-shop or through the Amazon portal.

Then we reported here, as a third characteristic, the peculiarity of the reduction of the Y-Brush brushing time by 91.67% compared to the two minutes required by the other models.

Lastly, we have chosen two competitive factors included or not in each of the analyzed models: Interaction with wearable and Data Analytics. The first concerns the possibility that the smart toothbrush interacts with one of the wearables on the market, as well as the phone, and in the Colgate case, the toothbrushes can be directly connected to the Apple smartwatch. The second factor is the performance of data analytics by some of the coaching apps connected with the toothbrushes, that records the brushing history, filtered by week, month, and year, and analyzes it to give individual coaching tips and insights tailored to each unique brushing behavior. This tool has revolutionized oral health, because statistics show that brushing with a smart toothbrush connected with the app transforms the brushing behavior: over 90% of brushing sessions last longer than the dentist-recommended 2 minutes with almost no instances of overly applied pressure.

All the characteristics just mentioned have been analyzed through appropriate units of measurement and then reported in a scale from 1 to 5 in the second part of the model. The final result is the Value Strategy Canvas shown below.

Overall the graph is uniform, so each model has some features and is lacking in others, but we could see that the toothbrush with the best properties is the Oral-B iO (in light green), as it was highlighted in the Cost-Benefit matrix.

In some cases the characteristics of the models are the same, therefore with equal score, and the lines of the graph overlap.
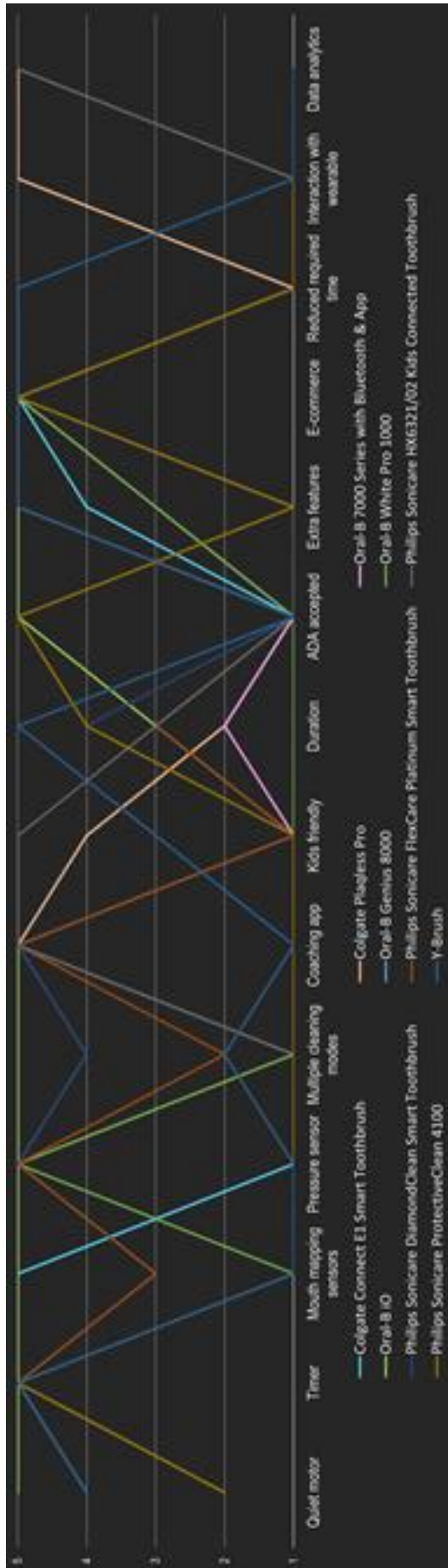
Figure 3: VSM

Customer Tier Analysis

We are going to focus on three different tiers, with the goal of breaking free from the current market and investigate different consumers in other markets to expand the firm's range. The tool personas will be used to explain the segmented tiers and the main goal is to investigate and collect factual information about the different personality of the user and consumer.
- The first tier is about non customers that are on the edge to jump in and buy the product.
- The second tier is about non customers that concisely purchase different products, because the actual product of the firm does not attract them.
- The third tier is mainly about unexplored customers and non-customers that are at a big distance from the market.

Figure 4: Customer Tier Analysis

The customers of the current market of smart toothbrushes are people with an interest in smart innovations, looking for a way to make every day toothbrushing easier and more effective. These young women and men are very active on social media, like Instagram, Twitter and Snapchat and everyday are affected by what celebrities, influencers or other people show and advertise. So they become curious to new trends, new technologies and new self-care products and desire to be like the celebrities who always show themselves on screen with a very good picture of their teeth.

Our clientele includes Malin, a young woman, who is entering now in the job world after completing a master's degree in Business Administration and dreams of a future as CEO in a large company.
Malin, 24 years old, has Swedish origin, but is living in London for her university studies. She is now looking for a job, the first step towards a brilliant career as a manager.
She grew up in a large family, as the eldest daughter, with two brothers and a sister. She has always shown herself to be responsible and capable, especially at the eyes of her parents, ever since she babysat her younger siblings to put away some money.
During the school years she was never the brightest of the class, she didn't like history, geography and even literature, but she was committed to study even the less interesting subjects because she wanted to be a good role model for her brothers and sister.

She has always been a very tidy girl with a strong sense of organization in her life and in her daily activities. She divided her time between school, studying, caring for her brothers, riding horses and seeing her friends.

She has confidence in her abilities, thanks to her parents' education, so she decided to go abroad to do her degree because she wanted to put herself to the test and stand out.

She has a lot of attention to oral hygiene and wants to keep the brushing process of her teeth under control, to make sure they are clean and white.

As every 24-years-old, she follows many celebrities and influencers on Instagram and sometimes gets influenced by them if she finds them interesting. A year ago she saw an advertising for a smart toothbrush and went quickly to buy it, out of curiosity. In the last 5 years she has always used the electric toothbrush, that was recommended by her dentist, so she was even more attracted by the new features offered by the smart toothbrush, such as mouth mapping and pressure sensors and data analytics of the coaching app.

After using it, she recommended it to his family and friends, saying also that a good smile is a business card in the job world.

Every day she includes toothbrushing in her beauty routine, which is best done thanks to real-time monitoring from the app, and for a few minutes she feels just like the influencers that she follows on socials.

Regarding the introduction of BBT measurement into the toothbrush, we have three types of personas, which we will explain below.

Tier 1 - soon to be customers

Women that want to be pregnant can use the BBT data to map up the menstrual cycle to know when they are most fertile, while keeping a very good oral hygiene. So we present *Jasmine*, 34 years old, married for 5 years and living in a little city in the south of Sweden. She works as a school teacher, after graduating from educational and sociology studies.

Her ambition was to become a researcher in the field of child sociology, but during the University she found a job in an elementary school and she was very happy to be able to educate, teach and raise the new generation of children.

Her monthly income is stable, along with her husband's one, and thanks to the fact that her grandparents left her their home as an inheritance, they do not have a mortgage and so manage to set aside a small sum every month.

She is a socially active person and loves to organize fika and dinners to invite friends to spend time together. She is an excellent cook; she uses her grandmother's recipes to amaze her friends with different dishes every time. She also has many ideas for children's food and her friends, already mothers, often turn to her for advice on children's nutrition.

She is trying to get pregnant for 6 months now, so the main subject of discussion between her and her friends are all the methods, even the funny ones, to get pregnant as soon as possible. They discuss mostly what they find on the internet, but also old recipes from their mothers, like drinking ginger and lemon.

Jasmine is influenced by celebrities and online shopping on social media. At the moment she follows lots of pregnancy pages, that also advertise mapping apps to predict the menstrual cycle and every symptoms related to it.

Feeling connected to this matter, Jasmine spends time looking at some of the recommended apps and searching on the internet products for self-care. She is even the kind of person that likes to read reviews before she buys a product and look at YouTube videos of unpacking, to get a picture of other users' experience.

Lately, Jasmine started training more and keeping fit, because she has read many articles and newspapers online that has inspired her to train and be healthy to get pregnant and lead a safe pregnancy.

The smart toothbrush with a BBT sensor integrated in the hardware is the optimal solution for Jasmine, to take advantage of the sensors of pressure, mouth mapping, plaque-detection and timing and the data analytics of the app, to implement a better oral hygiene, but also to measure her BBT temperature in the morning and chart her fertile phases.

Tier 2 - refusing customers

The elderly part of the population, people not active socially and without information about the usefulness of data collection on BBT.

Lisa is a 70-years-old, who used to work as a secretary in a law firm. She spent her life working long hours and managed to create a family with her husband and their two children, who recently made them grandparents of a pair of twins. Currently the economic situation of the couple is stable, as they receive their monthly pension, but in the past, they used their savings to buy a house for each of their two daughters.

As retired people, she and her husband take care of grandchildren every morning and spend the afternoons out in nature having long walks, reading, watching their favorite programs on TV or playing the violins.

Lisa and her husband have created their own routine that they love to follow, including eating well and varied to stay healthy. She doesn't like to take any medicine, so she sticks to the old methods handed down from her mother and grandmother and so far, has not had any particular health problems.

When it comes to lifestyle, she remembers that her mother always told her to lead a simple life, well connected with nature, to be happy. She isn't interested in new techniques, because they seem too complicated and for example, she takes care of her oral health with a regular toothbrush, as since she was young.

Her main source of information is the advertising on television, since she doesn't use social media or chatting apps, but rarely trusts advertisements; instead, she prefers to listen to the advice of her friends and daughters.

Therefore she is not aware of the beneficial factors for her type of persona of the collection of daily data of the BBT, like the detection of hormone variation. So the smart toothbrush could easily provide her with the ability to measure her BBT on a daily basis, to monitor changes and contact a qualified expert only if needed, as a prevention action.

The most effective methods to convince her to buy it would be the word of mouth and positive reviews from people she trusts.

But, most of all, it would be important that the change to an electric toothbrush should be accompanied by a daughter's or an expert's assistance to learn how to take advantage of the simplest features that the smart version offers, for a more effective brushing and reduced visits to the dentist.

Tire 3 - unexplored customers

People suffering from Hashimoto's thyroiditis without being aware of it.

Christian is Swedish 45-years-old, born in Uppsala and living in Karlskrona with his family.

He has two children, who go to primary school, and numerous nieces and nephews, with whom he loves to spend his free time.

He has always used a manual toothbrush to brush his teeth and very often brushes his teeth for less than two minutes because he does not count them and thinks that 40-50 seconds are enough.

He graduated from Uppsala University with a bachelor's degree in economics and a specialty in sales management.

As a true Swede, he likes to cycle to work, even on rainy days and he works for a multinational household appliances company as a sales manager for 10 years.

For about 6 months now, he has been complaining of physical tiredness, a melancholic mood and difficulty in concentrating at work. In recent months, he has also started to experience muscle and joint pain while cycling and poor digestion and constipation.

He therefore consulted his doctor, who among other possibilities suspected hypothyroidism and prescribed blood tests.

Hashimoto's thyroiditis is a frequent form of hypothyroidism, more common than one may think, official statistics say it affects 5% of the population, and its incidence is steadily increasing from generation to generation.

Many patients wander from one doctor to another without anyone seeming to understand what is wrong with them. They continue to be unwell but their laboratory tests are within the normal range and the doctors then say that it is just stress, or anxiety, or the passing years.

The blood tests commonly used today to diagnose hypothyroidism often fail to detect it because there is a problem in the metabolism of circulating hormones.

There are many cases of hypothyroidism where tests are within the normal range and which can only be diagnosed by the skill and clinical experience of the doctor supported by careful observation of signs and symptoms and empirical methods such as the Barnes Test.

The Barnes Basal Temperature Test measures a patient's body temperature at rest to determine whether they are in a hypometabolic, normal or hypermetabolic state. As the thyroid gland regulates how much the body consumes, a low body temperature will correspond to reduced metabolic activity and therefore a likely state of hypothyroidism.

The test should be repeated for at least five consecutive days, and values below 36.5°C are suggestive of hypothyroidism, and the lower these values are, the stronger this possibility becomes.

In addition, the Barnes Test is to be conducted repeatedly during the course of the healing therapy, together with other periodically repeated medical checks.

Therefore, the smart toothbrush with thermometer head offers the possibility to carry out the Barnes Test for the detection and treatment of the disease and in the meantime to significantly improve the oral hygiene of the patient.

Focus on pregnancy theme

After developing the Customer Tier Analysis, we decided to focus on the first tier, women who want to get pregnant, because for them the measurement of BBT is essential to maximize the chances of conception. This makes them highly likely customers.

To ensure a good job, we decided to apply the empathy model to better describe the persona and develop another Cost-Benefit matrix, populating it with methods available on the market to measure ovulation and the fertile phase.

The empathy map is a useful tool for studying and comprehending the persona's characteristics in more detail and adapting our product to her needs.

The following map was built through a brainstorming process and it reports tasks, feelings and influences, but also pain points and overall goals of a 34-years-old Swedish woman.
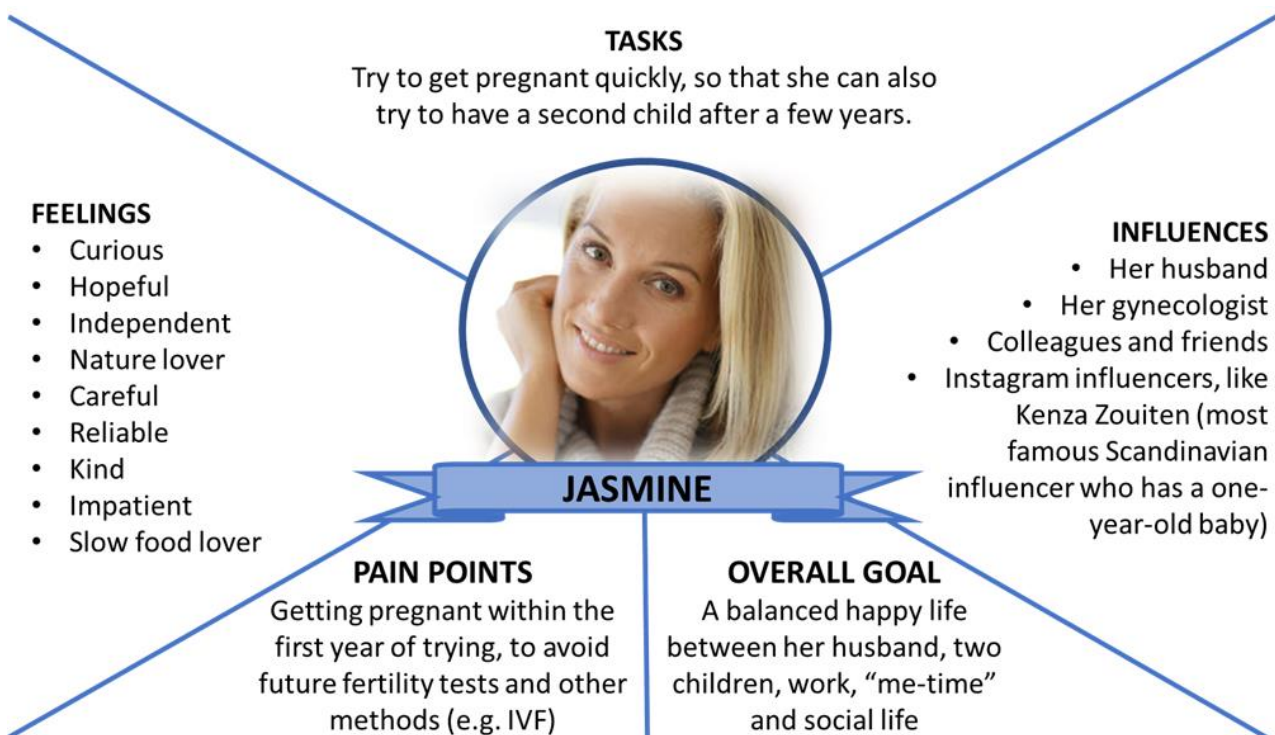

TASKS
Try to get pregnant quickly, so that she can also try to have a second child after a few years.

FEELINGS
- Curious
- Hopeful
- Independent
- Nature lover
- Careful
- Reliable
- Kind
- Impatient
- Slow food lover

INFLUENCES
- Her husband
- Her gynecologist
- Colleagues and friends
- Instagram influencers, like Kenza Zouiten (most famous Scandinavian influencer who has a one-year-old baby)

JASMINE

PAIN POINTS
Getting pregnant within the first year of trying, to avoid future fertility tests and other methods (e.g. IVF)

OVERALL GOAL
A balanced happy life between her husband, two children, work, "me-time" and social life

Figure 5: Empathy Map

Regarding the creation of the Cost-Benefit matrix on ovulation measuring products, we found nine ways available on the market, divided into three categories:
- thermometers to measure BBT (it is important to measure your temperature for three months to understand what your basal temperature baseline is);
- ovulation sticks (they measure the urine concentration of a hormone, LH Luteinizing hormone, which increases when you are about to ovulate, on average 20 sticks are used each month);
- mathematical calculation through a smartphone app of the most fertile days of the month (using the so-called Ogino-Knaus method and requires at least one year of data to be efficient).

Lastly the ninth tool is *Eveline prediction kit*, which transforms the smartphone into a modern fertility guide, combining LH diagnostic strips with a patented technology that allows the phone camera to

track LH surges with pinpoint accuracy; it also simplifies the recording process while the built-in AI algorithm calculates the ideal timing for intimacy.

The benefit indicators we have chosen, through the study of methods and the market, are the following.
Accuracy: the accuracy in the detection of fertile days, based mainly on the categories previously presented (the thermometers exploit the BBT, with a medium accuracy towards ovulation, the sticks exploit the detection of hormones in urine, then with a very high accuracy towards ovulation, and the app uses a mathematical calculation, which does not take into account countless external factors, then with a very low accuracy towards ovulation).
Efficiency: intended as the efficiency of the method within its own category. For thermometers, the best is the Digital Basal Thermometer, because it's more accurate in the measurement; for the stick, tests with double hormonal indicators are more effective than tests with one hormonal indicator. The final calculation of the values were then revised according to the efficiency of each category of belonging.
Easy to use: for easy handling of the tool.
Clear results: easy to read and interpret the results (for BBT you need a graph that shows the daily measurements of multiple months, so the single measurement is easy to read but with little value alone; the sticks are complex to interpret if they are traditional and very simple in the digital version, likewise the app is very easy to read).
Build-in graphs: only Eveline Prediction Kit detects the data and creates a monthly graph.
AI Forecasting: Eveline's AI algorithm tracks and learns unique cycles of a woman, then sends automatic alerts when ovulating and lets her know when it's time to test again.
Instant efficacy: indicator to give weight to the fact that it takes three months of BBT measurement to make the thermometers effective and at least one year of menstrual cycle duration data to be entered in the app.
The weight assigned to each of the indicators is 10%, except for Efficiency, which weighs 40%, to show both the efficiency of the individual tool and the category it belongs to.

Regarding the cost, the only indicator is the price in euros, as it has a significant influence on the method chosen by each woman.
It is essential to make a clarification: the prices quoted for ovulation sticks (Eveline included) are for one month's supply, while thermometers are bought once and last for a few years, so the comparison should be made carefully.

The resulting Cost-Benefit matrix is shown below. In particular we have highlighted the most important areas, in gray the death zone, in red the red ocean and in blue the blue ocean.

The death zone is empty because there is a strong correlation between benefit and cost.
Instead the app for fertility is positioned in the area of low cost and low benefit because it is free of charge but gives back a low level of accuracy and efficiency towards ovulation.
The central competition area largely includes both thermometers and ovulation sticks but shows a clear distinction between them in the benefit, even though they seem to have the same average price (bearing in mind that sticks are only a month supply).
The only test that does not fall within the competition area is the Digital test with double hormonal indicator because it corresponds to a higher price than all the others, for just a little more benefit.

Finally, the Blue Ocean Area includes the Eleveline prediction kit, as was to be expected, as it uses the stick method, but at a low price, and adds numerous features of the connected app, as well as the innovative mechanism for reading the sticks through the phone's camera.
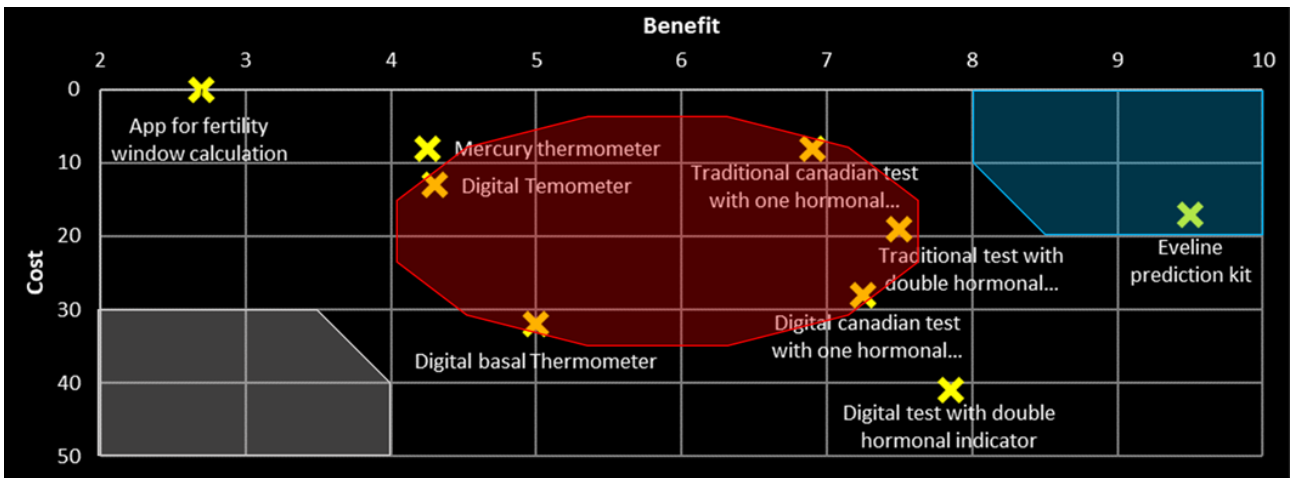

Figure 6: Cost-Benefit matrix on ovulation measuring products

Kano model

Focusing on the pregnancy theme and our objective of study, we have developed the process of need finding activities, together with the analysis of the trends inside and outside the toothbrushing sector and the BBT measurement sector. Then we build the Kano model, in which we have grouped and categorized each information previously found.

Attractive qualities
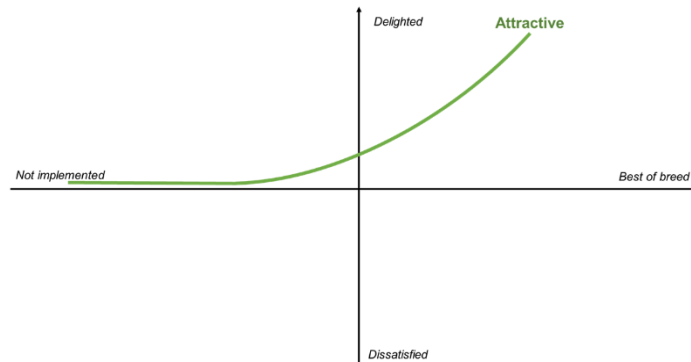
Environmentally friendly and sustainable toothbrushes: people are more and more environmentally considerate, so new toothbrushes should be the most sustainable possible and this includes recyclable brushes and products made from biodegradable materials. Regarding the materials, we thought about recycled aluminum for the handle and the magnetic stand and fully biodegradable, made from bioplastic, toothbrushing head.
Or another idea is to replace just the bristles, instead of the whole toothbrush head, to substitute just 1/6th of the brush head and resulting in a lot less landfill.
In the market, biodegradable toothbrushes aren't completely new, thinking about bamboo toothbrushes, but until now having a biodegradable brush has meant having a manual brush, instead the sustainability trend is moving in the direction of smart and electric toothbrushes too.

Multifunctionality product: Global Consumer Trends 2020 shows people's desire to have products with more than one functionality which are versatile to meet different needs (for example smartphones have many more skills than just making calls and sending messages).
A smart toothbrush can easily be transformed into a multifunctional product by replacing the head, new heads can be a thermometer to measure basal temperature or a flosser, that can be dry or water (with the addition of a water tray). In this way the body of the product, which contains the motor, remains the same and can also be equipped with an alarm clock to remind you every day at the same time of the BBT measurement.

Connectedness: smart dental products should communicate with each other or other devices such as a smartphone and wearable to assist with improving oral hygiene routines.
The real-time tracking is built-into the toothbrush, using sensors in the handle and artificial intelligence in the smartphone application. It can do mouth mapping, tracking the position of the toothbrush in the mouth and the movement of the brush, to provide educational feedback via the smartphone application, help in reaching all areas of the mouth and surfaces of the teeth, highlighting where brushing improvements or extra attention is required. All the data about the brushing process are fed back to the smartphone to record them, analyze them and provide comments on the recent performance and the entire brushing history.

The same applies to BBT measurement, as the connection between the toothbrush and the phone or other wearable allows the BTT value, date and time of measurement to be seen directly on the connected device.

In this way, all information is saved on the smartphone and is always available to the person.

Efficiency: brushes should clean the teeth in a shorter space of time or achieve a higher standard of clean.

One of the biggest innovations in toothbrushing technology was the introduction of the so-called 'mouthpiece toothbrushes. A mouthpiece toothbrush cleans all of the teeth at the same time and by doing so, it significantly reduces the amount of time taken by the current approach of cleaning one tooth at a time, one side at a time and it actually delivers more brushing time to each tooth surface.

It aims to clean the teeth by applying the perfect pressure and angling the bristles at 45 degrees to the gumline. Another innovation is the brush with three oscillating brush heads, that cup all sides of the teeth and get deep into interdental spaces, it can even be adjusted so the heads clean better around the different sized teeth you have at the front and back of your mouth.

Regarding the technological innovations we have found the use of light therapy technology to kill bacteria on the teeth and gums, the vibrating sonic technology (a sonic toothbrush makes a thousand times more brushing motions then a manual one in one brushing session) and the plaque-detecting mechanism (optical sensor built into the brush head that detect the plaque).

Lastly, a simpler innovation is the introduction of microchip that tracks the brush head usage and then notifies you via a light on the brush when it's time for it to be replaced.

USB charging: whether the cable is connected to the charging stand, to the brush directly or to the travel case, toothbrushes should now be charged via the more convenient USB connector, instead of the normal electrical outlet, which varies from country to country.

In this way you can plug the charging cable into a computer's USB port, to a USB mains socket or to a USB mains adapter.

Induction charging: it allows the toothbrush to rest on the charger without any metal contacts to connect the body of the brush to the base. This has the great advantage of allowing the toothbrush to be completely sealed, so that water cannot enter through exposed contacts. It also avoids any problems with water getting into the contacts and shorting out the charger.

Essentially, in the inductive charging the toothbrush and the base form a two-part transformer, with the base having one part of the transformer and the toothbrush having the other. When you slide the toothbrush onto the base, the complete transformer is created and charge can flow.

Engine noiselessness: inside the electric toothbrush there are a rechargeable battery, a circuit, a gear, a cam, a motor and the head attachment. The role of the gear, cam and motor is to vibrate and make the head oscillation. A standard toothbrush oscillates at a speed of 26 times in a second.

Most of the noise comes from the motor as it moves the head to give it the rotating and back-and-forth movement needed to clean the teeth, while parts, like the battery and the gear, are reasonably quiet.

The first solution to reduce the noise, and the most expensive one, is to use the sonic technology, that is able to keep the noise level low, because it can achieve much larger oscillation speed, around 260 oscillations per second, with a higher vibration frequency, which makes it quieter.

Secondly, sealed joins in the brush ensure fewer parts to vibrate and also cover the toothbrush's body in silicone, provides both a better grip and dampens the vibrations.

One-dimensional
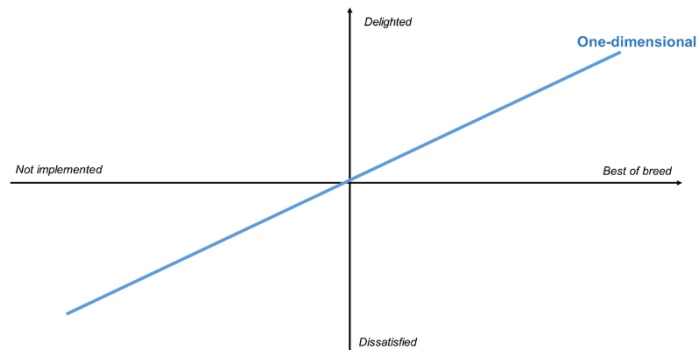
Battery life: it is a one-dimensional feature because users have the desire for a longer battery life without often remembering to put the toothbrush in to recharge it.

Typically, the cheaper the brush, the less battery life it offers. A lithium-ion battery allows the user not to keep the toothbrush recharging every time it is not in use and it is more expensive. In fact, it is more effective at holding a charge for longer without fading, so a person can brush without a recharge for anywhere between two and six weeks, as opposed to the two weeks offered by other types of battery, like the Nickel-metal one.

In addition, most models have some ways to tell when it is time for a recharge, these can be lights and beeps of the toothbrush to indicate the charging behavior. Some toothbrushes have only one indicator light, while others have three, or even a battery shaped LED that flashes different colors to indicate the battery life left.

BBT chart: Having an app on your phone directly connected to the thermometer head and automatically creating monthly graphs with all BBT measurements can make an otherwise seemingly tedious task interesting. In fact the automatic graph allows a woman to see the spikes clearly, without having to make a note of the temperature, date and time of the measurement each day.

BBT charts are a safe, simple, and reasonably accurate way to figure out when you're ovulating, with an accuracy rate of 76 to 88 percent. After a few months' worth of data, it is possible to predict when a woman is about to ovulate and can get easily pregnant.

Indifferent
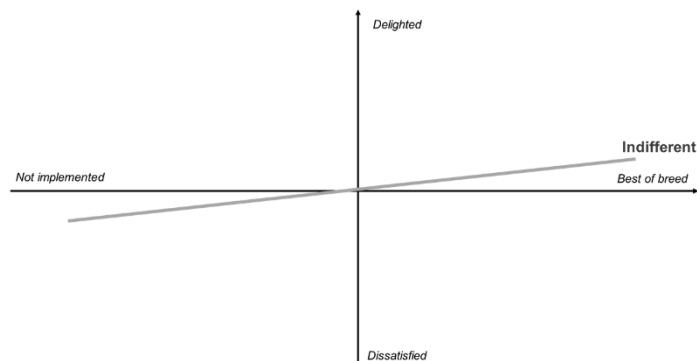
Multiple cleaning modes: It is an indifferent feature because people are confused by the different brushing modes available on a smart toothbrush, not sure what each mode means and what is the difference between each mode.

For the majority, a single cleaning mode, the standard one mode is perfectly sufficient. Therefore, it is better to have a toothbrush with one cleaning mode that you use regularly, for the correct amount of time and with the correct technique than it is having a brush with multiple modes you use incorrectly.

Extra modes can potentially provide benefit for some people, particularly those with an oral healthcare goal in mind.

Personalization: in products such as toothbrushes and basal thermometers, the personalization of external aesthetics is not of particular relevance, as people are more focused on other factors such as cleaning efficiency and precision. In particular, if customization implies a higher price, then the standard model is almost always chosen.

Must be
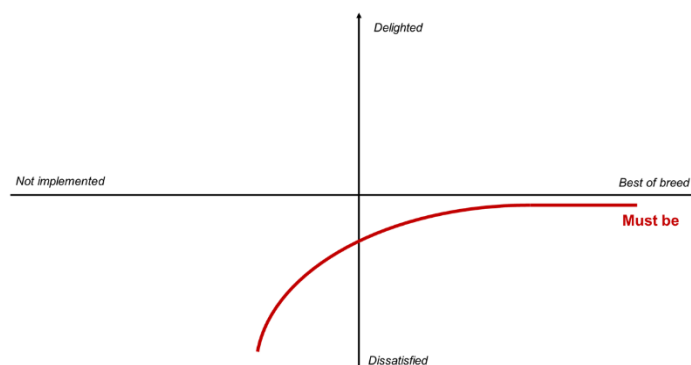
Presence of a timer: current recommendations from the American Dental Association (ADA) encourage brushing for two minutes, twice per day. If you spend less than two minutes brushing, you won't remove as much plaque from your teeth.

Built into many electric toothbrushes, the timer counts up to that 2 minutes, from the moment the brush is powered on. When the 2 minutes are completed, there is an alert either via a pause or change in sound from the brush head motor or an automatic power-off of the brush at the end of the cleaning cycle.

The timer can also be more advanced than simply a 2-minute timer, with a 30 second or quad pacer. The reason behind this is that the mouth is split into 4 sections (the upper right and upper left quadrant as well as the lower right and lower left quadrant) and each of these sections should get brushing attention for 30 seconds. So, the timer ensures a balanced clean around the mouth and tries to ensure that time is not focused just on the front or back teeth, but an equal time is applied to all teeth.

Pressure sensors: they are small components inside the brush handle that detect when you are applying too much force during the brushing routine. When it detects the use of excessive pressure, the brush will illuminate. It is a really useful tool, especially for first time users of an electric toothbrush.

In fact, hard and aggressive brushing will not normally help, Professor Peter Heasman of Newcastle University says, "You could actually be harming your gums and possibly teeth" and Whilst Jay W. Friedman remarks "Too much pressure and too frequent brushing can abrade enamel, or the root if the gum has receded." This abrasion, he says, can cause teeth to become hypersensitive to hot and/or cold.

Reverse
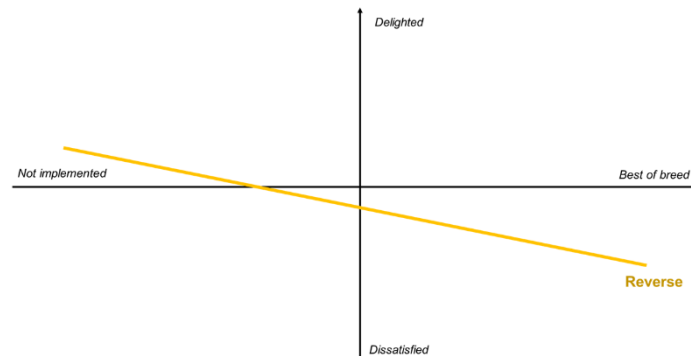
Toothbrush oscillating-rotating movement: smart electric toothbrushes use a back-and-forth rotating motion to cup each tooth. Their heads tend to be smaller than a conventional toothbrush, because they are intended to be used to clean one tooth at a time, as opposed to brushing multiple teeth simultaneously (like with a regular toothbrush).
Some people may find that this method of brushing does not appeal to them.
In addition, oscillating toothbrushes generally have a brushing action ranging from 2500 to 7500 rotations per minute as opposed to roughly 300 per minute when using a manual toothbrush. This is what allows the electric oscillating toothbrush to remove much more plaque, although a downside reported by some people is that this can feel a little too harsh for them on their gums.

Complexity: the smart toothbrush is equipped with many functions and features and, for some people, it can be too complex to use.
The toothbrush has several LED signals (e.g. battery charge duration, excessive pressure on teeth, etc.) that have a precise meaning and must be understood by the user to be useful.
If the meaning of the lights is not easy to understand by sight alone, this should be clearly written on the box and/or the consumer should be asked to read the instruction sheet, as she/he may feel confused and frustrated by the switching on of different LEDs, or the same one with different colors (with a different meaning).
Similarly, the app shows several features to help the customer improve his brushing experience, including summary reports on brushing sessions and colorful graphs. All of these features are intended to help the user and provide interesting data, but they must be comprehensible to be of any value.
Indeed, it is essential that the coaching feature is understood and followed, or at least that it does not lead in the wrong direction due to misunderstanding.

Security risk due to Bluetooth technology: Bluetooth allows the two proximal devices (the smart toothbrush and the smartphone) to connect to each other over the air and the pairing can last as long as both devices are in use. Fundamentally, Bluetooth opens up a channel for the two devices to communicate and this is an extremely useful arrangement, but it also opens the door for dangerous interactions. Without strong cryptographic authentication checks, malicious third parties can use Bluetooth to connect to a device they shouldn't have access to, or trick targets into thinking their rogue device is a trusted one.

Multi Criteria Decision Making

Since the objective of the project is "design a smart solution which is able to measure, record and transmit the BBT through a temperature sensor integrated in the hardware", we decided to develop our own solution, integrating it into a smart toothbrush model already on the market.
For this reason we applied one of the tools of the Multi Criteria Decision Model, to determine which current model would be the basis for the final product.

The chosen tool is TOPSIS, because it is the most suitable for our application case, in which we inserted six smart toothbrush models previously studied in the Cost-Benefit matrix and Value Strategy Canvas.
The criteria adopted for the analysis were the attractive features analyzed in the Kano Model, as the must-be and one-dimensional characteristics related to brushing were already implicit in the selected models.
In fact, from the starting eleven models, we have reduced them to six, selecting those equipped with pressure sensors and a timer and with an average battery life of more than 14 days.

Here is the list of six smart toothbrush models already on the market, which can be the basis for our multifunctional toothbrush:
- Colgate Plaqless Pro;
- Oral-B Genius 8000;
- Oral-B iO;
- Philips Sonicare DiamondClean Smart Toothbrush;
- Philips Sonicare FlexCare Platinum Smart Toothbrush;
- Philips Sonicare ProtectiveClean 4100.

Below is the result of our TOPSIS analysis, in numerical values and in a graphical version.
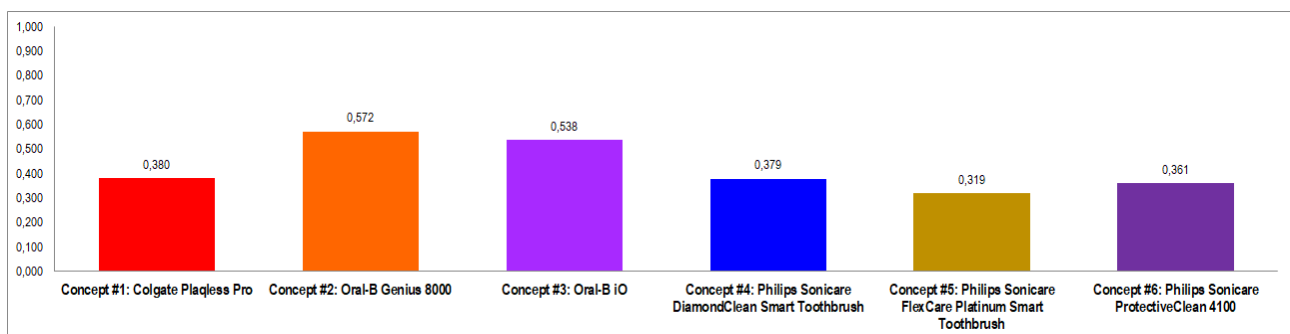
	Concept #1: Colgate Plaqless Pro	Concept #2: Oral-B Genius 8000	Concept #3: Oral-B iO	Concept #4: Philips Sonicare DiamondClean Smart Toothbrush	Concept #5: Philips Sonicare FlexCare Platinum Smart Toothbrush	Concept #6: Philips Sonicare ProtectiveClean 4100	Ideal	Negative
Ideal	4,182	2,869	2,901	3,941	4,783	6,787	0	5,127101941
Negative	2,561	3,839	3,376	2,402	2,245	3,827	5,127101941	0
TOPSIS results	0,380	0,572	0,538	0,379	0,319	0,361	1	0

Figure 7: TOPSIS results

It can be seen that the model most similar to the Ideal Solution is the *Oral-B Genius 8000.*

Figure 8: Oral-B Genius 8000

As a result of previous analyses, we can state the following about the *Oral-B Genius 8000*:
- the model falls within the red zone of competition of the Cost-Benefit matrix;
- it is currently priced at $180 for the package and $7 for a single replacement head;
- it features the Oral-B coaching app, which also performs data analytics and 3D cleaning feedback, connected via Bluetooth technology;
- the mouth mapping sensors are per area, not per tooth;
- it has five different cleaning modes (daily cleaning, gum protection, sensitive teeth, whitening and Pro-Clean);
- it has a 2-minute timer;
- it has sensory pressure indicators, for the protection of teeth and gums (the pressure control technology reduces the brushing speed, while the Smart Ring LED at the top of the body alerts you when you are brushing too aggressively);
- it has a state-of-the-art lithium-ion battery that lasts for more than 14 days and comes with a travel case with a dual charger to charge the toothbrush and phone with just one plug; plus it has a charge indicator in the lower part of the body;
- the engine is quiet enough, but it is not built with vibrating sonic technology, which would have made it more effective and quieter at the expense of the price.

Total Cost of Ownership

To elaborate the Total Cost of Ownership of our solution we started by getting information about the cost effectiveness of the ideal smart toothbrush prEtotype. We got in touch with the Ph.D. student Omsri Kumar Aeddula, who is working on a similar project.

During the interview there was a brief discussion about the type of solution conceived and designed, ready to be printed out in 3D.
According to the experts, the solution is acceptable and the prEtotype turns out to be cost effective. In fact, main parts of it are cheap:
- the temperature sensor has a price of approximately 40 Sek;
- the toothbrush head (featuring all smart functions) has a value between 400-800 Sek and it depends mostly on the material it is made of;
- the body of the toothbrush with a display costs around 200 Sek.

In conclusion, hypothetically, the sum of the costs of the toothbrush is around 840 Sek to be produced and we consider this value as the most important one for a manufacturing company.

Another important cost to analyze is the price of data storage for every user.
During the meeting there were a lot of thoughts and discussions about the need of clouding for data storage for a working product in real life. The answer from the experts was directly related to their experience with the same problem. Their project group has found out that the Oral-B company actually stores the user data directly on the application, through the phone storage, because the data has a little size that does not require clouding.
This type of solution for data management is completely free for the selling company, and this is the main reason why the manufacturing cost remains the most important one to focus on.

PrEtotype

In conclusion, the result of our project is the prEtotype of the chosen smart toothbrush, the *Oral-B Genius 8000* featuring a thermometer head.
In particular we are going to analyze three sides of it:
1. the design of the hardware (physical prEtotype, designed through a CAD model);
2. the storyboard describing how the hardware is intended to be used;
3. the app and its lifecycle data management (in form of a flow chart describing how the data are transferred from the tool to the database to be stored).

Design of the hardware

To construct the model of the prEtotype, we used the software Autodesk Inventor.

The body and head of the brush reproduce the shape and size of the *Oral-B Genius 8000*, as a result of the previous analysis and decisions.

The prototype consists of three separate units:
- the body, containing the engine, a Bluetooth transmitter, a timer and a screen;
- the toothbrush head, consisting of brushes, pressure and mouth mapping sensors per area;
- the temperature sensor head, consisting in a metal stick with the temperature sensor.

The two heads are easily removable and interchangeable, thanks to an interlocking mechanism that also connects the sensors to the motor, which then sends the data to the app on the phone via Bluetooth.

The length of the body is 100 mm, which is a measure that allows users with either big or small hands to use it easily and comfortably.
The body shows a recess in the upper part, where a small LED screen is to be positioned. In addition at the top of the body there is a Smart Ring LED, to alert on the pressure applied to teeth, and, at the bottom, there is a charge indicator.
The selected battery is a state-of-the-art lithium-ion, to ensure a minimum of 14-day charge.

The head of the toothbrush is equal to 90mm, which incidentally is a universal measure and therefore users can have the opportunity to change the head when the brush has been worn out and easily find a large number of compatible units, for example at ICA Kvantum.

Then to choose the length of the temperature sensor, we investigated the thermometer industry and studied the tolerance of a measurement sensor and we reached a conclusion by choosing a measure between 70-50 mm, to make it easy for users to place the thermometer under the tongue.

On the next page there is a picture of the physical prEtotype, printed in pink using a 3D printer at the Blekinge Institute of Technology.

As it can be seen, there are the three main components and the thermometer head is assembled on the body, while the brush head lies next to it.

Figure 9: Physical PrEtotype

The advantages of our prEtotype are several:
- Hygiene: the thermometer is never in contact with the toothpaste;
- Practical: non-morning tooth brushing does not require the use of the thermometer head;
- Comfortable: the thermometer head is thin so it can be easily placed correctly;
- Easy to use: easily replacement of the two heads;
- Reliable: the measurements are trustworthy as a normal single thermometer;
- Two-in-one: the single product offers two features, toothbrushing and temperature control.

Storyboard

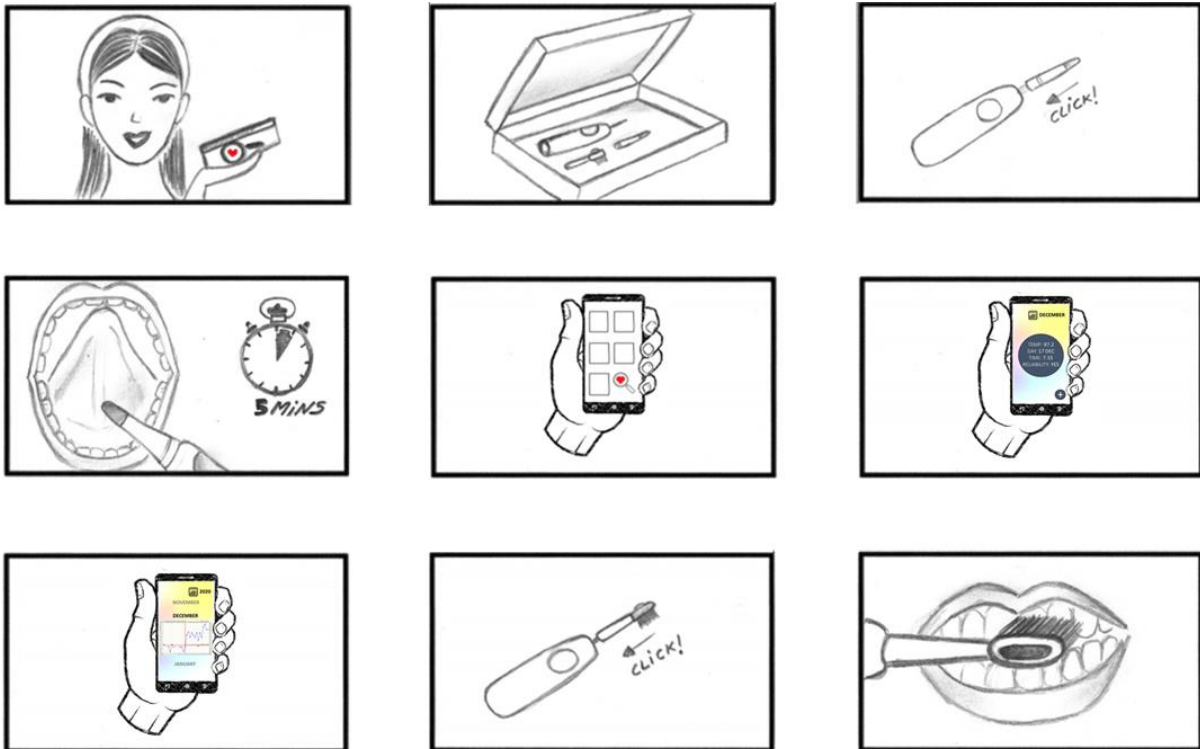Below can be seen the storyboard describing how the hardware is intended to be used.

Figure 10: Storyboard

Here are the steps drawn in detail:
1. The woman takes the product package in her hand.
2. The woman opens the package, which contains the toothbrush body and the two heads.
3. The woman mounts the thermometer head in the toothbrush body.
4. The woman places the thermometer under her tongue for 5 minutes to measure the BBT.
5. The woman takes the smartphone and opens the application.
6. The woman sees the value of the measurement she has just taken.
7. The woman switches screens and sees the monthly BBT graph.
8. The woman takes the toothbrush and changes the brush head.
9. The woman brushes her teeth.

App and lifecycle data management

In the third step of the analysis of our prEtotype we focused on the BBT app and its lifecycle data management, to describe the process used to store and control data of the BBT measurements.

It is essential to point out that our analysis of the app has only been carried out with regard to the integration of BBT measurements, as the app that includes all brushing functions already exists, it is called *Oral-B App* and is compatible with all devices.

Figure 11: App user interface

The BBT application is rather simple and intuitive.
The homepage consists of a monthly graph, in which the measurement data are displayed.
It is possible to view the details of each reading: the temperature value, the day and the time at which it was taken.
In addition, you can manually add the reliability of the measurement:
- a reading is reliable when taken in basal conditions;
- a measurement is not reliable when one or more factors potentially invalidate it;
- a measure can be averagely reliable in case of doubt (e.g. in case of disturbed sleep but with sufficient hours of sleep).

It is always possible, even at a later time, to change the reliability if it is deemed necessary.

Concerning the lifecycle data management, we started from the assumption made earlier about storage availability and costs.

Since the company can store the user data directly on the application, through the phone storage, we have included a small database within the application.

Therefore, the app consists of:
- the user interface,
- the authorization server,
- the connection server that is linked to the toothbrush body, which is connected to the thermometer head,
- the database.

Below we present the UML sequence diagram of the interactions between the application components with the user and between the components themselves and a list of steps in chronological order.
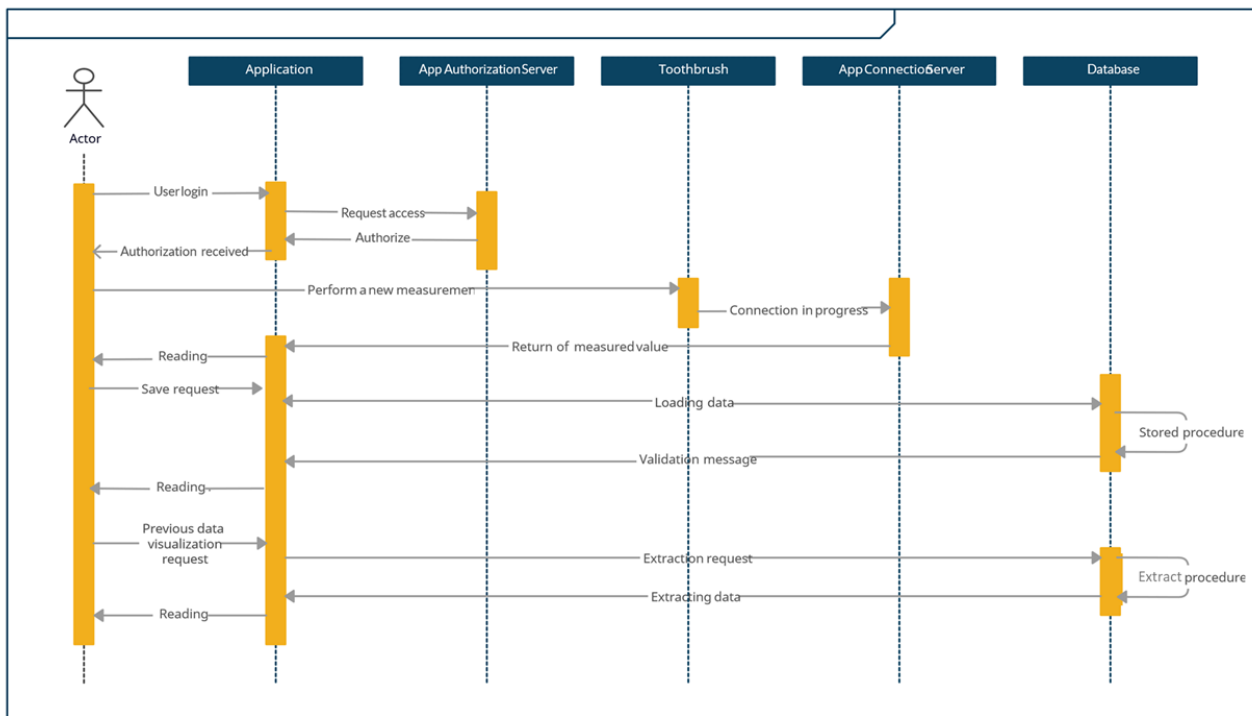

Figure 12: UML Sequence Diagram

Step 1: User logins with its account.
Step 2: Application checks the requested access for the user.
Step 3: Authorization message gets back to the user.
Step 4: Authorization is received and the user knows if she/he gets access.
Step 5: User performs a new measurement.
Step 6: Connection is applied between the thermometer head of the toothbrush and the app connection server.
Step 7: Return of the measurement values from the app connection server to the app.
Step 8: The measured value is back to the user.
Step 9: The user requests to save the data.
Step 10: Loading of the data to the database of the app.
Step 11: The data is now stored in the database.
Step 12: A validation message is sent to the user.

Step 13: User wants to visualize previous data stored in the database.

Step 15: The extraction request is sent to the database.

Step 16: Extracting procedure is on.

Step 16: The extracted data are sent to the user.

Step 17: The user reads the values of the data.

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