Project Deliverable D: **Detailed Design and Prototype 1**
GNG 2101 – Intro. to Product Dev. and Mgmt. for Engineers
Faculty of Engineering – University of Ottawa

Date : October 3rd 2019
Group number: Group 10
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Introduction:

MK is constrained to a wheelchair and has no hand control, as well as limited arm range. She has difficulty brushing her teeth with no assistance. Although she can hold an electric toothbrush, the action of rotating the toothbrush to reach beyond the front tooth surface is a challenge. Having a device that can assist in the rotation of the electric toothbrush will allow her to live more independently. This rotational toothbrush must use off-the-shelf brush heads for sanitary reasons. Ideally, this toothbrush is rechargeable, but a secure power wire is acceptable.

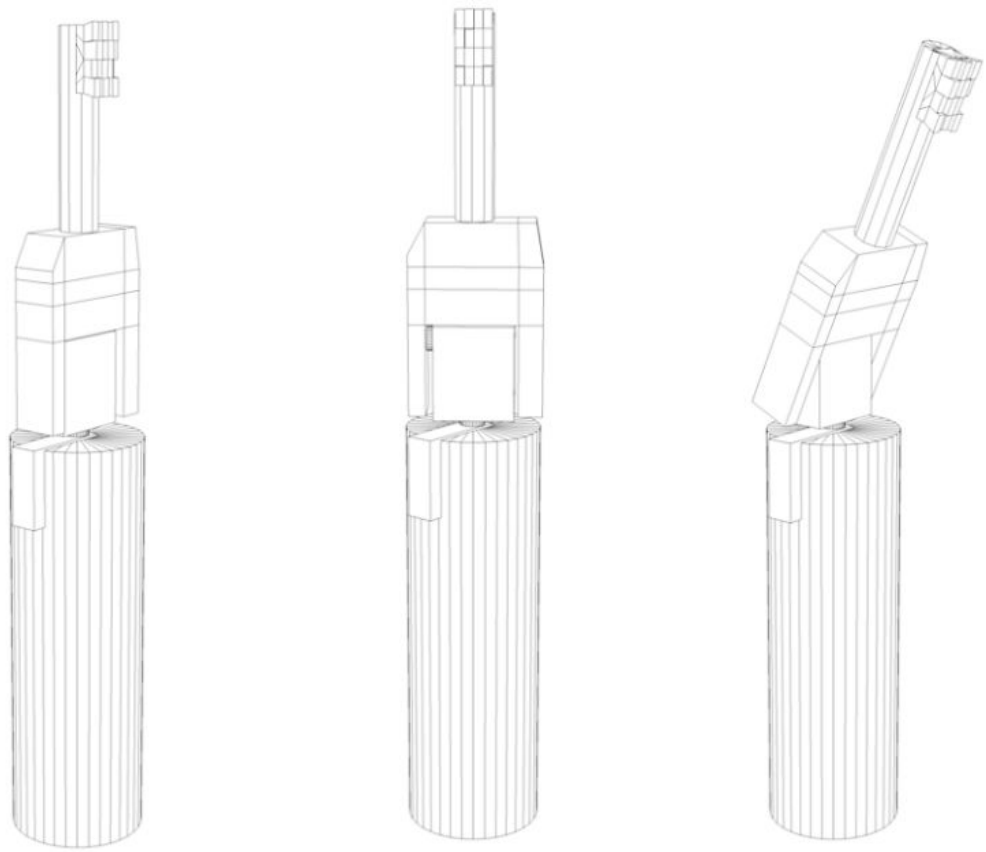
Since being assigned the task to solve MK's problem, our team has worked long and hard in formulating a viable solution for our client. Following the directions in deliverable C, we were able to clarify the core functionalities our solution was to have. We then pooled together our ideas, further analyzing them using concepts learned in class such as the decision matrix. Using the results obtained from these matrices, we developed a group concept that integrated key components found in the most promising solutions. Finally, we developed a project plan, conducted a feasibility study and created a bill of materials and parts to verify the viability of our proposal.

Our current objective is to design details for our concept and to build our first prototype. This will serve as a means to test the product's most critical functionality and target specifications. We will then use the prototype to interact with our client and obtain valuable feedback on our next meeting.

1. Summarize the client feedback that you received during your second meeting for your conceptual design and clearly state what needs to be changed or improved in your design.

Upon meeting with our client for a second time, we were able to present our group concept we had at the time. This meeting was extremely informative as we were given feedback regarding the feasibility aspects of our concept.

At the time of our second meeting, our group concept was a customized standard electric toothbrush that would have two degrees of freedom. While being operated, the upper portion of the toothbrush would be able to spin and tilt, allowing the user to reach an increased amount of surface area without necessitating hand motion. We created the sketches below as an accurate representation of our product concept at the time.



However innovative the concept was, the client did express some concerns with its design. The proposed device needed a continuous flow of energy from a power outlet in order to power the various electrical components while being operated. Since our

product will be in contact with water, we were advised that the device must be unplugged while in use to ensure the safety of the user. To improve this design characteristic, we decided to modify our concept to contain an external battery component that the device would draw energy from and that could be recharged when not in use. This would also be of great use to house the wires, keeping them away from the chairs vicinity and to prevent potential damages to the system from contact with water.

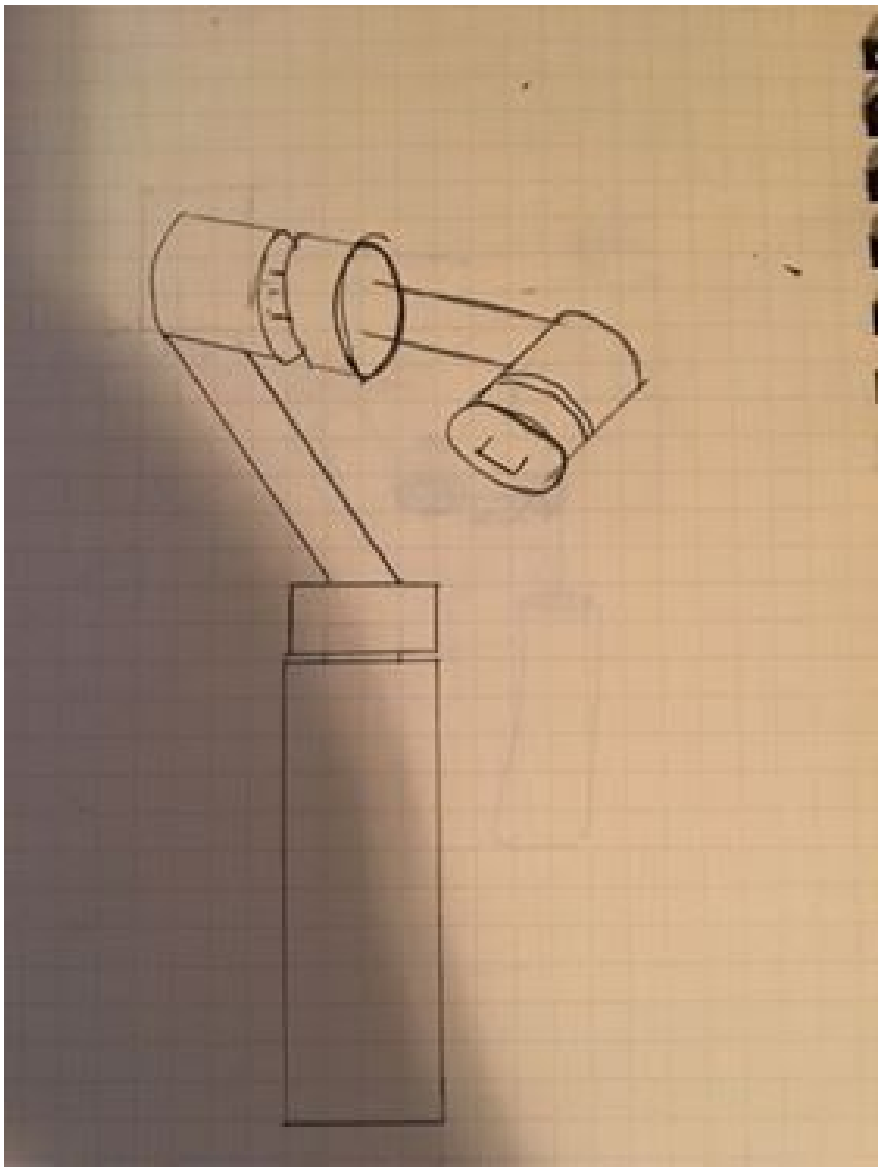
Our client also expressed concerns with regard to the weight of our design. As the weight of our concept included a standard electric toothbrush as well as an arduino, two servos, wiring and a longer 3D printed case, the weight of the device would not meet our clients needs. In order to have a viable concept, our target specification for weight must not significantly exceed the weight of the current toothbrush she uses. We realized that an alternative concept was needed, ideally one that did not require all the components to be affixed to the toothbrush itself.

Another concern from our client was the complexity of our design. Given the course's restricted timeline and the limited time allocated to build the final prototype, the client recommended that we keep our design as simple as possible to make sure that we are able to complete it on time. In order to achieve that, we planned on developing a simpler design to ensure that we could complete each design process milestone leading to our final prototype on time. Also, crucial steps such as software testing will have to be completed well ahead of design day to ensure that it is functioning properly and according to our target specifications.

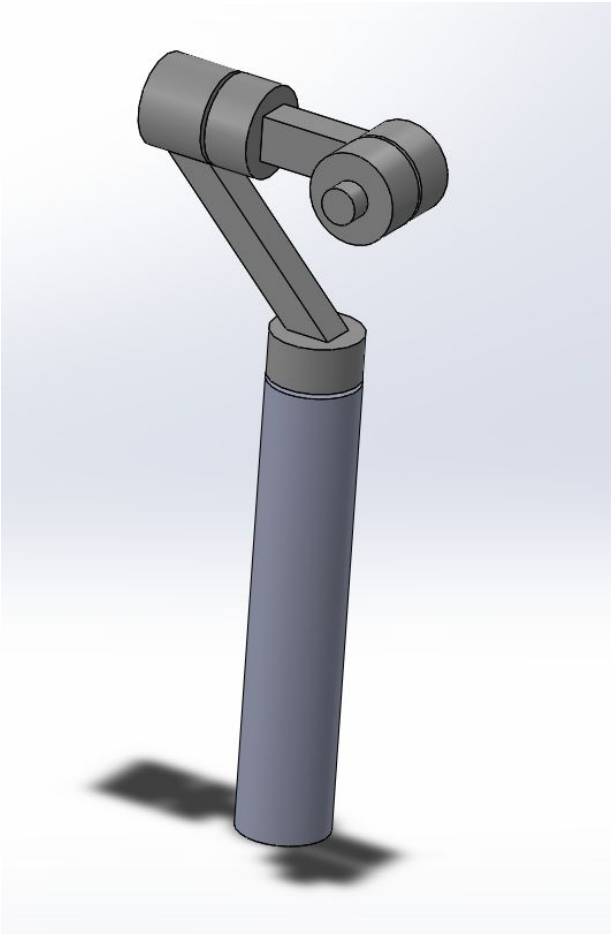
Given the feedback provided by our client and project manager, we decided to make important changes to our design. We realized our design needed to be first and foremost safe, light weight, cost effective and simple in nature. In order to meet these specifications, the device had to work independently to the toothbrush. By choosing a design concept as such, we would dramatically decrease the cost of our product as we would simply use our clients current toothbrush. This would also maintain the integrity of the electric toothbrush and prevent any safety concerns that could arise by directly altering its components.

2. Develop an updated and detailed design of your concept, based on your client meeting, which includes: Visual representations of the overall concept, as well as each subsystem. Clearly define how each subsystem is linked to other subsystems (including fasteners and electrical wires).

Through a collective effort, we were able to conceptualize a design that met our product specifications. Our new design is a hand held device that would attach to our clients toothbrush and perform various movements. The design was inspired by a phone gimbal, a hand held device that is meant to stabilize a phone while taking video. A sketch of our new design is provided below.



An updated, visual design of our overall concept created in Solidworks is provided below.



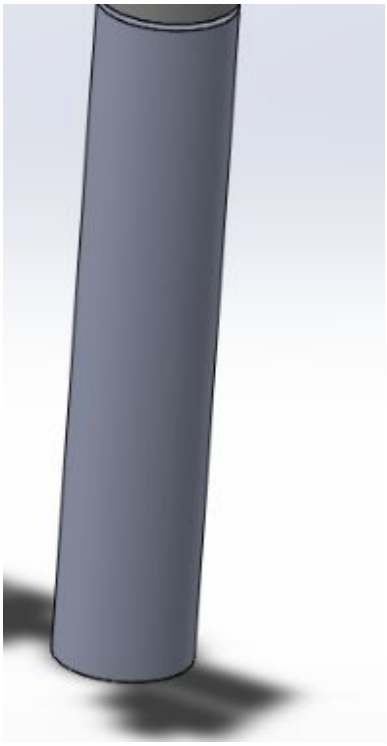
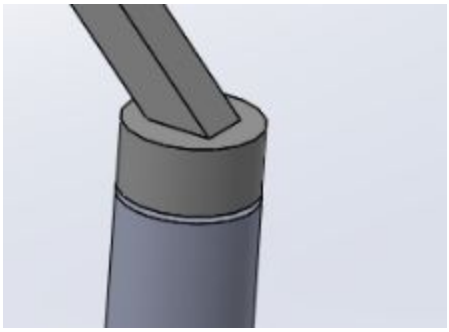
Subsystems at a glance: Handle, servos, wires, different pieces on the gimbal.

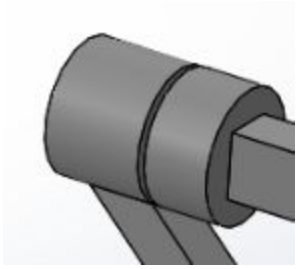
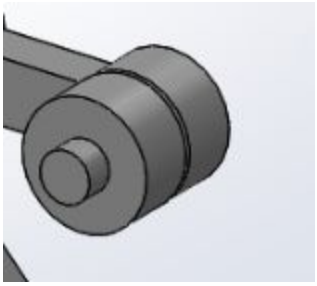
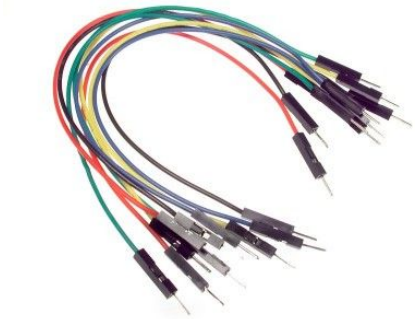
Our concept incorporates a simple design that would be comprised of a handle, various pivots through the use of servos and a fastener that would latch onto the toothbrush, providing the motions needed for the user to brush their teeth.

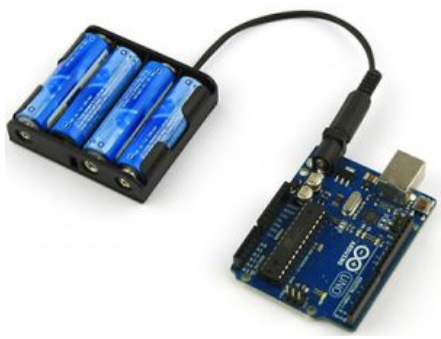
In order to guarantee full product functionality to our client, certain preconditions must be met during the external boundary phase. To begin, the toothbrush intended to be used must be picked up, wrinsed, have toothpaste applied to the bristles and the toothbrush must be attached to the device. Additionally, both the toothbrush and device must be charged to ensure proper functioning. The device must also be handed to our client and turned on as she is incapable to do so alone.

The system will now perform as advertised until our client has completely brushed all of their teeth. While holding onto the device, the toothbrush will have a timed sequence of various positions, ultimately providing the user with an ample amount of time to

thoroughly brush each section of their teeth. This will be achieved using the dynamic subsystems that compose our device. These include the handle, joints/servos, battery, arduino and wires.

 Handle	The handles function will serve as a replacement to the original toothbrushes handle.It will be of similar diameter to an electric toothbrush and easy to grip. Padding will be added to ensure comfort while operating device.
 First Joint	The first Joint allows the device to rotate on the xy plane. The servo will be mounted in the handle and the second piece will be mounted onto the splines of the servo. The wires that lead to the following two servos will be routed through this joint.

 Second Joint	The second joint allows for the joint to have freedom of rotation on the xz plane. The joint will be assembled in the same manner as the first joint. The wires for the third servo will route through this joint in a manner that will not interfere will other motions.
 Third Joint	The third joint allows for freedom of movement on the xy plane. This joint will also be assembled in the same manner as 1 and 2. The third servo will allow the toothbrush to be angled away from and toward the client.
 Wires	The wires are not illustrated in the visual design as they will be hidden from plain sight. They will serve as a means to connect all electrical components in order to ensure proper functioning of the device.
 Arduino	The Arduino microcontroller is programmed to control the rotations of the servos. After a certain amount of time, the microcontroller will adjust the toothbrush to let the client brush other sides of her teeth. After a full cycle, the microcontroller will send signals to reorient every joint to its initial position and then automatically turn itself off.

 Battery	The battery pack we have will supply power to the arduino. We are using an external battery pack so it does not have to be plugged into a standard wall outlet. Plugging the Arduino into the wall would present an obvious safety hazard as the task of brushing your teeth involves water and having wires and power running around the client is not ideal.

Once a cycle is completed, the device will turn itself off. When the user has fully brushed their teeth, the aide will unmount the toothbrush and rinse it off. The batteries of the device and toothbrush will then need to be charged for the next use. A function will be implemented that resets the devices positioning prior to turning off.

3. Define your most critical product assumptions and create your first product prototype, which will be used to test those assumptions.

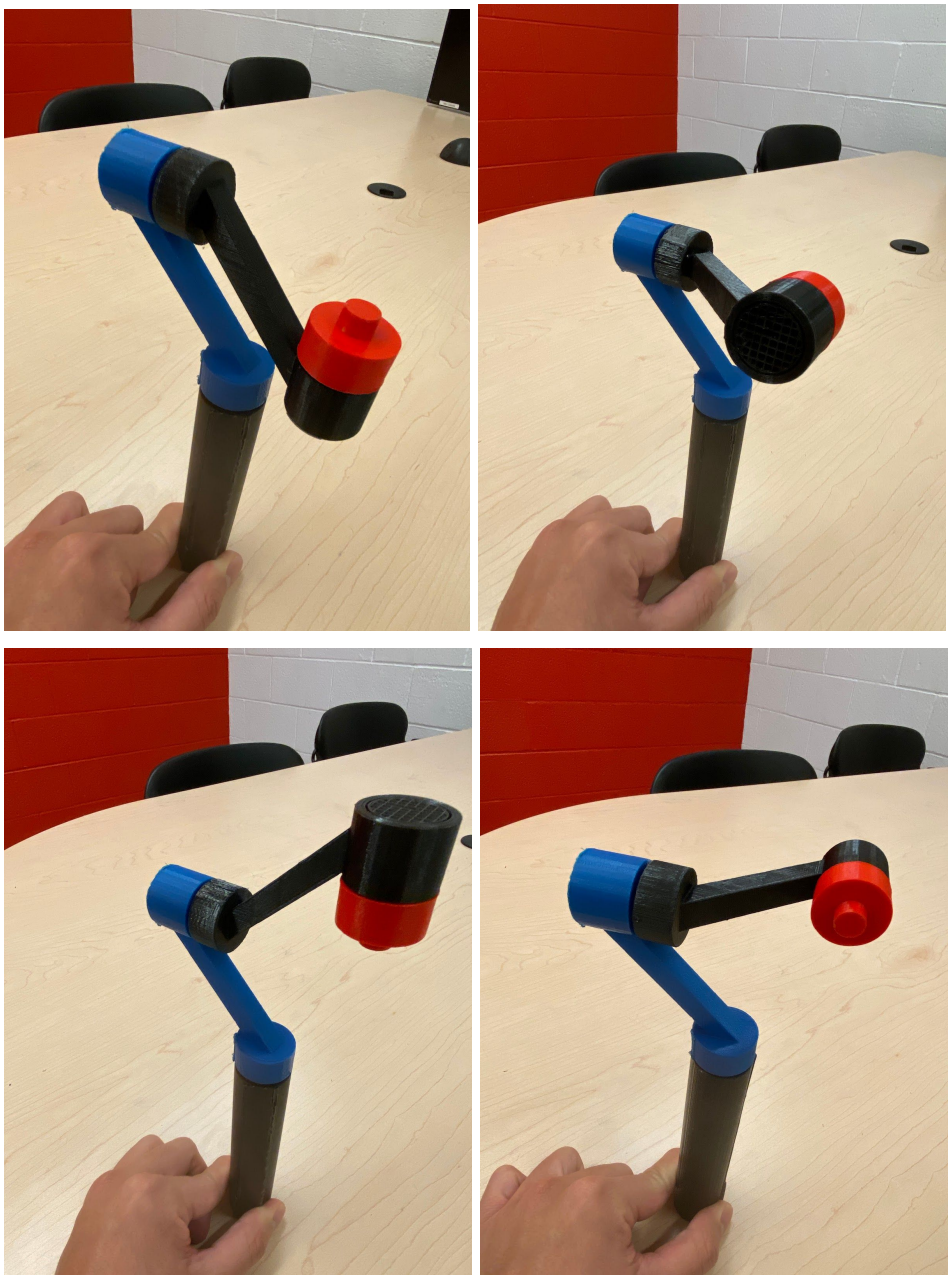
In an ideal scenario, we would be able to fully test our product specifications using an unlimited amount of resources. Unfortunately, as we are advised to follow a strict budget, multiple assumptions must be made prior to developing our product. Notably, the components that tend to be the most expensive are the ones that utilize energy and perform work. These include components such as the servos, arduino and batteries.

The servos are expected to perform enough work to rotate a designated area of the device, we must assume that they will perform as intended. The device must also accomplish a sufficient amount of degrees of freedom in order to work as advertised.

To add, we must assume that our product in its entirety will share a similar weight to a standard electric toothbrush. Having it be too heavy will hinder our clients ability in utilizing it, rendering the device useless. Also, if certain areas are of too much weight, this will once again prevent our servos from completing their rotations and may potentially damage the equipment.

Taking these product assumptions into consideration, we are ready to create our first product prototype which will be used to test our assumptions.

4. Document your prototype using as many sketches/diagrams/pictures as required and explain the purpose and function of your prototype.



We created a low fidelity prototype to quickly test our idea with no cost to the team. Each of the four fidelity factors have been addressed within the initial prototype.

Functional Fidelity: This is a moderately functioning prototype. Since all the pieces were printed independently they are able to be assembled and manipulated to simulate the movement that will be happening with the servos. There is no software within the prototype so all of the movement is done manually by the user.

Visual Fidelity: This prototype is not an accurate representation of what the finished product would look like visually. The structure and shape of the product will be similar but the colors and coordination of the product will be improved.

Content Fidelity: Currently there are no placeholders for the servos what will be added to the final product. A servo will be placed at each of the three joints where the parts meet.

Depth and Breadth: The overall completeness is very surface level. From now until the final prototype there will be mechanical aspects added, a battery system will be implemented, servos will be incorporated, and a clasp to hold the toothbrush will be added as well.

The main purpose of prototype 1 was communication, specifically the validation of our ideas. Creating the prototype as a 3D printed model that we can manipulate allowed us to confirm that gimbal style will be functional and allow the client to reach all the areas of her mouth with ease. The model also let us get a feel for the weight of the product. Since the client is not able to hold something that is too heavy or off balance we are able to keep the weight in mind when building on the design.

5. Carry out prototype testing, analyze and evaluate performance compared to the target specifications developed in Project Deliverable B and document all your testing results. Present your testing in an organized, tabular format that shows expected versus actual results.

As our concept was recently developed due to the feedback provided in our second client meeting, we decided to follow the preliminary steps completed for our older designs found in Deliverable C prior to creating our first prototype. We created a decision matrix for our gimbal design to identify, analyze, and rate each design criteria in relation to the selection criteria. The values for our matrix are set to 1 being not ideal and 5 being ideal.

Selection Criteria	**Gimbal Design**
Ease of Use	5
Size & Weight	4
# of Adjustments per cycle	5

Safety	4
Durability	4
Cost Estimate	5
Is it Realistic	4
Total	20

As the purpose of creating a prototype is to reduce uncertainty, we wanted to create one that would provide insight on our final product. The purpose of our prototype was to test basic functionalities of our device. Notably, we wanted a physical model that would shed light on the dimensions, weight and ergonomics of the device. We decided the optimal way in testing our product specifications was to 3D print our design as it could demonstrate the basic motions, shape and weight of our final device.

For our product size, we decided it would be best if the handle component to emulate the dimensions of a standard electric toothbrush, being 11 x 5 x 24.1 cm. We also wanted to demonstrate that the weight of our final product was expected to be relatively light. Thus, we made sure to keep the handle hollow and made sure that all components did not weigh more than an electric toothbrush ~331g. By using a simple design made of plastic for our first prototype, we were able to conceptualize where the servos would be inserted and how they would behave with respect to motion.

The portion of our functional decomposition that could be tested using our prototype were the steps included within our system boundaries. Once the toothbrush is on, attached to the extremity and given to the user, we would then illustrate the different positions the toothbrush could achieve without the movement of the users hand.

The assembly of the prototype was relatively easy, though not completely stable. It did suffice to give the user a general idea as to how the form of the final concept would be like. We then provided our prototype to our friends to receive user feedback. Overall the feedback was positive. The metrics of what was tested, expected results and actual results are provided in the table below.

Test	Expected	Actual
Length when standing up with the red component	20cm	23cm

shown in the picture facing down	Size of the apparatus is similar to an electric toothbrush.	Size of handle and feel were accurate. Upper components were slightly big and could be a problem when oriented too close to the users face.
Weight	200g Product is lightweight, similar to that of an electric toothbrush.	164g Weight was very similar to an electric toothbrush. Though the prototype did not contain any of the components we plan on adding, the fact that it was significantly lighter provides good prospects of a light final product, for when we do decide to add them.
Ergonomics	Prototype demonstrates efficiency and is easy to use. Provides a comfortable and natural feeling, similar to holding a toothbrush.	Emulated with significant accuracy the feel and design of an electric toothbrush. Upper components were slightly big and could be a problem when oriented too close to the users face.

Overall the feedback was positive. Some confusion arose as to how the device was to behave when on. Recommendations on timed intervals as opposed to buttons for the various different motions were asked. To get accurate feedback regarding our client, when we informed our testers on the physical constraints of our client, the majority of our testers preferred a timed design.

Testing our prototype was an inexpensive and time saving process that provided important insight on the direction we should follow from here on out.

6. Outline what your team intends to present to your client(s) and what information you would like to gather at your next client meeting.

Much has changed since our second client meeting. As a team, we have decided upon a completely different product design due to the concerns and criticism provided by our client and project manager. Given the fact that our next client meeting is scheduled in roughly three weeks, we plan on taking advantage of this opportunity to further refine our current product design prior to the meeting. Based on our current expected milestones, we plan on providing our client with a high fidelity prototype by October 23rd. This comprehensive prototype will implement many of the attributes our final product will contain and be of great use for rigorous testing. This will also provide our client with a better sense of the solution, the expected features and functionalities of the final product, the option to test our prototype and ultimately give insight on preferences they may have, allowing us to further refine and finalize decisions pertaining to our final product.

By inquiring on our clients personal preferences, taking into account their exact movement capabilities, we are given the opportunity to further meet their needs by altering the specific timing and positioning preferences they may have with respect to the motion of the device. We will achieve this by modifying the code affecting the functionality of our servos. This is now a possibility due to our newly acquired knowledge upon completing our most recent laboratory. During this lab, we utilized the Arduino IDE Software platform to write control logic commands used to create inputs and outputs connected to an Arduino Uno microcontroller.

Conclusion:

This week, we decided to develop a completely new design influenced by the feedback provided during our second client meeting. We then created our first prototype using the designed details of our concept through the use of sketches and 3D models. We tested our products most critical functionalities and target specifications with friends to get informative criticism on our product design. Finally, we established what we plan on presenting in our next client meeting as well as inquire on preferences that will be used to finalize our product.