# Development of a Modular Below-Elbow Prosthesis with Bidirectional Signaling for Children

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**Massachusetts Academy of Math and Science**
**STEM Project Documents/Logbook**
**Instructor: Kevin Crowthers, Ph.D.**

## Table of Contents:

# GLP Record Keeping Contract

**I, Travis Tran, commit to record keeping in accordance with Good Laboratory Practices.**

- My experiments and records will be reproducible, traceable, and reliable.
- I will NOT write my notes on scraps of paper, post-it notes, or other disposable items. My notes will go directly into my laboratory notebook.
- My data will be recorded in real-time. If I cannot record data in real-time, I will record raw data as soon as physically possible.
- I will record both qualitative and quantitative observations in my laboratory notebook and laboratory reports.
- My laboratory notebook will include information on the materials and instruments utilized during experimentation.
- I will initial and date over the edge of any material that is taped into my laboratory notebook.
- I will provide a real-time record of any analysis I perform.
- I will use blue or black pen to make entries in my laboratory notebook. I will NOT use pencil.
- I will define ALL abbreviations.
- If I make a mistake in my laboratory notebook, laboratory worksheets, or other written material, I will not obliterate or obscure the mistake. Instead, I will cross out the mistake using a single line. Any empty spaces in tables or partially used notebook pages will be crossed out using a single diagonal line.
- If I record information online (ex. In Google Drive), I will login so that my contributions are traceable.
- I will initial and date each page in my notebook and the front of each laboratory report.

**Travis Tran**________________________________

Printed name

______________________________

Signature

**8/23/22**___________________________________

Date

A more detailed description of GLP is located here:
https://docs.google.com/document/d/1zeYoNSniKTc7MlBgTG1SEnhJiCK3UimCvTcKPQcyHGw/edit?usp=sharing

# Logbook Etiquette Date

For research and engineering purposes, a logbook is considered a legal document and will help in providing documentation for the origin of ideas.

1- When adding something written in Pen- Blue or Black ~~not a Pencil~~ (and DO NOT USE WHITEOUT- ~~mistakes~~ can be corrected by adding the information above the crossed out material and adding your initials and date

2- Don't worry about neatness- it is a living document but **should be legible but understandable**

3- Page Numbers should be consecutive and located on the top corner of the page- outer edge

4- Do not remove pages

5- Put a line through empty space

6- Neat handwriting

7- **Make an entry every time you work on your project**

8- Make sure your entries are verified by a mentor/ teacher signature and your signature

9- Organize your Notebook: Format
    A: Table of Contents
    B: Brainstorming and Topic Ideas
    C: Project Introduction: Topic, Phrase 1(Testable Question/Engineering Need/Mathematical Conjecture), Phrase 2 + Timeline
    D: Communications (i.e. to corresponding authors, mentors, and expert consultation, etc)
    E: Draft of Materials and Methods (this can be performed for daily entries if variations occur over the course of the project).
    F: Background- ie. competitor/market analysis, criteria/constraints
    G: Daily Entries (every time you complete work on the project)
        1: Title and Date
        2: Short Introduction (putting the experiment/observations into context/objectives)
        3: Methods/Materials (if not included in the beginning of the notebook)
        Materials become important when someone needs to repeat your experiments
        4: Observations/Experimental Data (both RAW and ANALYZED)-
            A: graphs/figures
            B: data tables
            C: pictures
            D: sketches or proof of concepts and prototypes (with labels)
            E: Decision matrices
            E: Ethical responsibility
        5: Calculations and Data Analysis (STATISTICS)
        6: Final Concluding Remarks

**<u>Things to keep in mind:</u>**

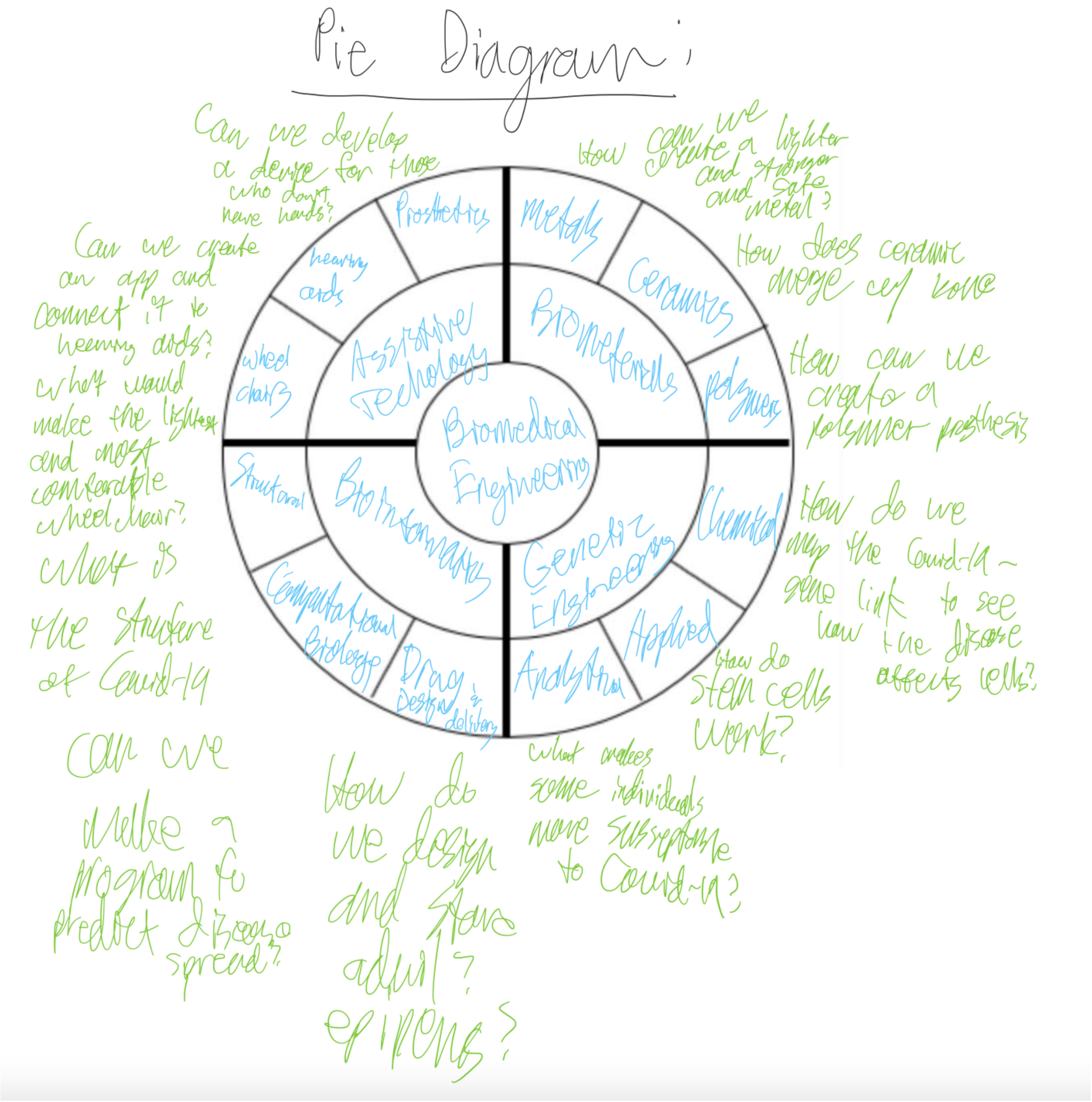
-You don't want to have too much blank space

-If you are adding a pre-printed graph or sketch, paste in and sign + date.

# Brainstorming

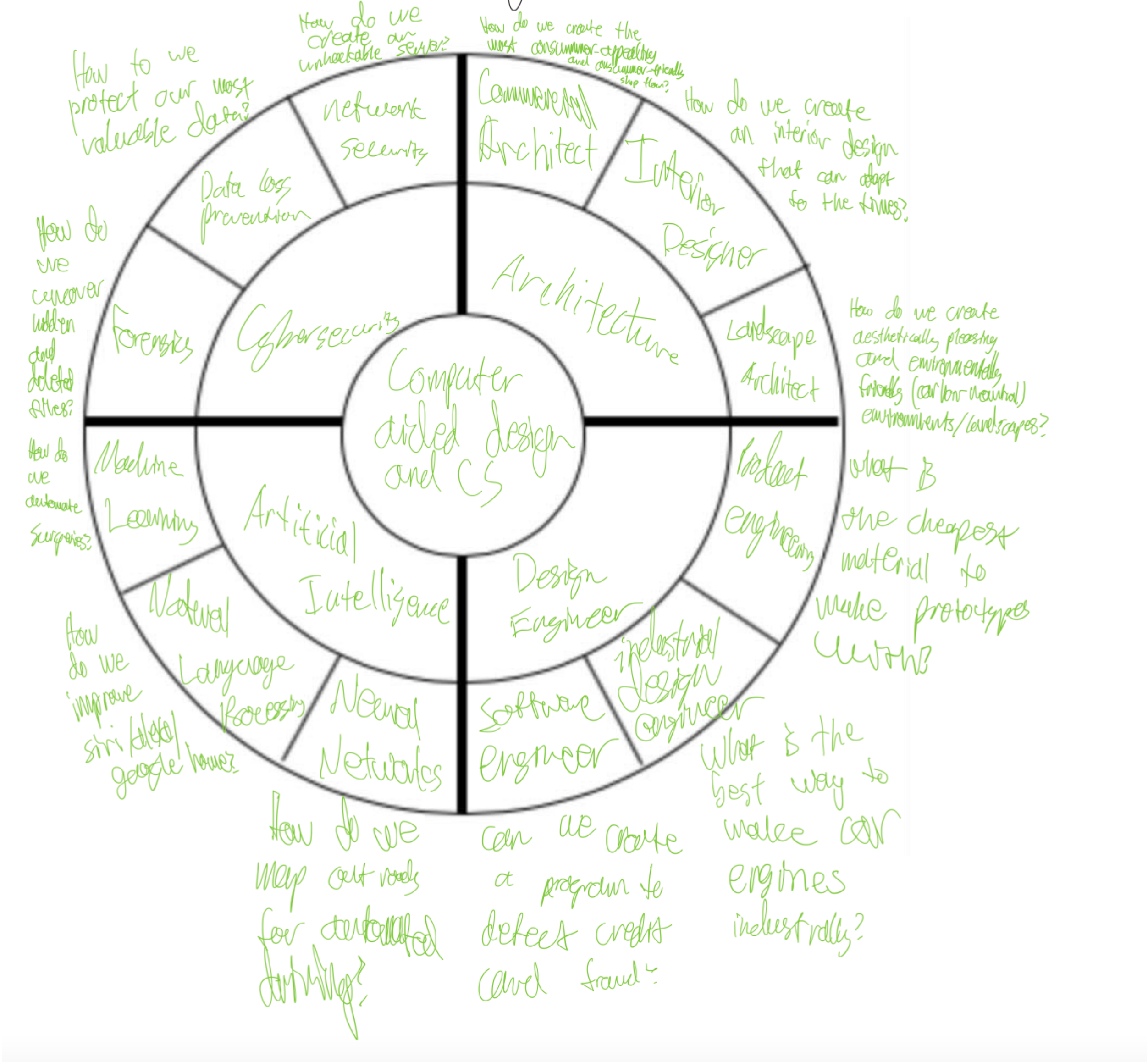
Pie Diagrams:

All three were created pre-project

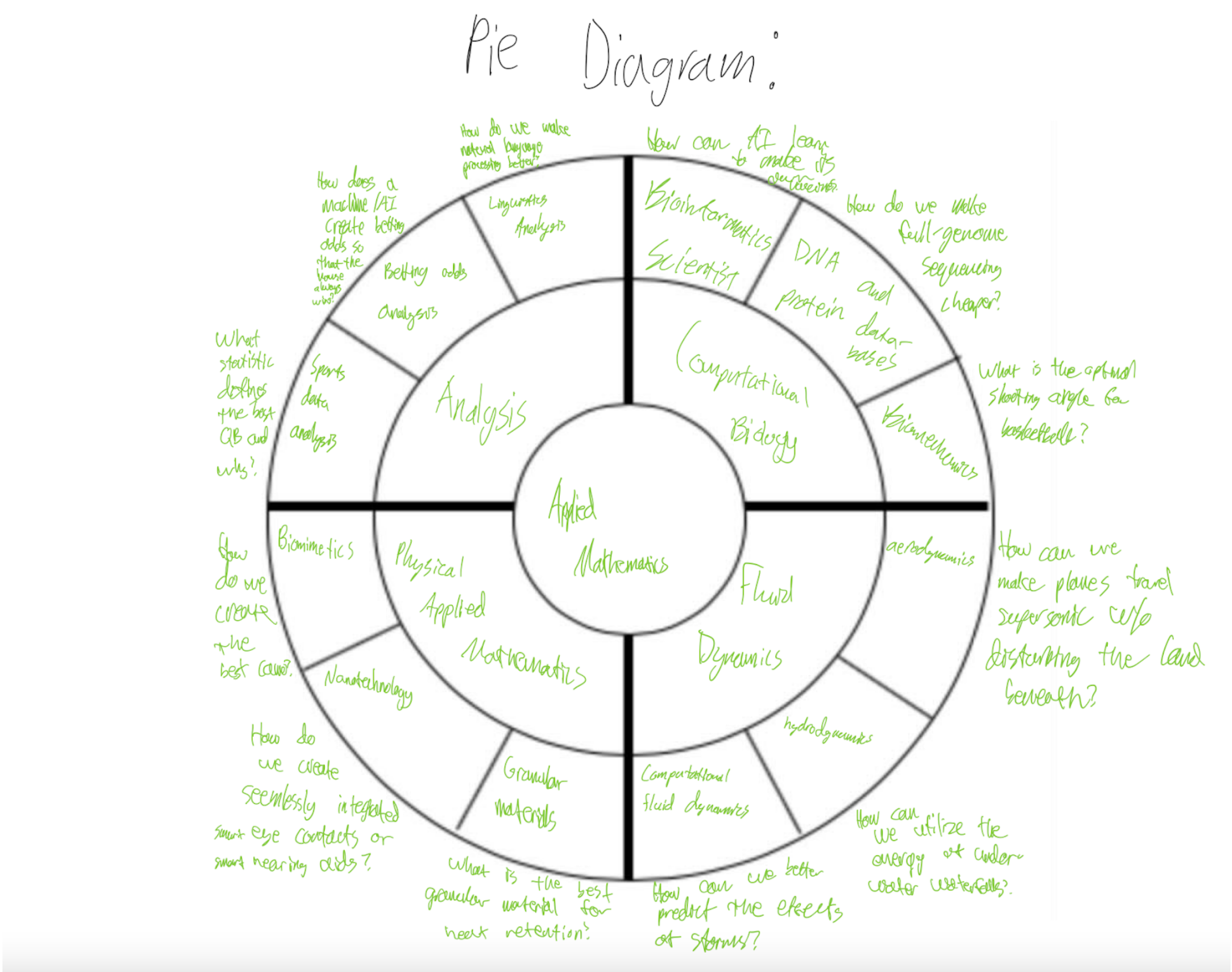


Brainstorming topic one: BME

# Pie Diagram;



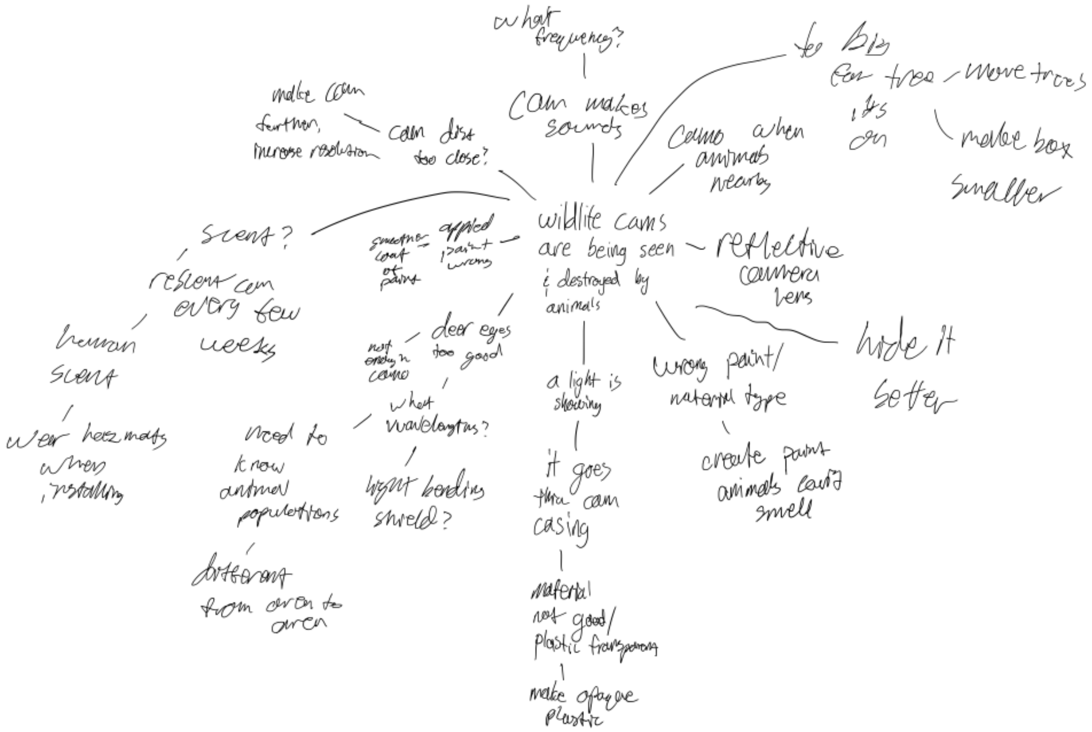
Brainstorming topic two: CS/CAD



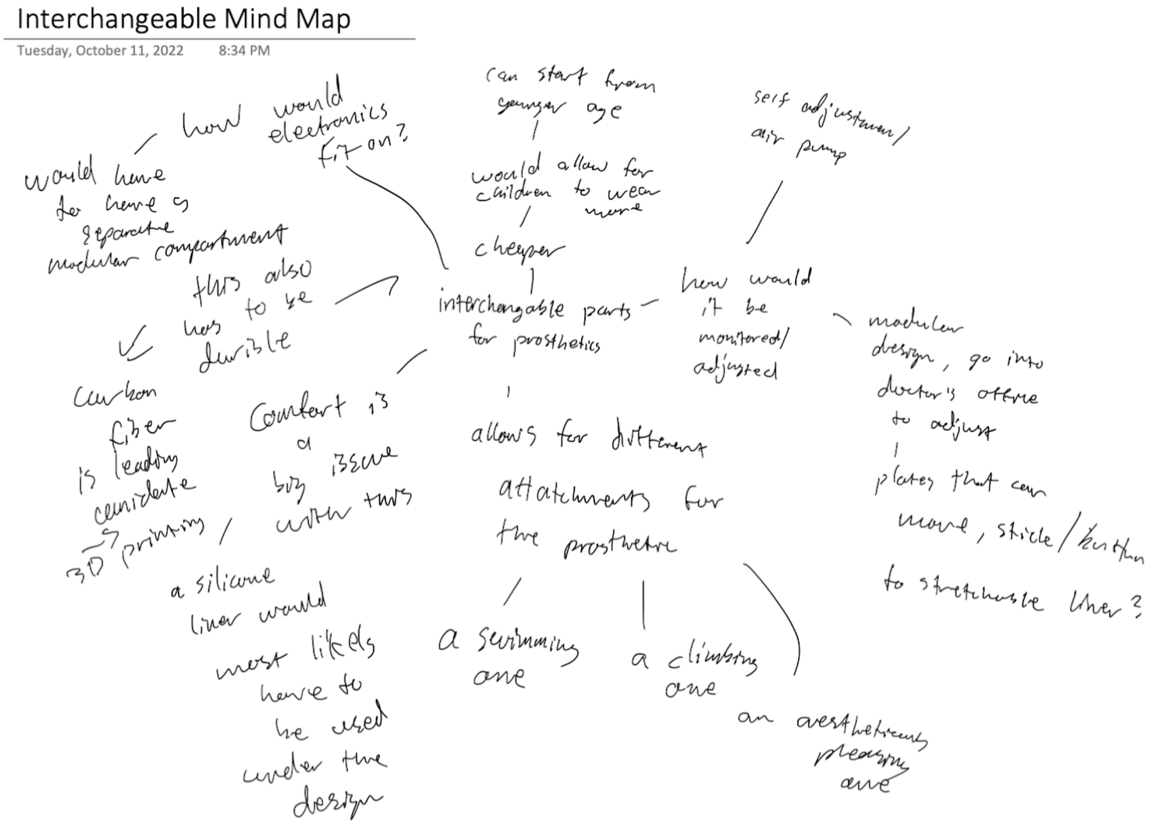
Brainstorming topic three: applied mathematics

Mindmaps

August 22, 2022



wildlife camera mind map/summer exercise



Interchangeable Mind Map

Tuesday, October 11, 2022 8:34 PM

interchangable parts for prosthetics

how would electronics fit on?

would have to have a separate modular compartment

this also has to be durible

carbon fiber is leading canidate

3D printing

Comfort is a big issue with this

a silicone liner would most likely have to be used under the design

cheaper

would allow for children to wear more

can start from younger age

how would it be monitored/adjusted

self adjustment/air pump

modular design, go into doctor's office to adjust

plates that can move, strickle/button to stretchable liner?

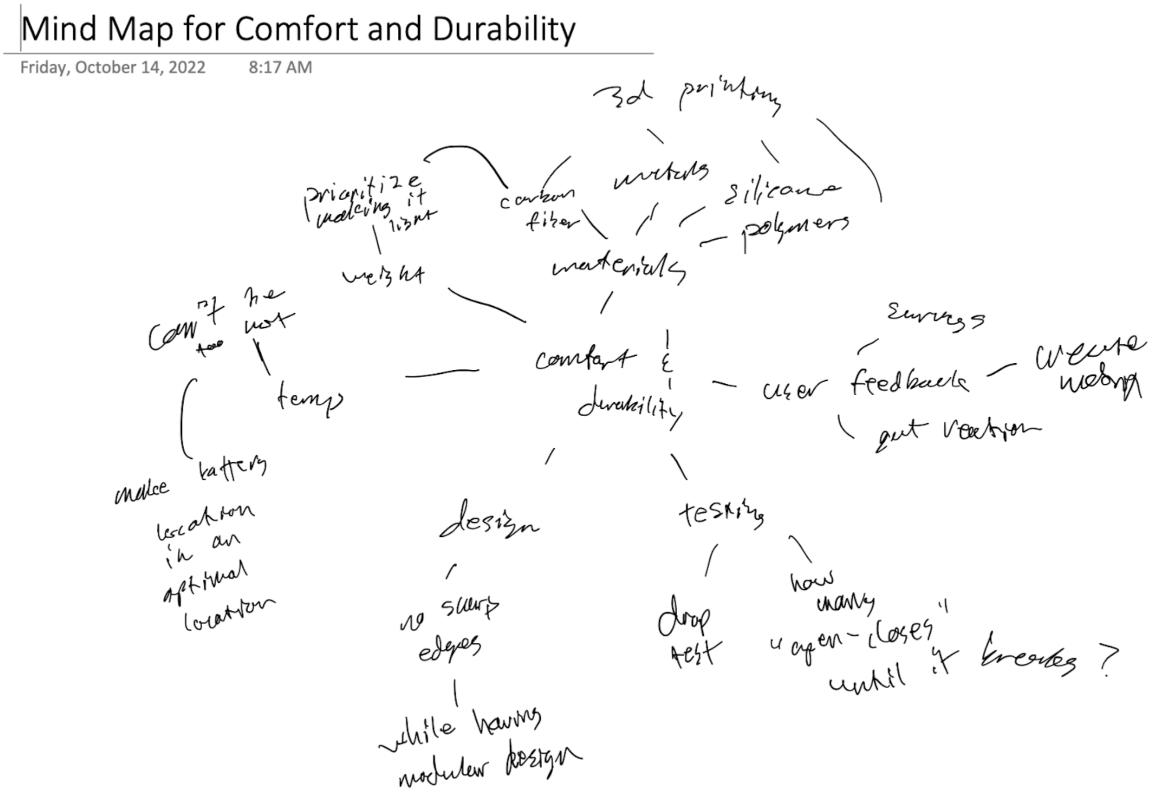
allows for different attachments for the prosthetic

a swimming one

a climbing one

an aesthetically pleasing one

Mind map concerning interchangeability in prosthetics and how it could possibly be integrated



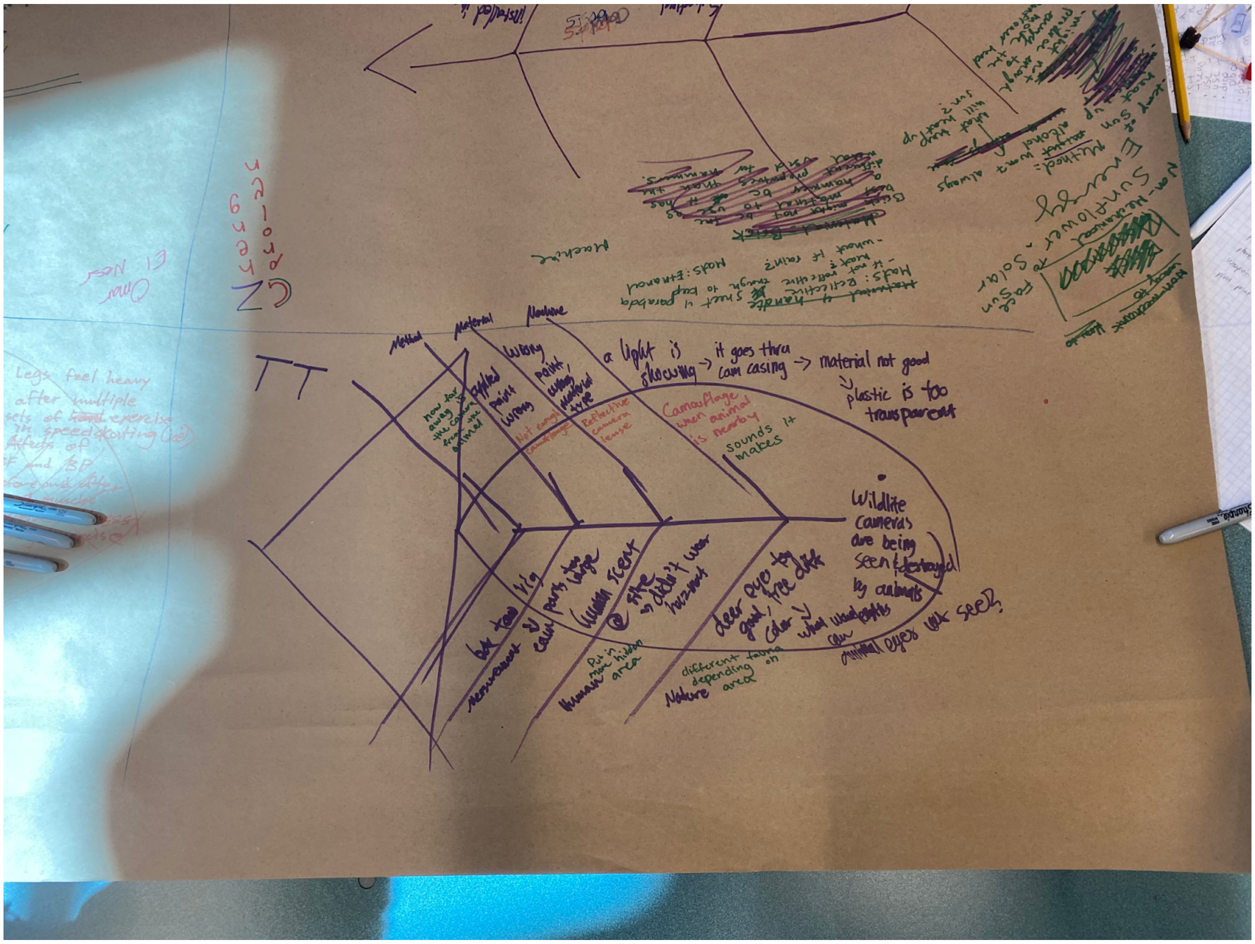
Mind Map for Comfort and Durability

Friday, October 14, 2022 8:17 AM

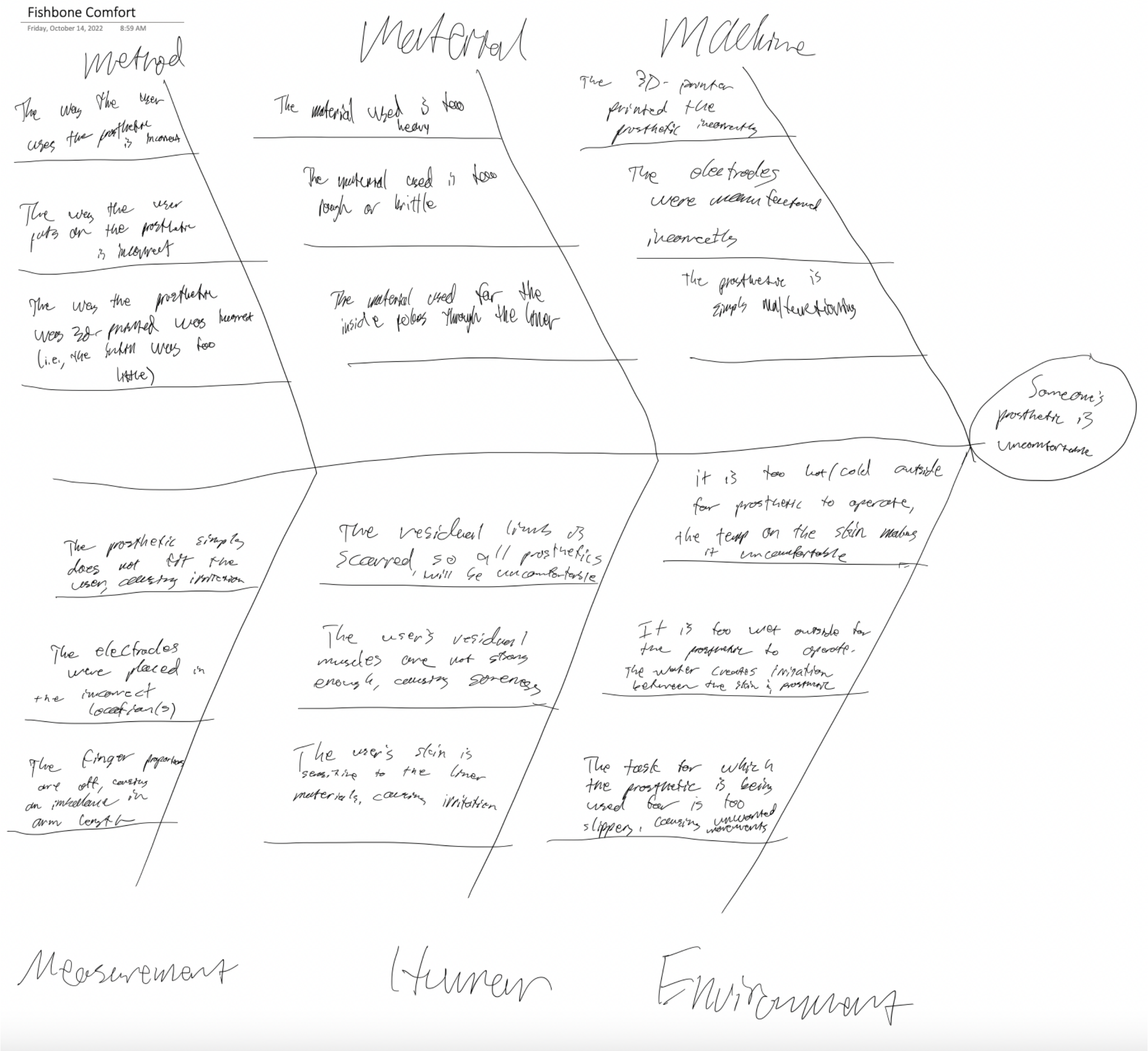
Mind map regarding comfort and durability of prostheses

Fishbone Diagrams

## Created pre-project



Fishbone version of the wildlife camera mind map



Fishbone Comfort

Friday, October 14, 2022 8:59 AM

Someone's prosthetic is uncomfortable

The way the user uses the prosthetic is incorrect

The way the user puts on the prosthetic is incorrect

The way the prosthetic was 3D-printed was incorrect (i.e., the infill was too little)

The material used is too heavy

The material used is too rough or brittle

The material used for the inside pokes through the liner

The 3D-printer printed the prosthetic incorrectly

The electrodes were manufactured incorrectly

The prosthetic is simply malfunctioning

The prosthetic simply does not fit the user, causing irritation

The electrodes were placed in the incorrect location(s)

The finger proportions are off, causing an imbalance in arm length

The residual limb is scarred, so all prosthetics will be uncomfortable

The user's residual muscles are not strong enough, causing soreness

The user's skin is sensitive to the liner materials, causing irritation

it is too hot/cold outside for prosthetic to operate, the temp on the skin makes it uncomfortable

It is too wet outside for the prosthetic to operate. The water creates irritation between the skin & prosthetic

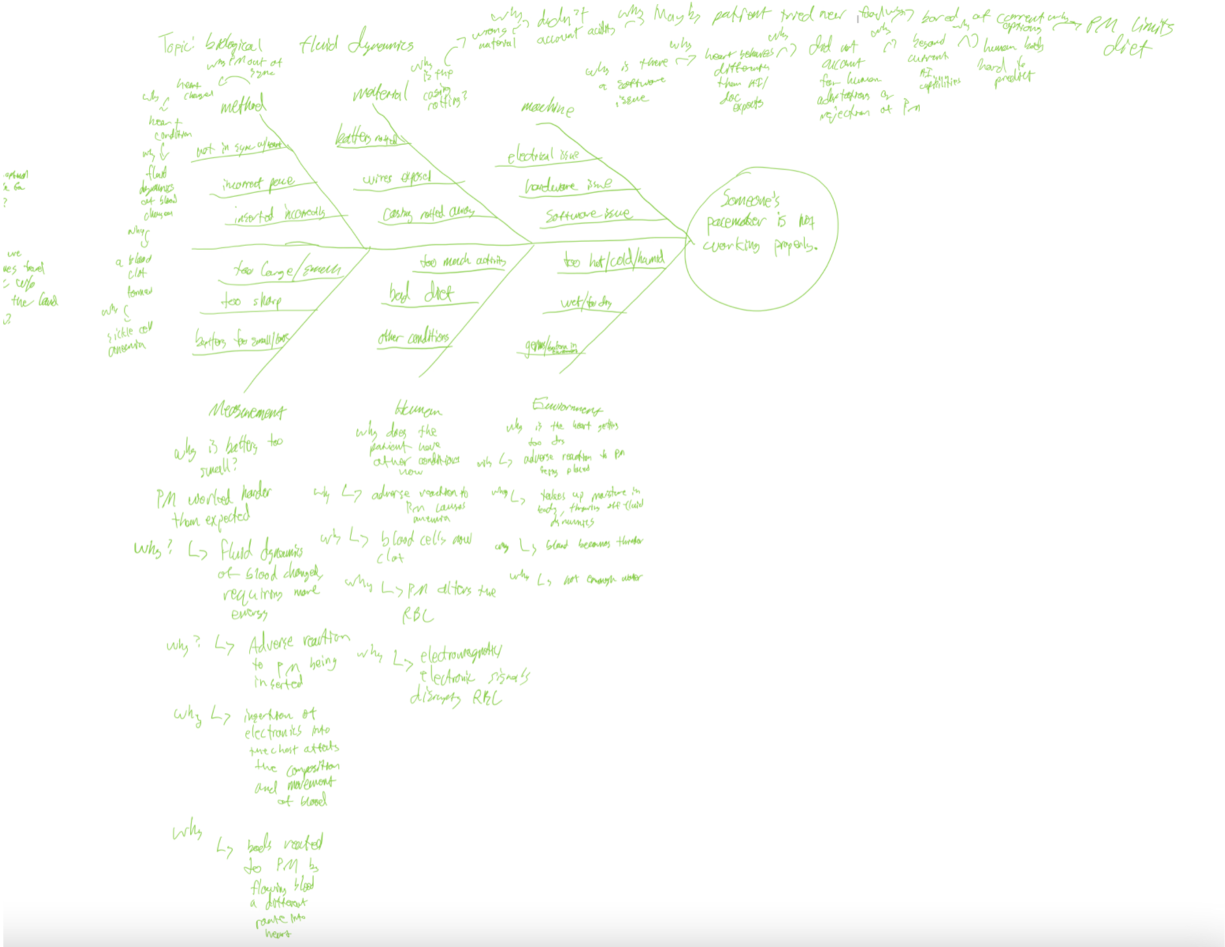
The task for which the prosthetic is being used for is too slippery, causing unwanted movements

Comfort fishbone

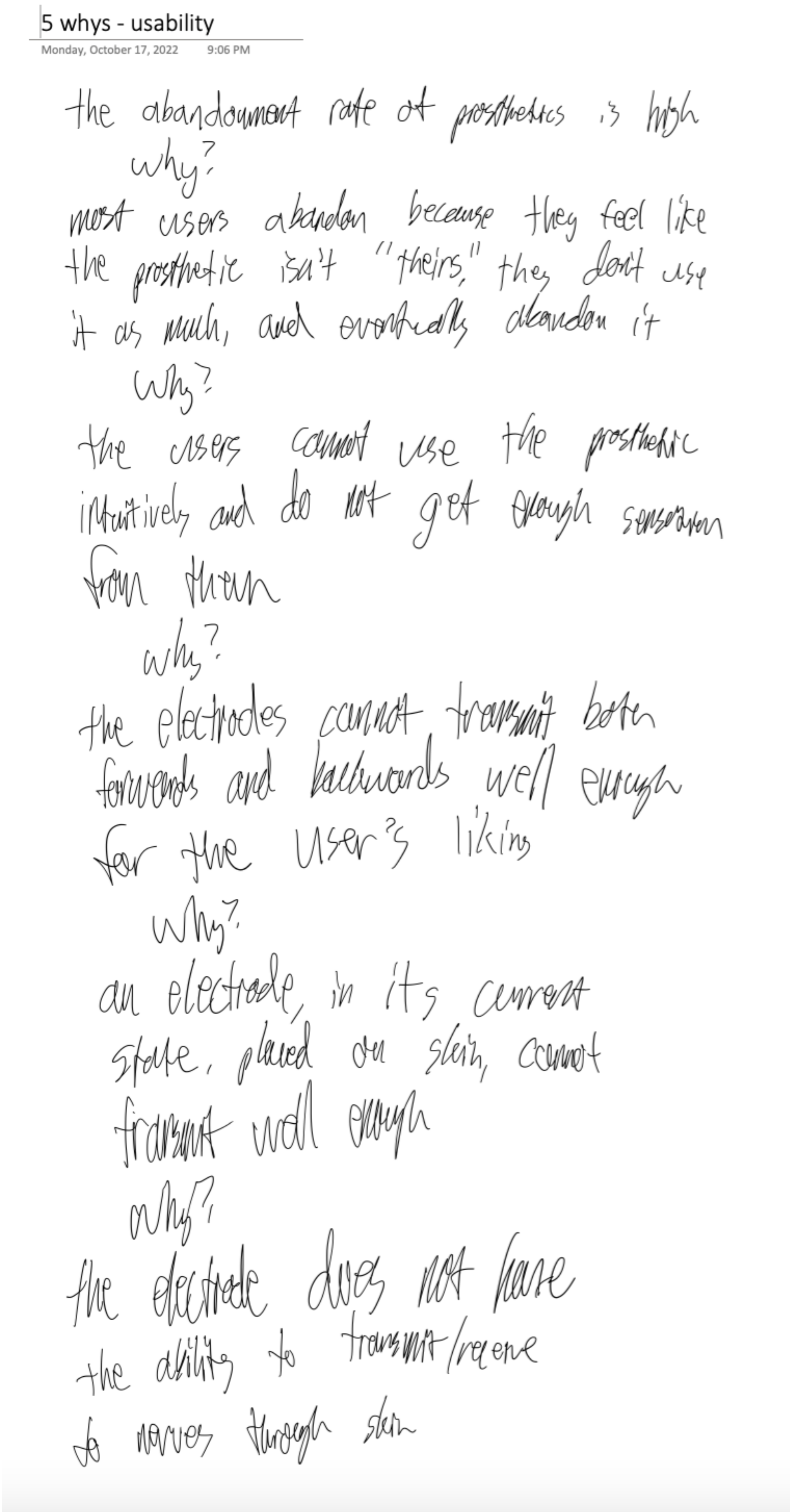
Interchangeability fishbone

5 Whys

August 25, 2022



5 whys practice exercise, issue: pacemaker not working



## 5 whys - usability

Monday, October 17, 2022 9:06 PM

the abandonment rate of prosthetics is high

why?

most users abandon because they feel like the prosthetic isn't "theirs," they don't use it as much, and eventually abandon it

why?

the users cannot use the prosthetic intuitively and do not get enough sensation from them

why?

the electrodes cannot transmit both forwards and backwards well enough for the user's liking

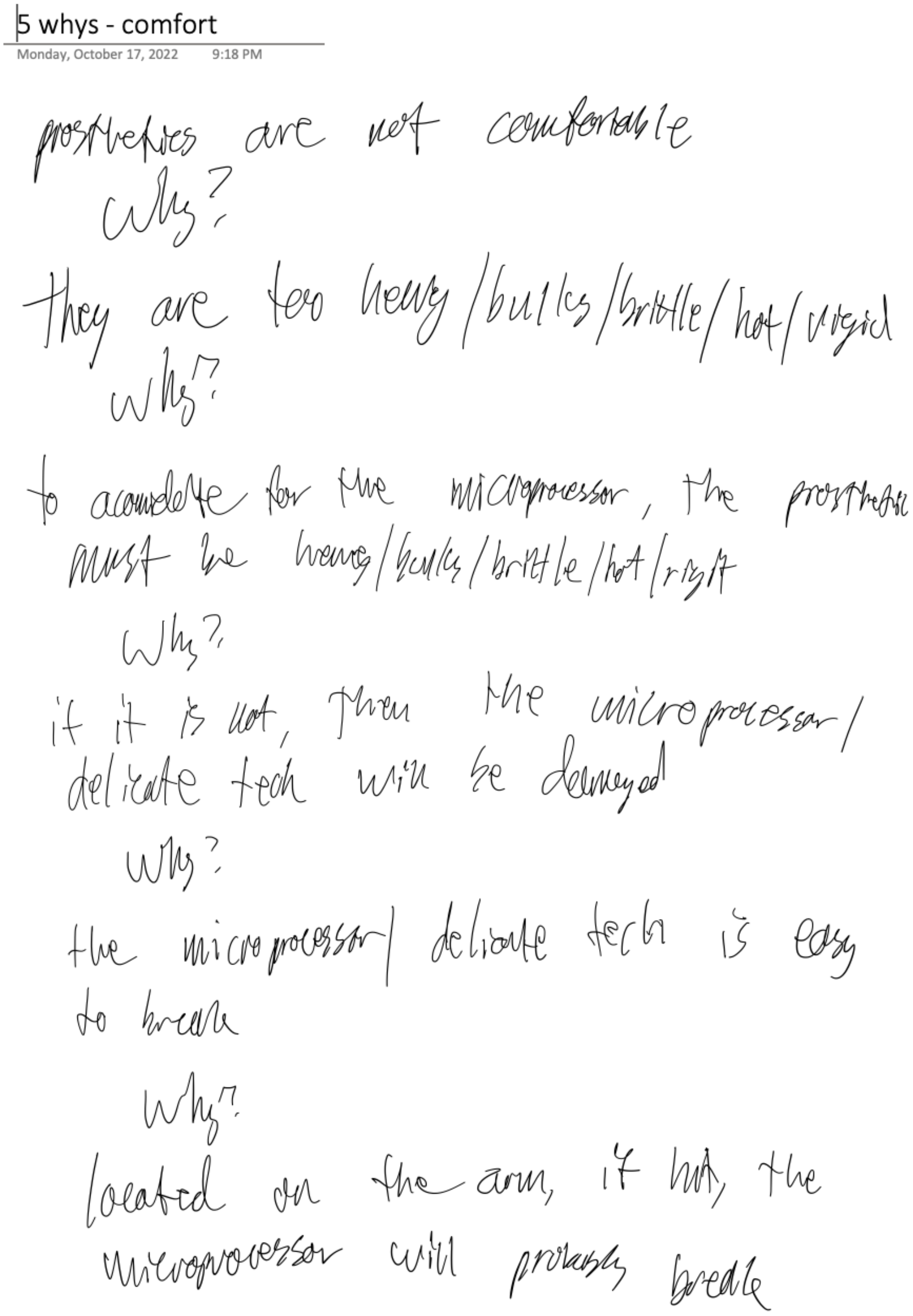
why?

an electrode, in its current state, placed on skin, cannot transmit well enough

why?

the electrode does not have the ability to transmit/receive to nerves through skin

5 whys for usability



5 whys - comfort

Monday, October 17, 2022 9:18 PM

prosthetics are not comfortable

why?

they are too heavy/bulky/brittle/hot/rigid

why?

to accomodate for the microprocessor, the prosthetic must be heavy/bulky/brittle/hot/rigid

why?

if it is not, then the microprocessor/ delicate tech will be damaged

why?

the microprocessor/ delicate tech is easy to break

why?

located on the arm, if hit, the microprocessor will probably break

5 whys comfort

# Abstract (250 limit):

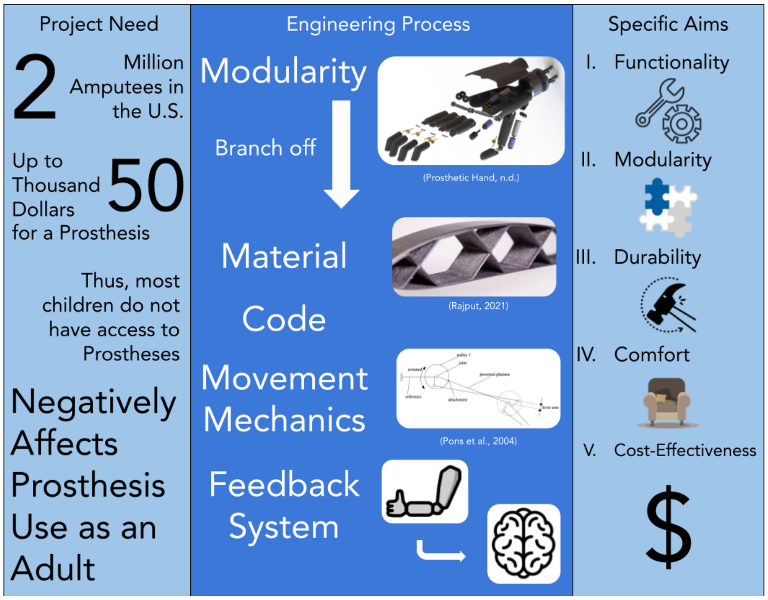
Today, many prosthetic options are too expensive for the majority of individuals to obtain, causing a lowered quality of life for millions of amputees around the world. For children with a limb difference, it is even harder to obtain functional prostheses, as the child outgrows the limb too quickly, thus, new prostheses are needed every 12-18 months. In order to combat the price barrier surrounding advanced prostheses, a modular myoelectric prosthesis model was created. The movement control of the myoelectric was implemented through an Arduino-microcontroller and powered by servo motors and photoelectric sensors by way of electrical signals emitted from muscles. The modular prototypes were developed with many different 3D-printed materials, infill levels, Arduino code, and movement mechanic designs, then tested on five specific criteria: functionality, modularity, durability, comfort, and cost effectiveness. Due to its modularity, the prosthesis will be more accessible to children who cannot afford to buy new ones. Additionally, bidirectional signaling between the prosthesis and the user was a major focus of this project so that the user would be able to feel simple sensations with the prosthesis. A cheaper, 3D-printed, and modular below-elbow myoelectric prosthesis will allow children to grow up with and utilize prostheses to a greater extent. The best prototype according to the criteria was selected via an engineering design matrix. Testing showed that the prototype performed at 42% the functionality of a human arm. Future work will be geared toward implementing permanent electrode sensors and continuing to improve upon the criteria.

Keywords: Sensory feedback, 3D printed, durability, comfort, cost-effective, myoelectric

P1: Today, many prosthetic options are too expensive for the majority of individuals to obtain, causing a lowered quality of life for millions of amputees around the world. For children with a limb difference, it is even harder to obtain functional prostheses, as the child outgrows the limb too quickly, thus, new prostheses are needed every 12-18 months.

P2: In order to combat the price barrier surrounding advanced prostheses, a modular myoelectric prosthesis model was created.

Graphical Abstract:



Graphical Abstract (Made by T. Tran in Google Drawings, 2022).

# Background:

**Prosthesis Types**

There are currently many different types of prostheses, all utilizing different technologies and targeting different patient groups. The most prevalent prosthesis types are passive, body powered, myoelectric, and hybrid (Smail et al., 2021). Passive prostheses are simply for aesthetics and have no functional ability. Made of mostly silicone, plastic, and paint, passive prostheses will look the most realistic, but will be just that. Passive prostheses are also the cheapest kind of prosthesis. Body powered prostheses have functional use, but have no electrical parts to them. Usually fitted with a shoulder harness and hook, body powered prostheses are the simplest and cheapest type of functional prostheses. Myoelectric prostheses are more advanced than the body powered prostheses and require an external power source, usually a rechargeable battery. Utilizing electrodes connected to the muscles on the residual limb, myoelectrics take input from the electrodes and move, with motors, the prosthetic limb. There are three main ways to map out control of a myoelectric prosthesis: sequential control (SeqCon), direct control (DirCon), and mapped control (MapCon) (Zhu et al., 2022). SeqCon utilizes “modes” within the prosthesis. When the user contracts a certain muscle, the prosthesis will move. When the user contracts a different muscle, the microprocessor on the myoelectric will switch modes on the prosthesis. Now, the original muscle contracted will control a different operation on the prosthesis. DirCon maps out certain prosthetic movements to specific muscle contractions (via the microprocessor code). This means that there are no “modes,” contraction x will control movement x and contraction y will control movement y. MapCon is similar to DirCon, but instead, the mappings are inverted. For example, contraction x will control movement y and contraction y will control movement x. DirCon is used most in congenital amputees who have never moved their hand on their residual limb before. The most common movements which myoelectrics mimic are open-close (Opn-Cls), pronation-supination (Pro-Sup), extend-flex (Ext-Flx), and radial-ulnar (Rad-Uln) movements (Zhu et al., 2022). Myoelectric prostheses are on the pricier side. SeqCon, compared to both DirCon and MapCon, is inferior because it is not as effective in multiple degree of function (DoF) situations (Zhu et al., 2022). This is why this proposal will focus on only DirCon and MapCon myoelectric control.

Hybrid prostheses are a combination of both myoelectric prostheses and body powered prostheses. Hybrid prostheses contain the harness of a body powered prosthesis in conjunction with the electric motors and electrodes of a myoelectric. Depending on the blend of the two technologies, a hybrid prosthesis’s price might range from a little more than a body powered prosthesis to more expensive than a myoelectric. Bidirectional signaling is also starting to be incorporated into myoelectrics. Sensors can be implemented into a myoelectric so that the user can receive some type of sensation when the prosthesis touches something. The myoelectric discussed in this proposal will incorporate this functionality as well. This process is currently being improved by machine learning and artificial intelligence algorithms.

**Prosthesis Materials**

The main materials used to create prostheses are: silicone, carbon fiber, polymers, aluminum, and titanium (Mota, 2017). The silicone is mostly used for the liner of the prosthesis which separates the skin of the residual limb from the prosthesis, like a sock, foot, and shoe. Silicone can also be used in the fingertips of the prosthesis and in the microprocessor as well.

Carbon fiber can be used for almost all parts of the prosthesis. It can be used to create the hand as well as the housing for the residual limb. Its main advantages are that it is light and durable. The only knocks on carbon fiber are that it is expensive and hard to 3D print. Polymers are used in the same fashion as carbon fiber as a cheaper alternative. Polymers are weaker and less durable compared to carbon fiber and can also be heavier. Aluminum and titanium, two similar metals, are used in creating some of the joints in a prosthesis. A high stress part, joints have to be made of strong materials, such as aluminum and titanium. It cannot be used too much though because it would make the prosthesis too heavy. Aluminum and titanium are used more in body powered prostheses because they are supported by shoulder harnesses and can handle the added weight. Hooks are usually made from metals such as aluminum and titanium.

### Prosthesis Modularity

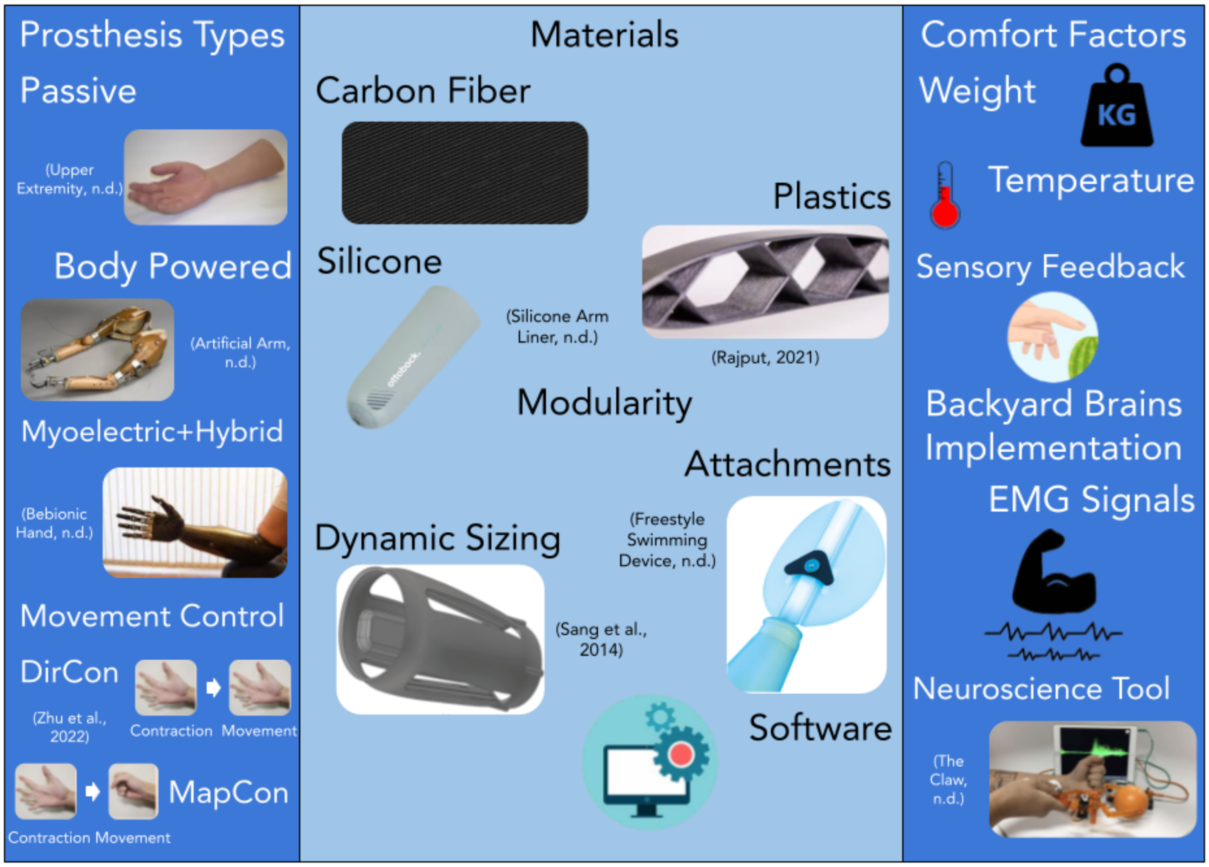
Today, few are pursuing modular prosthetics in the sense that the prosthesis will grow up with a child by getting physically larger. There is not much information out there regarding this type of prosthesis modularity. With 3D printing, the hope is that a type of shape-changing prosthesis will be able to be created. Modular parts of the prosthesis will be able to be added on to the existing prosthesis by a prosthetist without needing to change or scrap the entire prosthetic design. Or, possibly, a dynamically changing prosthesis could be made utilizing pressure sensors and an airbag and pump, similar to a shape-changing cast. Currently, the closest thing resembling the modularity which this proposal seeks is hand attachments for prostheses and modularly designed prostheses software, not the physical parts of the prosthesis (Johannes, 2011). For example, consider a fin attachment for a prosthesis so that the user can swim better with it or an algorithm on a microprocessor that can be used for a multitude of prostheses.

### Prosthesis Comfort

Today, a high percentage of amputees who receive prostheses abandon them and never use them again (Smail et al., 2021). It is a serious problem that wastes the user's money and lowers their quality of living. The main cause of this is the fact that their prostheses are not comfortable to use or wear. The main issues users find with their prostheses is that they are too heavy, too hot after an extended period of use, too rigid, and too bulky (Smail et al., 2021). These factors are the main attributes that a prosthesis should not have to be successful in truly helping the user to everyday tasks. In addition, users abandoned prostheses without sensory feedback, listing the lack of sensor feedback as a reason for their abandonment (Smail et al., 2021). The users who abandoned the prosthesis felt like it was not a part of them and that they could function better with just their residual limb.

### Backyard Brains

Backyard Brains is a company that creates neuroscience tools that utilize the human nervous system to control computers and robots. One of their products, named “The Claw,” will be used as the subject model in experimentation. The product comes with electrodes, an arduino (microcontroller), and a plastic claw which can be controlled by the user when electrodes sense a muscle contract (The Claw, n.d.). Prototypes of the prosthesis will be attached to The Claw to be tested. The arduino code will also be modified to control the prosthetic prototype. The testing will be similar to the able-bodied participants in “Myoelectric Control Performance of Two Degree of Freedom Hand-Wrist Prosthesis by Able-Bodied and Limb-Absent Subjects” (Zhu et al., 2022).



Graphical Background (Made by T. Tran in Google Drawings, 2022).

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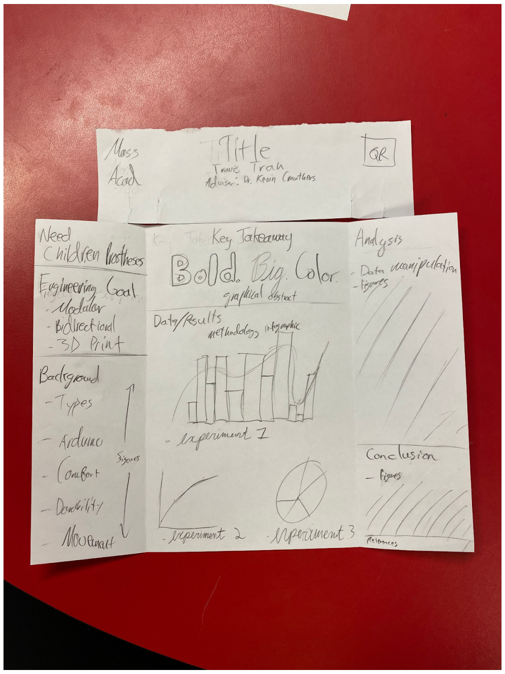
More updated version found in Tran Grant Proposal 2022v3 .

Poster Plan preDecFair 12/1/22



# Project Introduction:

## Development of a Modular Below-Elbow Prosthesis with Bidirectional Signaling for Children

There are over two million amputees in the United States and many cannot afford prostheses, especially children who grow out of them quickly (Zhu et al., 2022). The price of body-powered prostheses range from $4,000 to $50,000, while the price of the externally-powered prostheses cost from $25,000 to $50,000 (Cabibihan et al., 2018). Modern prostheses are so expensive because each one of them must be personalized. Each situation is different, so there is no way to generalize the traditional silicone casting process, which is time consuming. Because of this, most child amputees do not grow up using a prosthesis, decreasing the likelihood of prosthesis use as an adult (Huizing et al., 2010). This absence of prostheses during childhood can cause detrimental effects to the user's prosthesis use later in life as it depends on the age the prosthesis is fitted (Huizing et al., 2010). The children are not used to operating daily life activities with a prosthesis. The older the children get, the harder it will become for them to adapt to using a prosthesis.

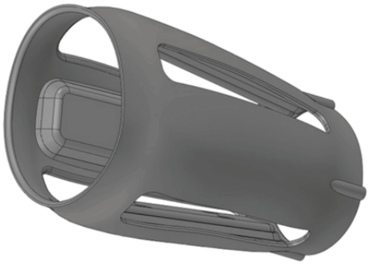


Figure 1: Novel socket design. Airbag and pump powered shape-changing prosthetic socket (Sang et al., 2014).


Figure 2: Prosthetic Fin Attachment. Designed to attach to prosthesis for swimming (Freestyle Swimming Device, n.d.).

To combat this price barrier surrounding advanced prostheses, a modular prosthetic design can be developed to grow with the user. The modularity aspect of this project has not been found predominantly in the field yet and is the main innovation being targeted. No other prosthesis accommodates for growing children in this way. With 3D printing, a shape-changing prosthesis was created. Modular parts of the prosthesis will be added on by a prosthetist (a healthcare professional who fits prostheses) without needing to change the design. A dynamically changing prosthesis made utilizing pressure sensors, an airbag, and a pump, similar to a shape-changing cast, was also considered as an option (Shoshan & Shamaev, 2015). As an arm grows, it will create more pressure against the prosthesis. The pump will then change the airbag (underneath the prosthesis) size to accommodate for the increase in pressure. This airbag concept has been prototyped, however, it only expands and contracts for extra support when the prosthesis is in use. This novel socket design utilizes four spring-air pump systems located around the socket to change its size (Sang et al., 2014). This design will be expanded on to create a shape-changing prosthesis for growing children as its primary objective. Using a modular design for childhood prostheses can increase overall comfort and accumulate children to use prostheses for the rest of their lives. Currently, for competitor analysis, the closest conceptual design resembling the modularity being sought is hand attachments for prostheses and modularly designed prostheses software (Johannes, 2011). For example, consider a fin attachment for a prosthesis so that the user can swim better with it or an algorithm on a microprocessor that can be used for a multitude of prostheses. Therefore, there is essentially nothing in the field which can be compared to the modular design pursued in this project.

Another important aspect of prostheses is the type of prosthesis. There are currently many different types of prostheses in the field, all utilizing different technologies or mechanics and targeting different patient groups. The most prevalent prosthesis types are passive, body powered, myoelectric, and hybrid (Smail et al., 2021). Passive prostheses are simply for aesthetics, have no functional ability, and are made of mostly silicone, plastic, and paint. Passive prostheses are also the cheapest type of prosthesis (Smail et al., 2021). Next, body powered prostheses have functional use, but have no electrical parts to them. Usually fitted with a shoulder harness and hook, body powered prostheses are the simplest and cheapest type of functional prostheses (Smail et al., 2021). Having been created more recently, myoelectric prostheses are more advanced than the body powered prostheses and require an external power source, usually a rechargeable battery. Utilizing electrodes connected to the muscles on the residual limb, myoelectrics take input from the electrodes and move the prosthetic limb with motors. Because of the batteries, electrodes, and motors, myoelectric prostheses are on the pricier side (Smail et al., 2021). Lastly, hybrid prostheses are a combination of both myoelectric and body powered prostheses. Hybrid prostheses have the harness of a body powered prosthesis with the electric motors and electrodes of a myoelectric. Because of this, a hybrid prosthesis's price might range from a little more than a body powered prosthesis to more expensive than a myoelectric (Smail et al., 2021). Bidirectional signaling is also starting to be incorporated into myoelectrics. Sensors can be implemented into a myoelectric so that the user can receive some type of sensation when the prosthesis touches something. The myoelectric discussed in this paper will incorporate this functionality as well. This process is currently being improved by machine learning and artificial intelligence algorithms to predict the movements the user desires.

There are three main ways to map out the mechanical control of a myoelectric prosthesis: sequential control (SeqCon), direct control (DirCon), and mapped control (MapCon) (Zhu et al., 2022). SeqCon utilizes "modes" within the prosthesis. When the user contracts a certain muscle, the prosthesis will move. When the user contracts a different muscle, the microprocessor on the myoelectric will switch modes on the prosthesis. Now, the original muscle contracted will control a different operation on the prosthesis. DirCon maps out certain prosthesis movements to specific muscle contractions (via the microprocessor code). Contraction of muscle x will control movement x and contraction of muscle y will control movement y. MapCon is similar to DirCon, but instead, the mappings are inverted. Contraction of muscle x will control movement y and contraction of muscle y will control movement x. The most common movements which myoelectrics mimic are open-close (Opn-Cls), pronation-supination (Pro-Sup), extend-flex (Ext-Flx), and radial-ulnar (Rad-Uln) movements (Zhu et al., 2022). SeqCon, compared to both DirCon and MapCon, is inferior because it is not as effective in multiple degree of function (DoF) situations (Zhu et al., 2022). This is why the project will focus on only DirCon and MapCon myoelectric control.

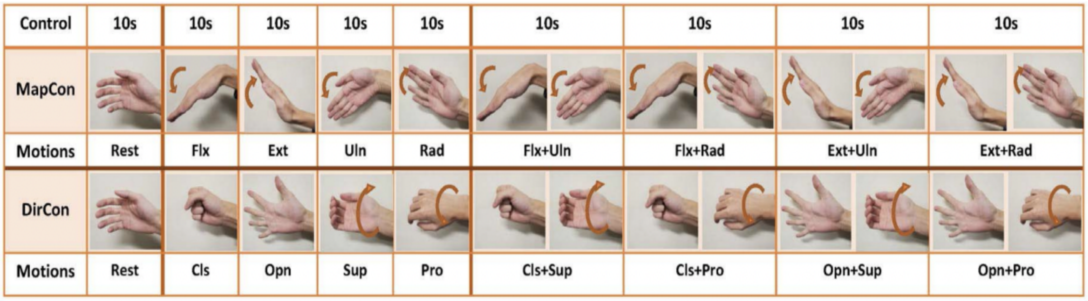


Figure 3: MapCon and DirCon. Common myoelectric movements with MapCon and DirCon control (Zhu et al., 2022).

A critical part in the creation of prosthesis is the material of the prosthesis. The main materials used to create prostheses are: silicone, carbon fiber, polymers, aluminum, and titanium (Mota, 2017). Silicone is mostly used for the liner of the prosthesis, separating the skin of the residual limb from the prosthesis, like how a sock separates a foot from a shoe. Carbon fiber can be used for almost all parts of the prosthesis. It can be used to create the fingers/hand as well as the socket for the residual limb. Its main advantages are that it is light and durable. However, carbon fiber is expensive and hard to 3D print. Polymers are used in the same fashion as carbon fiber as a cheaper alternative. Polymers are weaker and less durable compared to carbon fiber and can also be heavier. Aluminum and titanium, two similar metals, are used in creating some of the joints in a prosthesis. A high stress part, joints have to be made of strong materials, such as aluminum and titanium. Aluminum and titanium are used more in body powered prostheses because they are supported by shoulder harnesses and can handle the added weight. Hooks are usually made from those metals as well.

Currently, a high percentage of amputees who receive prostheses abandon them and never use them again (Smail et al., 2021). This wastes the user's money and lowers their quality of living. The main cause of this is that prostheses are not comfortable to use or wear, due to irritation or pain. The main issues users find with their prostheses is that they are heavy, hot after an extended period of use, rigid, and bulky (Smail et al., 2021). In addition, users abandoned prostheses without sensory feedback, listing the lack of sensation as the cause of abandonment (Smail et al., 2021). Users who abandon prostheses feel like it is not a part of them and they could function better without it. This project will focus on improving these comfort-related prosthetic issues.

To help implement the prosthesis design, Backyard Brains's “The Claw” is utilized as proof of concept and guide. Backyard Brains is a company that creates neuroscience tools that utilize the human nervous system to control computers and robots. One of their products, named “The Claw,” will be used as the subject model in experimentation. The product comes with electrodes, an Arduino (microcontroller computer), and a plastic claw which can be controlled by the user (The Claw, n.d.). When the electrodes sense

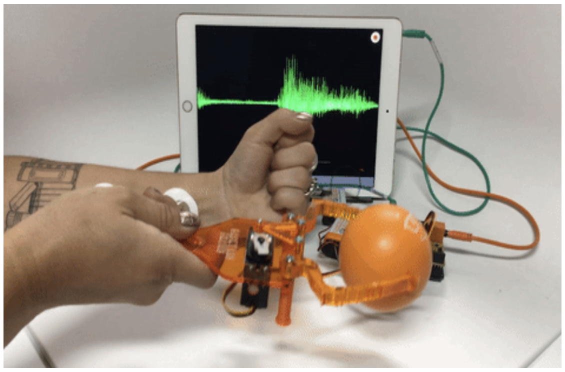


Figure 4: The Claw from Backyard Brains. Arduino also connected to tablet to visualize the strength of the EMG signals (The Claw, n.d.).

a muscle contract, they relay the EMG signal (electromyography signals, or electrical signals which the brain sends to muscles to control them) to the Arduino. The Arduino, coded in C++, then takes that signal to control a servo motor which rotates to move the plastic claw.

Along with the main goal of creating a modular 3D-printed prosthesis prototype, bidirectional functionality, durability, comfort, and cost-effectiveness will be specific focusing points. Modularity, in conjunction with the bidirectional functionality of the prosthesis allows children to grow up with prostheses at a cheaper cost with the functionality of a myoelectric.

The first and most important specific aim for this project is functionality. A prosthesis lacking functionality has no use. There will be three main trials to test the functionality of the prosthesis. Elaborated more in the methodology section, the three main trials are stacking wooden blocks, hanging clothespins, and twisting a round doorknob with the prosthesis prototype.

The second specific aim for this project is modularity. Modularity is what will allow the prosthesis to grow up with the children. As the residual limb of the child grows, so too will the prosthesis. Modularity can be achieved in many different ways, a few of which are: modular plastic 3D-printed pieces that attach to each other, airbags and an air pump which will adjust the size of the prosthesis, or a combination of the two.

The third specific aim for this project is durability. If the prosthesis is not durable, the user has to adjust their life to the prosthesis when it should be the other way around. This could ultimately lead to prosthesis abandonment, lowering the user's quality of life. The user must be able to trust the prosthesis, and for that to happen it must be durable and sturdy. Many different types of 3D-printing filaments at different infill levels will be tested in the creation of this prosthesis.

Comfort is the fourth specific aim for this project. One of the leading reasons for prosthetic abandonment is comfort. The prosthesis cannot be too heavy, rigid, hot, or bulky. The material used and the overall mechanical design for the prosthesis will determine these factors. Again, many different types of 3D-printing filaments at different infill levels will be tested in the creation of this prosthesis.

The last specific aim for this project is cost-effectiveness. Emphasized throughout this project, cost is one of the main hindrances of prostheses being widely available for both adults and children. Although the budget for this project is 2000 USD, the majority of that is not anticipated to be used. In addition, 2000 USD is only a fraction of the cost of current prostheses.

The process of the creation of the modular prosthesis prototype is as follows. In designing the product, the first step is to determine the modularity of the design. From there, branches can be made off of the modularity ideas. Material can be changed, the Arduino code can be changed, the feedback sensors can be changed, and the movement mechanics can be changed. This creates the possibility for many different prototypes. Each prototype will be tested, and one, via an engineering design matrix, will be chosen as the final prototype. In addition to the five specific aims, the engineering design matrix will focus on safety, control, and sensory feedback. During the design process, a 3D printer will be utilized to print most of the parts of the prosthetic prototypes. For the Arduino system, there will be two systems of input and output running through the same Arduino. The first system is composed of input from the EMG electrodes (adhered to the user's skin inside of the prosthesis socket) to the servo motors that control the movement of the prosthetic arm. The second system is composed of photoelectric sensors (which detect change in light intensity) on the tips of the prosthetic fingers which trigger vibration motors on the inside of the prosthetic socket. In this way, the user will receive sensory input. Note, along with the photoelectric sensors, infrared sensors will also be tested as well. The functionality testing will be similar to the testing in “Myoelectric Control Performance of Two Degree of Freedom Hand-Wrist Prosthesis by Able-Bodied and Limb-Absent Subjects” (Zhu et al., 2022). The Arduino/Backyard Brain apparatus will be used to test each prosthetic prototype. The Arduino code will be adjusted as needed. For the prototype, different materials, movement mechanics, and modular approaches will be tested. The prototype will then be compared to the baseline performances of “The Claw” and of a normal human arm. The four other specific aims also have their own testing strategies to be discussed in detail later. Future work will be geared toward implementing permanent electrode sensors and continuing to improve upon the criteria via new designs and materials.

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# Materials, Methods, and Results:

The materials used and why they were used for the methods in this project are as follows:
Materials:

- Backyard Brains "Claw" arduino system
- Arduino kit with various sensors and motors
    - Photoelectric sensor
    - EMG sensor
    - Servo motor
    - Vibration motor
    - Attachment cables
    - 2 9V batteries
    - Power Arduino Shield
    - Resistors
    - Arduino jumper cables
- Materials for testing
    - Clothespins
    - Door and doorknob
    - Wooden blocks (Jenga)
    - 3D printer
- 3D printing filament
- Silicone Liners
- Transistors

Methods:

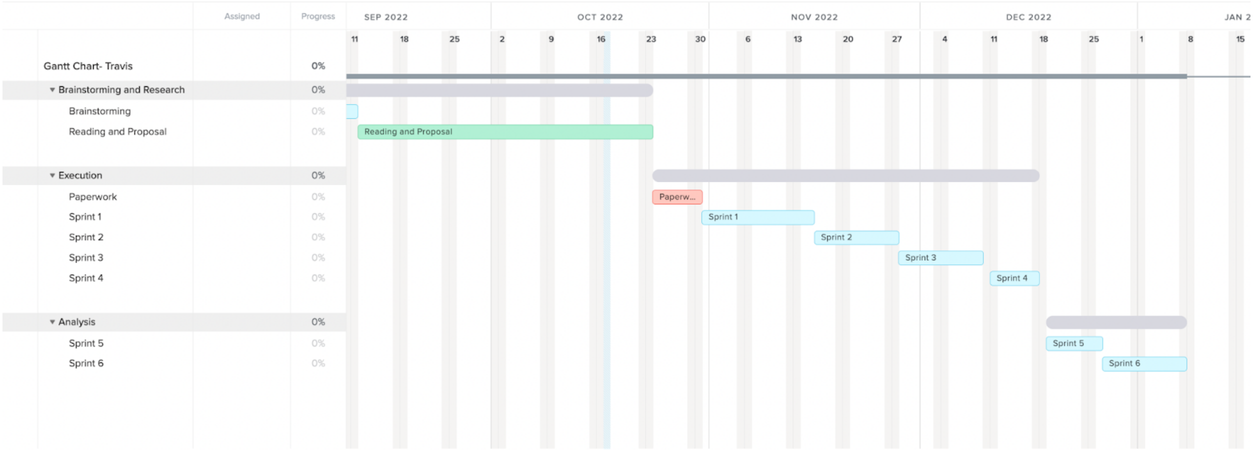
In designing the product, the first part to figure out is the modularity of the design. From there, branches can be made off of the modularity ideas. Material can be changed, the arduino code can be changed, the feedback sensors can be changed, and the movement mechanics can be changed. This creates the possibility for many different prototypes. Each prototype will be tested, and one, via an engineering design matrix, will be chosen as the final prototype. During the design process, a 3D printer will be utilized to print most of the parts of the prosthetic prototypes.

Procedure:

1. Create a schematic for the prototype that is to be made
2. Sketch the prototype
3. Design the prototype in CAD
4. Print out the parts for the prototype
5. Assemble prototype according to the schematic and sketch
6. Integrate the Backyard Brains system
7. Conduct trial 1, record results, repeat 3 times
8. Conduct trial 2, record results, repeat 3 times
9. Conduct trial 3, record results, repeat 3 times
10. Test for all other specific aims
11. Repeat steps 1-10 until a desirable
12. Select the best prototype via the engineering design matrix
13. Continue to test the final prototype
14. Go back to design phase if needed

Procedure infographic for prosthesis prototyping and testing (Made by T. Tran in Google Drawings, 2022).

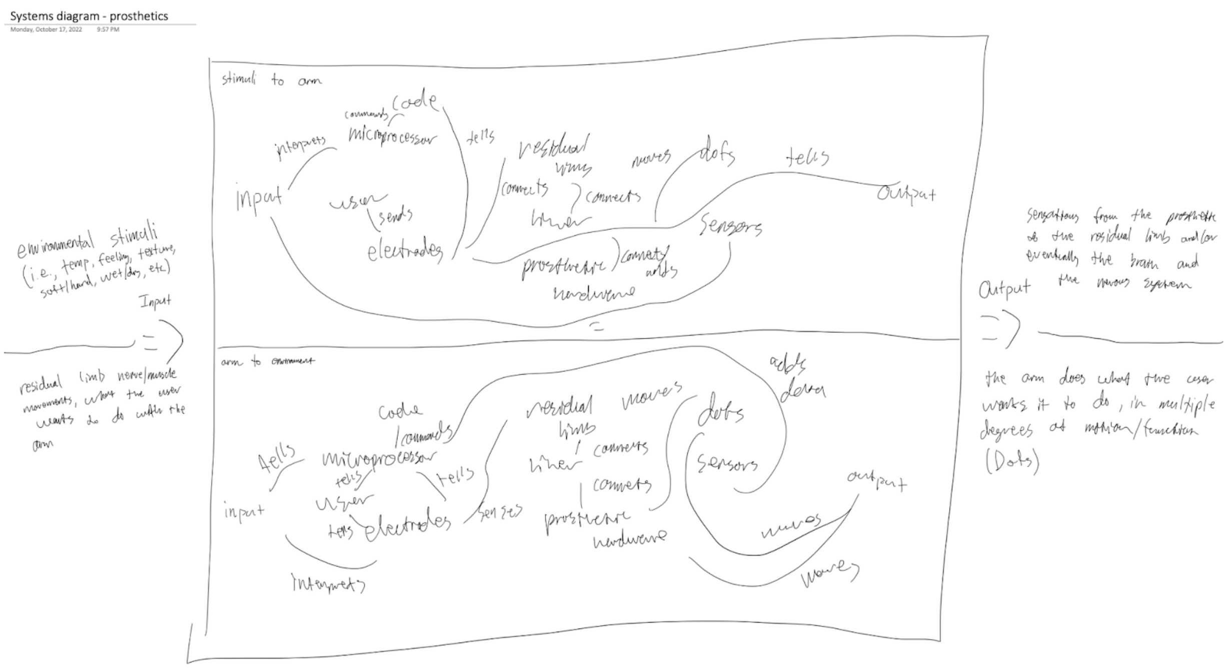
Gantt chart (tentative - 11/17/22):
Note: more detail under sprints



| | Assigned | Progress |
|---|---|---|
| Gantt Chart- Travis | | 0% |
| ▾ Brainstorming and Research | | 0% |
| Brainstorming | | 0% |
| Reading and Proposal | | 0% |
| ▾ Execution | | 0% |
| Paperwork | | 0% |
| Sprint 1 | | 0% |
| Sprint 2 | | 0% |
| Sprint 3 | | 0% |
| Sprint 4 | | 0% |
| ▾ Analysis | | 0% |
| Sprint 5 | | 0% |
| Sprint 6 | | 0% |

https://app.teamgantt.com/projects/gantt?ids=3244289

Systems diagram (12/6/22);



Systems diagram - prosthetics

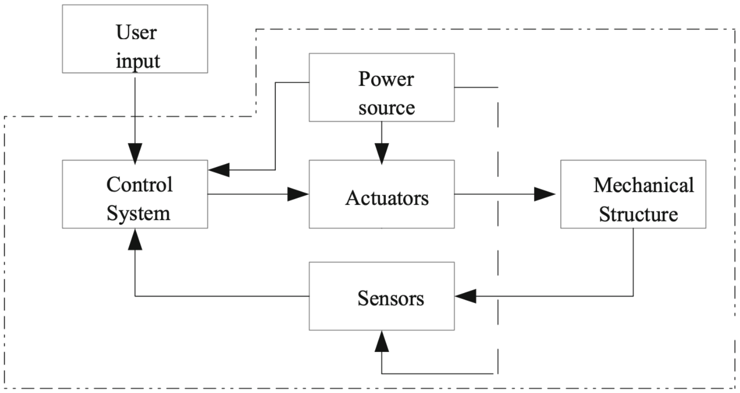
Monday, October 17, 2022 9:57 PM

environmental stimuli (i.e., temp, feeling, texture, soft/hard, wet/dry, etc)

residual limb nerve/muscle movements, what the user wants to do with the arm

sensations from the prosthetic to the residual limb and/or eventually the brain and the nervous system

the arm does what the user wants it to do, in multiple degrees of motion/function (Dofs)



Engineering Decision Matrix (12/6/22):

| Criteria (Rank) | Example | Design A | Design B | Design C | … |
|---|---|---|---|---|---|
| Safety - how safe the user feels when using the prosthesis; how well the user trusts the prosthesis (10) | 9 | | | | |
| Functionality - determined from functionality methodology (9) | 7 | | | | |
| Modularity - determined from modularity methodology (9) | 5 | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Comfort - determined from comfort methodology (7) | 10 | | | | |
| Durability - determined from durability methodology (7) | 3 | | | | |
| Cost-effectiveness - determined from cost-effectiveness methodology (6) | 6 | | | | |
| Control - how well the user can manipulate the prosthesis to do desired actions (8) | 9 | | | | |
| Sensory Feedback - how well the prosthesis conveys the sense of touch to the user (8) | 3 | | | | |
| Total (Max 640) | 421 | | | | |

Each criteria is given a 1-10 score, then multiplied by the rank and aggregate the results to calculate the final score. Max final score is 640. This table will be used to determine the best prototype/design.

Safety (10) - in any trials, products, or experiments involving humans, safety is always the number one priority.
Functionality (9) - Being one of the most important specific aims of this project, the functionality of the prosthesis determines to the user if they can use the device or not. If they cannot use the product, then the product is a failure.
Modularity (9) - Modularity is one of the features that makes this prosthesis design unique and separate from the rest of the field. If the prosthesis is not modular, then it is just like all of the other competition in the field. The project will then be considered incomplete.
Confort (7) - Comfort is one of the leading factors in prosthesis abandonment, so if the prosthesis is not comfortable for the user then it will be deemed unusable.
Durability (7) - If the prosthesis is not durable, especially considering the target group of children, then the product will be rendered unusable for most of the time and cost the user extra money.
Cost-effectiveness (6) - The price of prostheses is what keeps them from being available to a large proportion of the global amputee population, especially children. Being one of the specific aims of this project, price plays a factor, but is not as important as the others in this prototyping stage.
Control (8) - If the user cannot control the prosthesis, they would most likely abandon it. Going hand in hand with functionality, the prosthesis must be controllable.
Sensory Feedback (8) - Sensory feedback, in conjunction with control and functionality, plays an important role in the abandonment of prostheses. The prosthesis must have sensory feedback, no matter what kind.

A more detailed methods, materials, and results found in:
Tran, Travis - 2022-2023 Project Thesis

# Professional Communication:

Classwork (9/14/22)
Dear Doctor Luu,

I hope this email finds you well. My name is Travis Tran, and I am currently a high school junior at the Massachusetts Academy of Math and Science at Worcester Polytechnic Institute (MAMS) in Worcester, MA. I am reaching out to you today because I am in the process of pursuing a five-month-long independent research project regarding prosthetics. While doing preliminary research, I came upon your journal article *Artificial Intelligence Enables Real-Time and Intuitive Control of Prostheses via Nerve Interface* (2022) and became interested in the work you were conducting. I was hoping if you could, with your extensive knowledge in the field, provide me some insight into how I could develop my own 3D-printed, below-elbow arm prosthetists with motorized control and sensory feedback. Would this project be feasible for me to take on without a lab to provide model subjects or would I need to pursue one? Besides that, I am really interested in the AI and deep learning aspects of your project and hope to learn more about bidirectional communication via microelectrodes in relation to prosthetics. I appreciate your time and I am eager to learn more about the development of sensory prosthetics.

Thank you,
Travis

Travis Tran
Massachusetts Academy of Math and Science at WPI
My Website
ttran2@wpi.edu

Subject: An Inquiry About Myoelectric Control Performance of 2-DoF Prosthesis (10/14/22)

Hello Dr. Clancy,

I hope this email finds you well. My name is Travis Tran, and I am currently a high school junior at the Massachusetts Academy of Math and Science at WPI. I am reaching out to you today because I am pursuing a five-month-long independent research project regarding prosthetics, more specifically, below-elbow 3D printed myoelectrics with interchangeable parts designed for children to grow up with. While conducting preliminary research, I came across your journal article, “Myoelectric Control Performance of Two Degree of Freedom Hand-Wrist Prosthesis by Able-Bodied and Limb-Absent Subjects,” (IEEE Transactions on Neural Systems and

Rehabilitation Engineering, Vol. 30, 2022) and was intrigued by the work you were conducting. Reading your work introduced me to the three main paths I can take for the controlled movement of my own myoelectric. Because you have answered many of my questions about prosthetics, I was hoping if you could answer a few more.

Along with a modular form to accommodate for the growth of the residual limb, I also hope to implement simple sensations for the user. Regarding both DirCon and MapCon methods for control, the better options for 2+ DoF movements, would it be feasible for me to simultaneously implement bidirectionality into the system for this user feedback? Or would it require an external processor? When thinking about creating a prosthetic which grows with the user, the number of electrodes came to mind. Would it be easy to add electrodes onto the system as the prosthetic grows, or would the number of electrodes have to be fixed at the beginning? If the number would have to be fixed, the use of the prosthetic could decrease over time due to the development/enlargement of muscles, leading to new/different contraction patterns and magnitudes. How should I combat this? Additionally, how would you suggest I implement my testing without access to amputees or individuals with a limb difference? Could I potentially test myself using your method of testing able-bodied individuals?

While I can keep asking questions about your research, I understand how valuable your time and expertise are. I really appreciate you for taking the time to read this email and the expertise you have offered thus far. I am eager to learn more about the development of prosthetics.

Best Regards,
Travis

Travis Tran
Massachusetts Academy of Math and Science at WPI
My Website
ttran2@wpi.edu

RE: Subject: An Inquiry About Myoelectric Control Performance of 2-DoF Prosthesis (10/18/22)

Dear Dr. Clancy,

I would like to thank you for your time and responses to my questions. I really appreciate the depth of your answers and the insight you have given me. In addition, I was wondering if there is anything that I can do to help you in your lab to gain research experience. On my own, navigating through the processes and fronting the costs of my project will be difficult, so I am looking for someone to help mentor me. I know the value of your time, resources, and expertise and will not waste it. This subject is something that highly interests me because it has ignited my passion for both engineering and biology. I am eager to work hard and will not take any opportunity for granted.

Thank you,
Travis

Travis Tran
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ttran2@wpi.edu

STEM Project Help (11/18/22)

Hello Mr. Loven,

I hope this email finds you well. I am sending this email to schedule a zoom meeting with you tomorrow, Saturday November 19 for help on my STEM project. My project is on prosthetics, and I have bought a Backyard Brain device powered by an Arduino which powers the prosthetic. I need help regarding what attachments to use/buy and how to approach the coding aspect of the project as well. I am available all-day tomorrow and am looking forward to learning from you soon.

I really appreciate your help.

Best,
Travis

Travis Tran
Massachusetts Academy of Math and Science at WPI
My Website
ttran2@wpi.edu

## Daily Entries:

This section should include specific components to the Engineering Design Process (Build, Test/Evaluate/Revise, Reflection) or Research Process

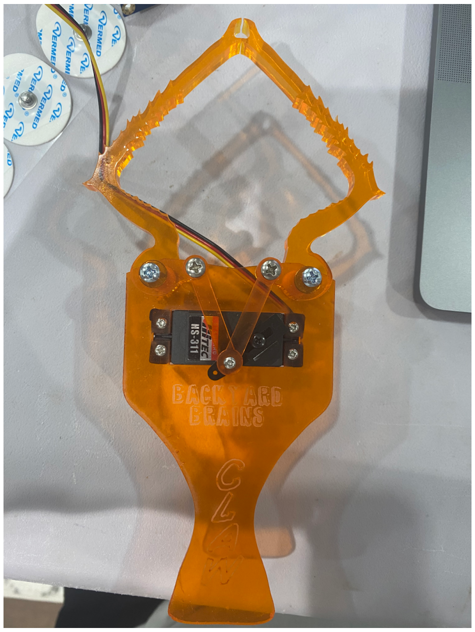
Experiment 1: Title, Date, eSignature
Introduction:
Methods/Materials
Observations and Experimental Data:
Calculations and Data Analysis:
Concluding Remarks
2021_STEMProject_Ex1Test1_Data_Crowthers_v1-01 (link to data file)

## Entry 1: Backyard Brains Opening/Preliminary Experimentation, 10/28/22,

Introduction: After purchasing the Backyard Brains “The Claw” kit, the package came a week later and was opened for opening experimentation and preliminary usage. Read more about the Backyard Brains “The Claw” above.

Methods/Materials: computer, Backyard Brains “The Claw” kit

Observations and Experimental Data: The package was opened and the Arduino controller and all of the parts were put together. Included in the kit was: the servo motor/claw apparatus, EMG electrodes, batteries, and Arduino UNO with preloaded code, jumper cables, laptop cable, and arduino power shield (goes on top of the Arduino to provide extra power for it). No data. Attached the electrodes and tested it on myself. Worked as expected: flexed when I flexed, relaxed when I relaxed. There was also a mode for sensitivity and for switching the mapping to reverse (flex is now relax and vice versa)



The Claw

Calculations and Data Analysis: n/a

Concluding Remarks: this was really fun to play with and the possibilities with this model seem endless. Many more attachments need to be purchased.

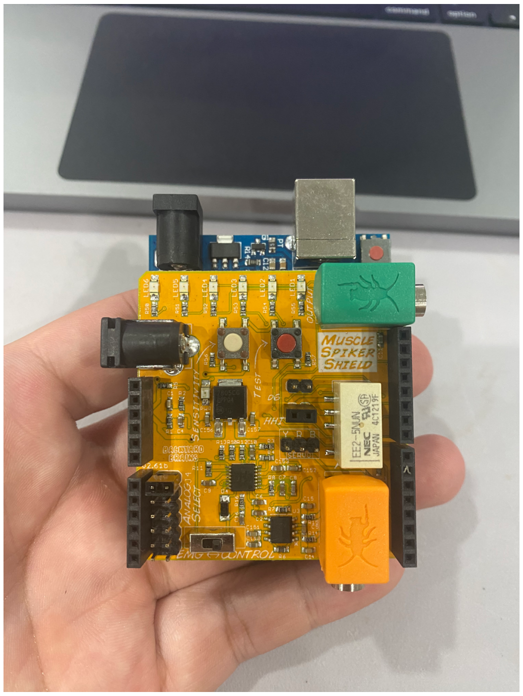
Total spent: $200

## Entry 2: Backyard Brains Opening/Preliminary Experimentation, Cont., 11/19/22,

Introduction: After using the Claw once and taking a break from it to do more research, I again do some preliminary testing with the claw and now try to do some tasks with it. I also called Mr. Pavel Loven for some advice and help on the project. Dr. Crowthers has also given me an Arduino attachment kit containing various attachments for the Arduino UNO as well as an attachment shield for it (allows for more attachments, goes on top of the Arduino).

Methods/Materials: computer, Backyard Brains “The Claw” kit, basic Arduino sensors from Dr. Crowthers.

Observations and Experimental Data: Mr. Loven, via zoom call, helped me with conceptualizing the entire Arduino apparatus and helped me code in C++ (Arduino attached to the laptop via cable, then code uploaded to the Arduino UNO). He also told me what sensors would be advantageous for my experimenting and design of the prosthesis: hall sensor, IR sensor, photoelectric sensor, vibration motor, and servo motor.



The Arduino provided by Backyard Brains with preloaded code

Calculations and Data Analysis: n/a

Concluding Remarks: From this call and experimentation, I have gotten more comfortable with C++, as well as with Arduinos in general, conceptually.

Total spent: $265

## Entry 3: Backyard Brains Investigation, 11/20/22,

Introduction:

Methods/Materials: computer, Backyard Brains “The Claw” kit, basic Arduino sensors from Dr. Crowthers.

Observations and Experimental Data: Following Mr. Loven’s advice and help, I coded the movement (back and forth constantly) of the servo motor apparatus that came with the claw. Simultaneously, the photoelectric sensor could pick up signals and click a relay module when triggered.

Preloaded code:

https://raw.githubusercontent.com/BackyardBrains/SpikerShield/master/Muscle/Arduino%20Code/Gripper/MuscleSpikerShieldWithGripper_V1_0.ino

My code:

```

  https://www.arduino.cc/en/Tutorial/BuiltInExamples/Button
*/
#include <Servo.h>

Servo myservo;  // create servo object to control a servo
// twelve servo objects can be created on most boards

int pos = 0;    // variable to store the servo position

// constants won't change. They're used here to set pin numbers:
const int buttonPin = 12;  // the number of the pushbutton pin
const int ledPin = 8;    // the number of the LED pin

// variables will change:
int buttonState = 0;  // variable for reading the pushbutton status

void setup() {
  // initialize the LED pin as an output:
  pinMode(ledPin, OUTPUT);
  // initialize the pushbutton pin as an input:
  pinMode(buttonPin, INPUT);
  myservo.attach(9);
}

void loop() {
  // read the state of the pushbutton value:
  for (pos = 0; pos <= 180; pos += 1) { // goes from 0 degrees to 180 degrees
    // in steps of 1 degree
    myservo.write(pos);
    buttonState = digitalRead(buttonPin);
      // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
  if (buttonState == HIGH) {
    // turn LED on:
    digitalWrite(ledPin, HIGH);
  } else {
    // turn LED off:
    digitalWrite(ledPin, LOW);
  }             // tell servo to go to position in variable 'pos'
    delay(6);
                    // waits 15 ms for the servo to reach the position
  }
  for (pos = 180; pos >= 0; pos -= 1) { // goes from 180 degrees to 0 degrees
    myservo.write(pos);
    buttonState = digitalRead(buttonPin);
      // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
  if (buttonState == HIGH) {
    // turn LED on:
    digitalWrite(ledPin, HIGH);
  } else {
    // turn LED off:
    digitalWrite(ledPin, LOW);
  }         // tell servo to go to position in variable 'pos'
    delay(6);                        // waits 15 ms for the servo to reach the position
  }
}


```

Calculations and Data Analysis: n/a

Concluding Remarks: It was really great to see my code work in action as a proof of concept for my actual prosthesis. But now I know that it will work software-wise.

# Entry 4: Backyard Brains Investigation, Cont., 12/4/22,

Introduction: A call with Mr. Loven again regarding the materials bought which have been delivered.

Methods/Materials: n/a

Observations and Experimental Data: I asked Mr. Loven about the vibration motors because they were of a different cable connection compared to the rest of the Arduino attachments. He told me that I would have to put a transistor in parallel with the system (solder it in) to get the vibration motor to work. I then bought the transistors and jumper cables he recommended. I will now have to learn to solder soon. Resistors: https://www.amazon.com/BOJACK-Values-Resistor-Resistors-Assortment/dp/B08FHPKF9V?th=1

Calculations and Data Analysis: n/a

Concluding Remarks: Although there was a hiccup in one of the parts I purchased, Mr. Loven provided me with all of the information I need to solve the problem. I feel confident that I can do it. Total spent = around $300.

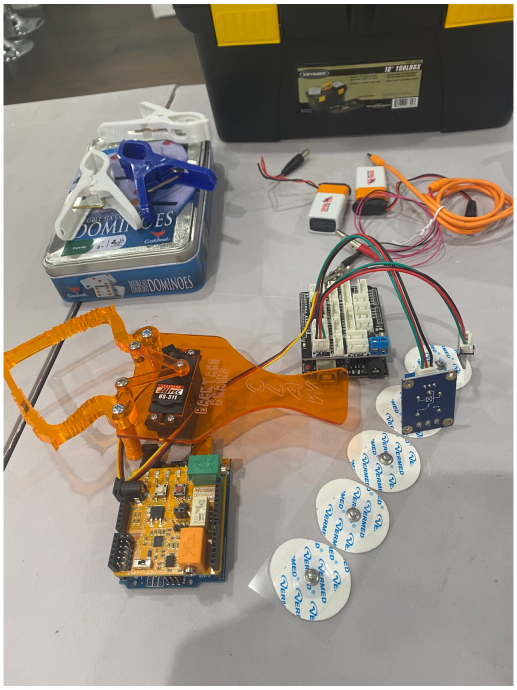
# Entry 5: Testing of the Backyard Brains, 12/6/22,

Introduction: First Data set, testing the specific aims (of the purchased Backyard Brains Claw as preliminary data for DecFair and data to compare all other prototypes to) with the methods outlined by the grant proposal: Tran Grant Proposal 2022v3. Used their preloaded code.

Methods/Materials: listed in detail in Tran Grant Proposal 2022v3

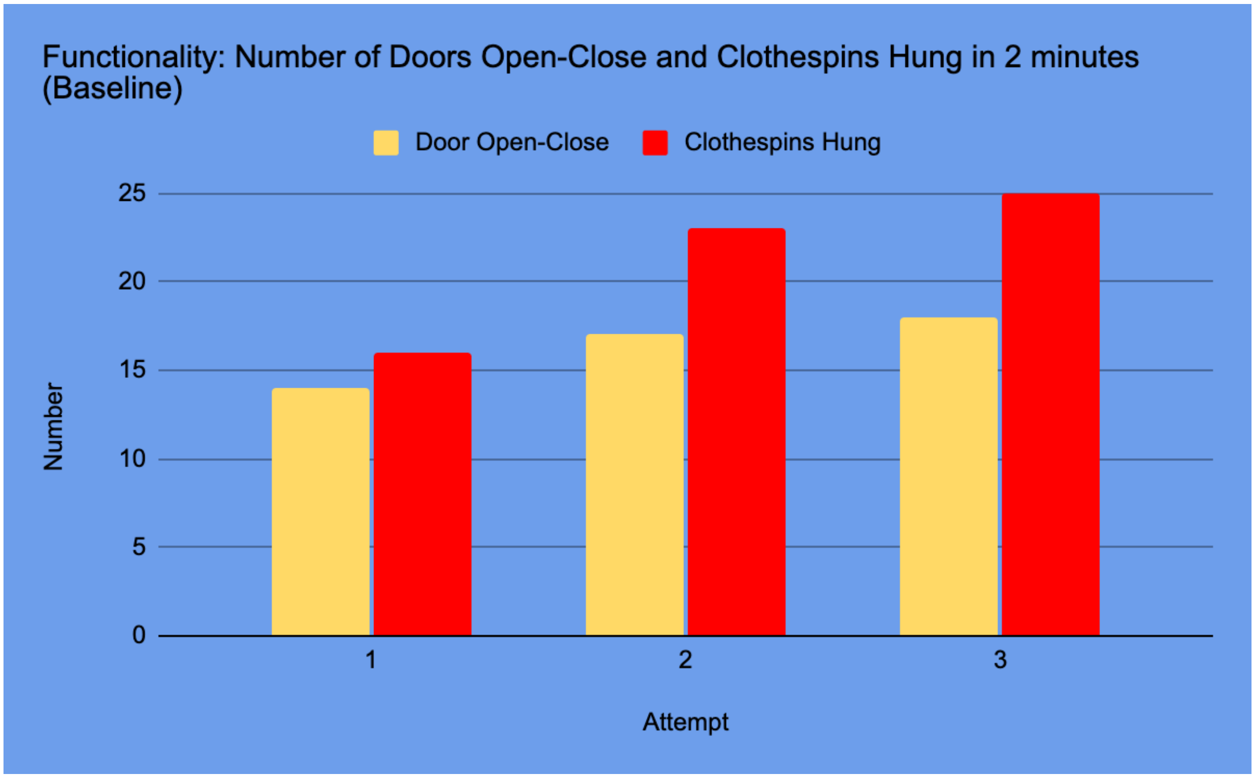
Observations and Experimental Data: Spreadsheet linked below.

STEM data

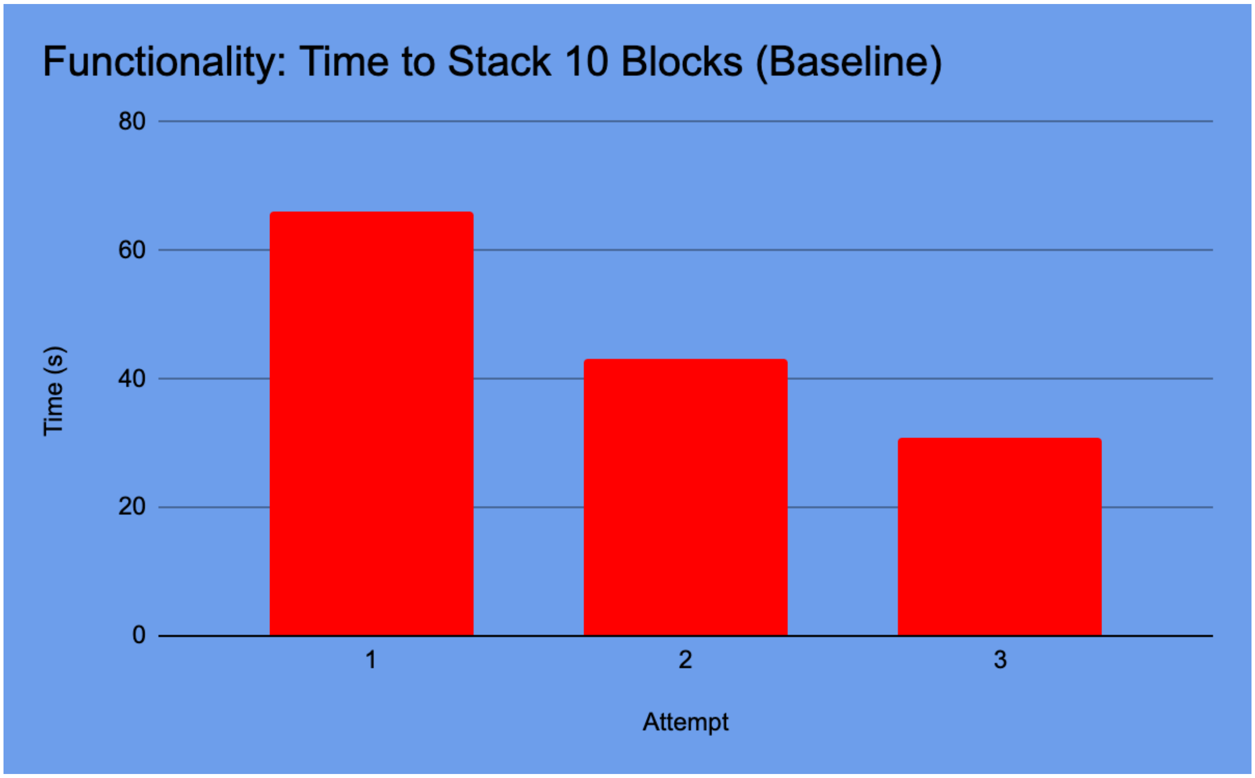


The trials setup/materials

Calculations and Data Analysis: Done in STEM data . Raw data made clear from analyzed data.



Graph of both of the 2-minute trials for the Backyard Brains baseline



Graph of time to stack 10 blocks for the Backyard Brains baseline

Decision Matrix: STEM data

Concluding Remarks: it was great to see my methods in use and that they were all conducted well and without issue. This is great preliminary data and will be used to compare all other prototypes. Next time, I need to create an apparatus to hold/store the batteries and Arduino system.

| Criteria (Rank) | Example | Backyard Brains "The Claw" | Reasoning |
|---|---|---|---|
| Safety - how safe the user feels when using the prosthesis; how well the user trusts the prosthesis (10) | 9 | 9 | Very safe, almost no potential sources of harm |
| Functionality - determined from functionality methodology (9) | 7 | 5 | Not as functional as it needs to be, but can still do some trials well |
| Modularity - determined from modularity methodology (9) | 5 | 0 | Not modular |

| | | | |
|---|---|---|---|
| Comfort - determined from comfort methodology (7) | 10 | 1 | Had to be held in the other hand, not comfortable |
| Durability - determined from durability methodology (7) | 3 | 6** | The plastic was quite strong**material unknown, 500g load |
| Cost-effectiveness - determined from cost-effectiveness methodology (6) | 6 | 7 | Not extremely pricey ($200) |
| Control - how well the user can manipulate the prosthesis to do desired actions (8) | 9 | 5 | Not great control but some control |
| Sensory Feedback - how well the prosthesis conveys the sense of touch to the user (8) | 3 | 0 | No sensory feedback |
| Total (Max 640) | 421 | 266 | |

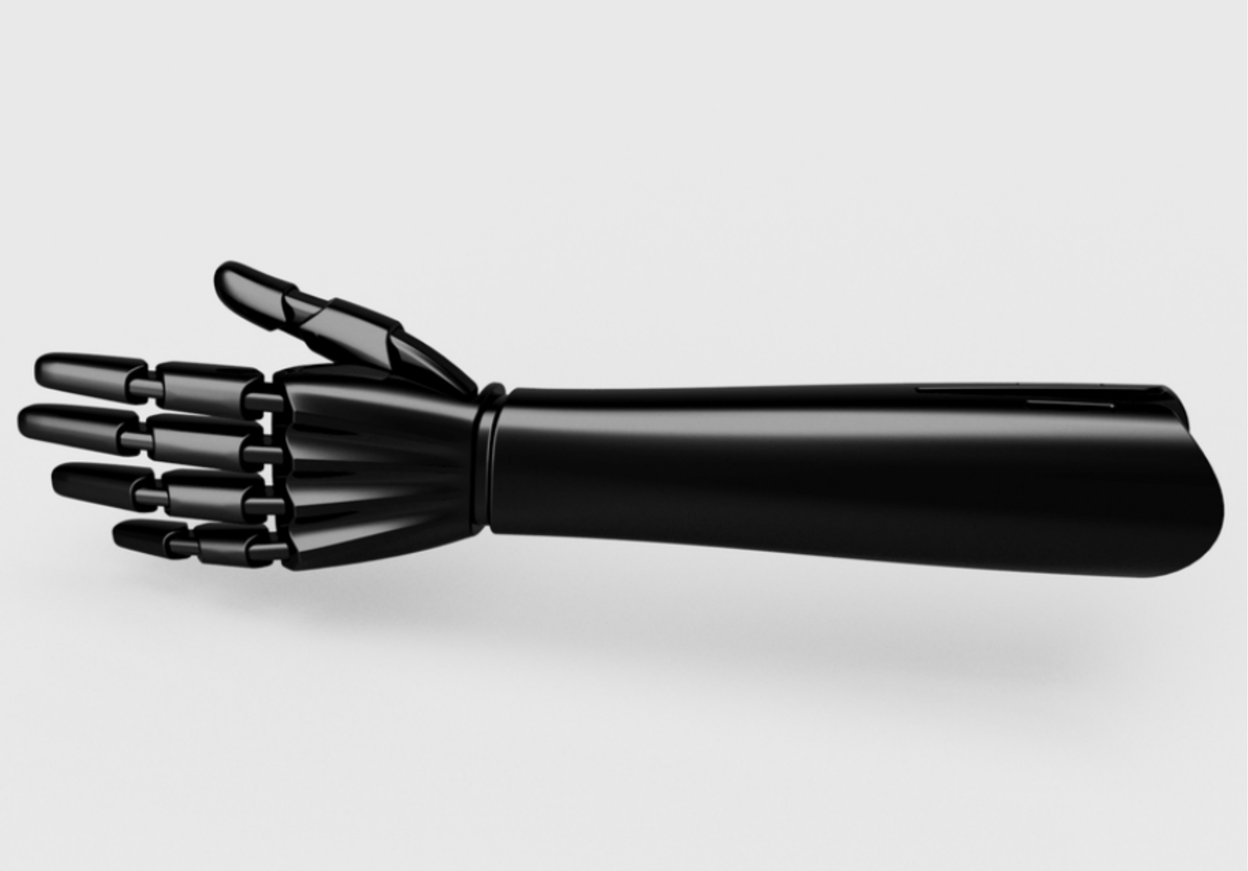
## Entry 6: Setting up Prototyping Software, 1/5/23,

Introduction: looked on grabCAD.com, free, public domain site for 3D printing files and projects. I looked at various different elbow prostheses and their prototypes as well as some Arduino Uno housing cases. https://grabcad.com/library/arduino-uno-box-tall-and-vented-1. I then went to set up a remote desktop for my laptop so that I could get access to solidworks through WPI. This also required the use of the Global Protect VPN to connect to WPI servers.

Methods/Materials: grabGad, solidworks, remote desktop, Global Protect VPN

Observations and Experimental Data: n/a

Calculations and Data Analysis:



A passive prosthesis model I viewed on grabCAD

Concluding Remarks: this was mainly a setup for the CAD modeling of the prosthetic prototypes. There was a little troubleshooting, but nothing serious

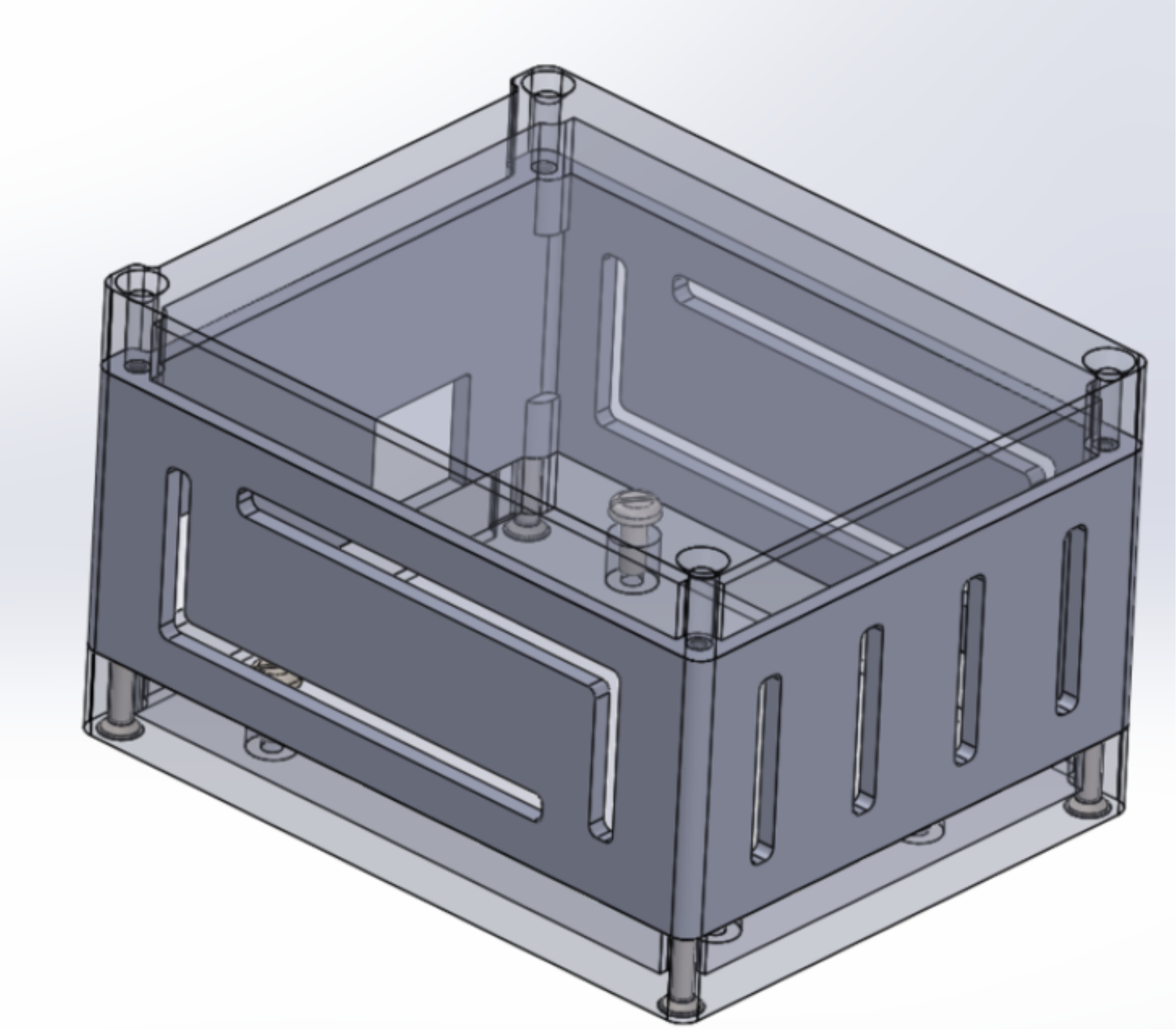
## Entry 7: Preliminary modeling of first prototype, 1/9/23,

Introduction: continued to search on grabCAD.com and found a few models which I thought could be easily modularized. Also found a good size-changing Arduino Uno case matching the dimensions of the one which I will be using to control the prostheses prototypes.

Methods/Materials: solidworks, remote desktop, Global Protect VPN, grabCAD

Observations and Experimental Data:

Calculations and Data Analysis: downloaded the stl files of the Arduino Uno from grabCAD and converted to solidworks part file to dimension and manipulate the part. Also did the same thing with various below-elbow prosthesis models to see how they were made and what software methods were used (i.e. extrusions, revolutions, various sketches, 3D sketches).

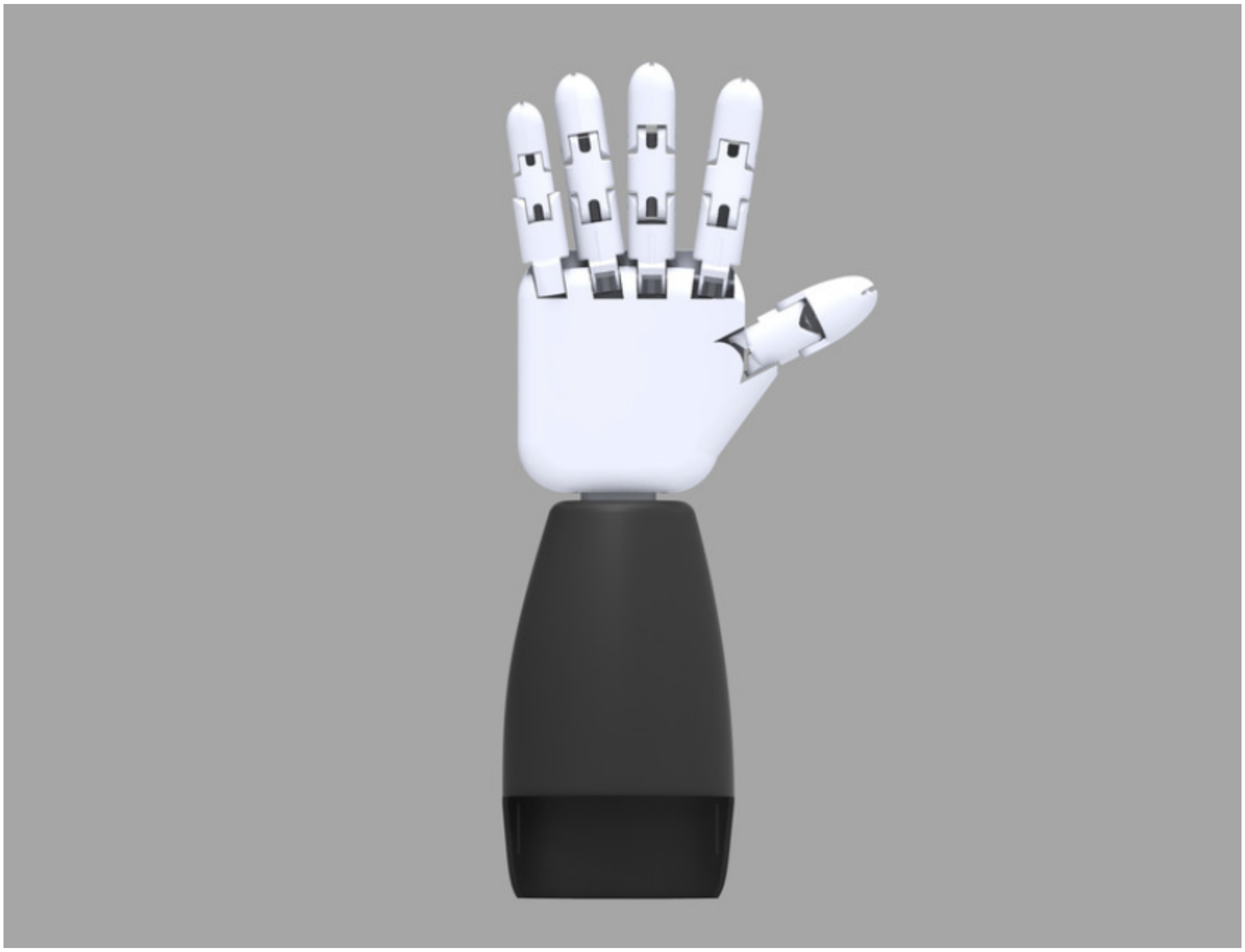


Arduino Uno housing file I found on grabCAD, it can change height (for wire room and toppers) by sliding the lid/cover up and down on the four corners

Antoine (2022). Arduino Uno Box—Tall and vented | 3D CAD Model Library | GrabCAD. *GrabCAD*.

Retrieved February 6, 2023, from

https://grabcad.com/library/arduino-uno-box-tall-and-vented-1



Modular prosthesis model I found on grabCAD. I see a lot of potential for true modularity in this design because the socket is so small and can be added on to with modular parts.

Maurya, Ravi (2020). Modular Prosthetic Arm Design | 3D CAD Model Library | GrabCAD. *GrabCAD*.

Retrieved February 6, 2023, from https://grabcad.com/library/modular-prosthetic-arm-design-1

Concluding Remarks: found a good Arduino Uno case, but it will need some changes made to it to be fixed on the liner housing of the prosthesis. It was good to familiarize myself with the software and this online designing process. As of now, an airbag/air pump design is seeming more far-fetched as I continue to find out how hard it is to create just a normal prosthesis model. It is looking like small lego-like pieces are the way to go. Perhaps the airbag and air pump method will turn to future work.

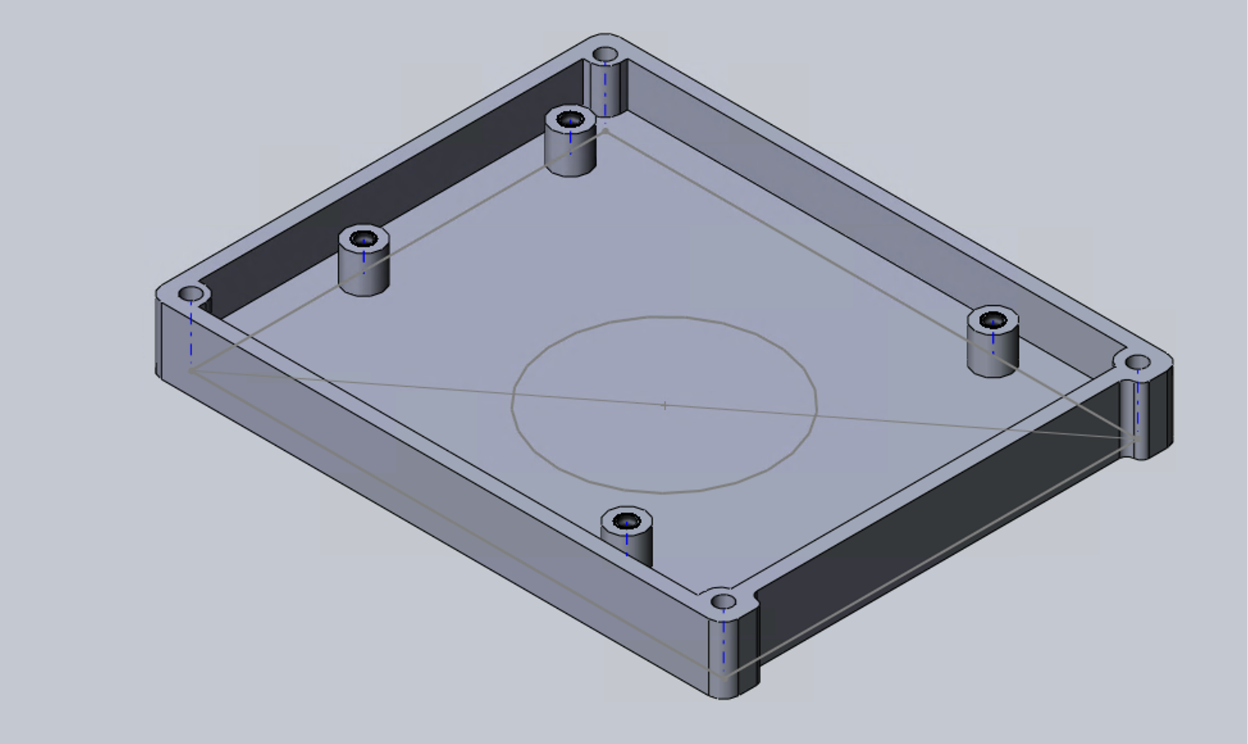
# Entry 8: Preliminary Modeling of first prototype (Cont.), 1/13/23,

Introduction: started to combine some of the parts of the two files which are in the previous entry. Need to create one part out of two to attach the Arduino Uno housing with the socket of the prosthesis.

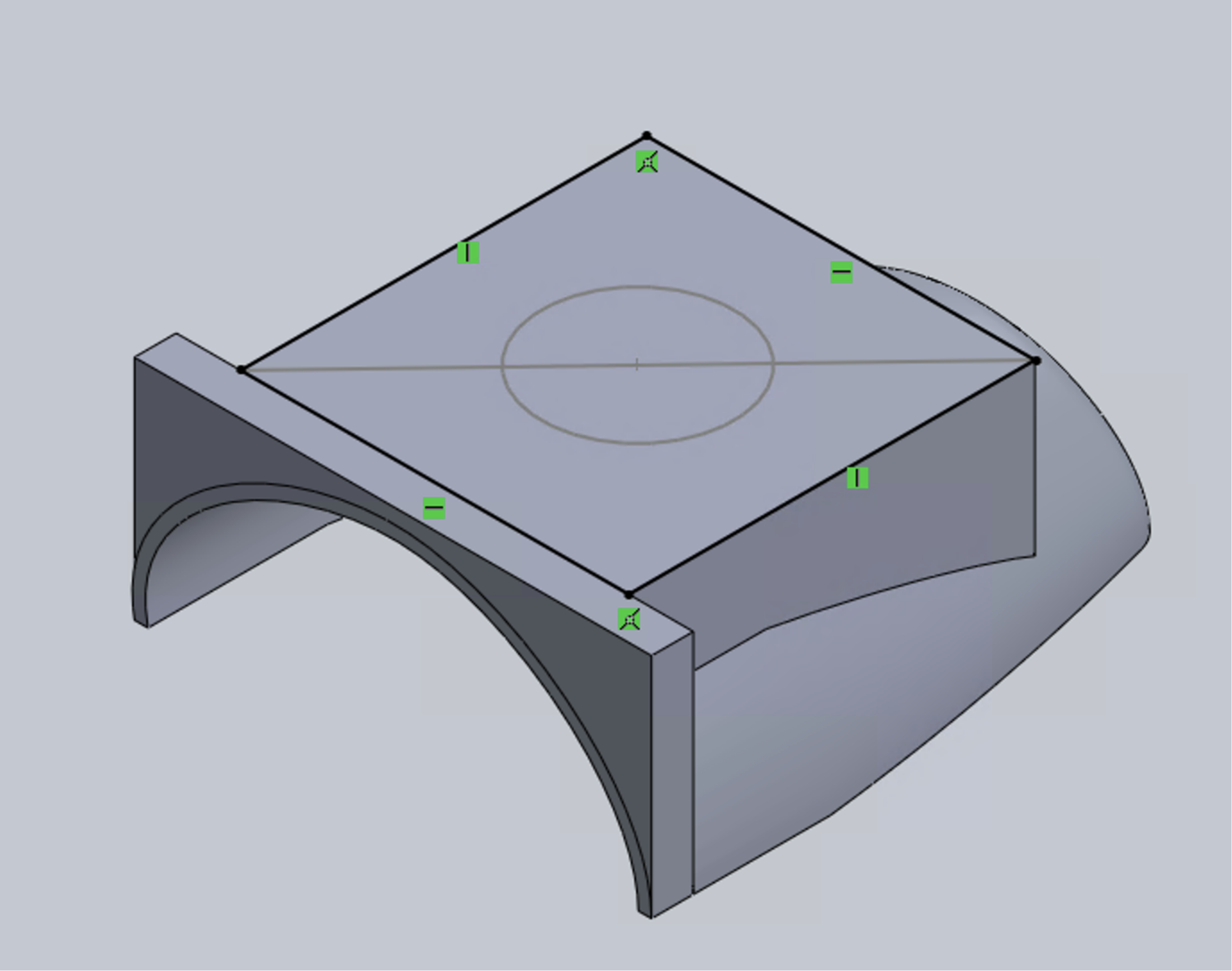
Methods/Materials: solidworks, remote desktop, Global Protect VPN, grabCAD

Observations and Experimental Data: it was very hard to convert the stl file of the parts/assemblies to an editable solidworks file. A lot of this session was troubleshooting and continuing to familiarize myself with the software. I managed to edit two individual parts of the Arduino Uno housing and prosthetic socket. I still need to combine the two, which will be hard.

Calculations and Data Analysis: the prosthesis socket part is around four inches long and the Arduino Uno housing part is around two. When I combine the parts, I need to make sure that the screw holes in the Arduino Uno housing part will be visible so that the rest of the housing can be attached to it



Arduino Uno box base



½ Socket base for the prosthesis. The raised platform is to connect to the Arduino Uno housing.

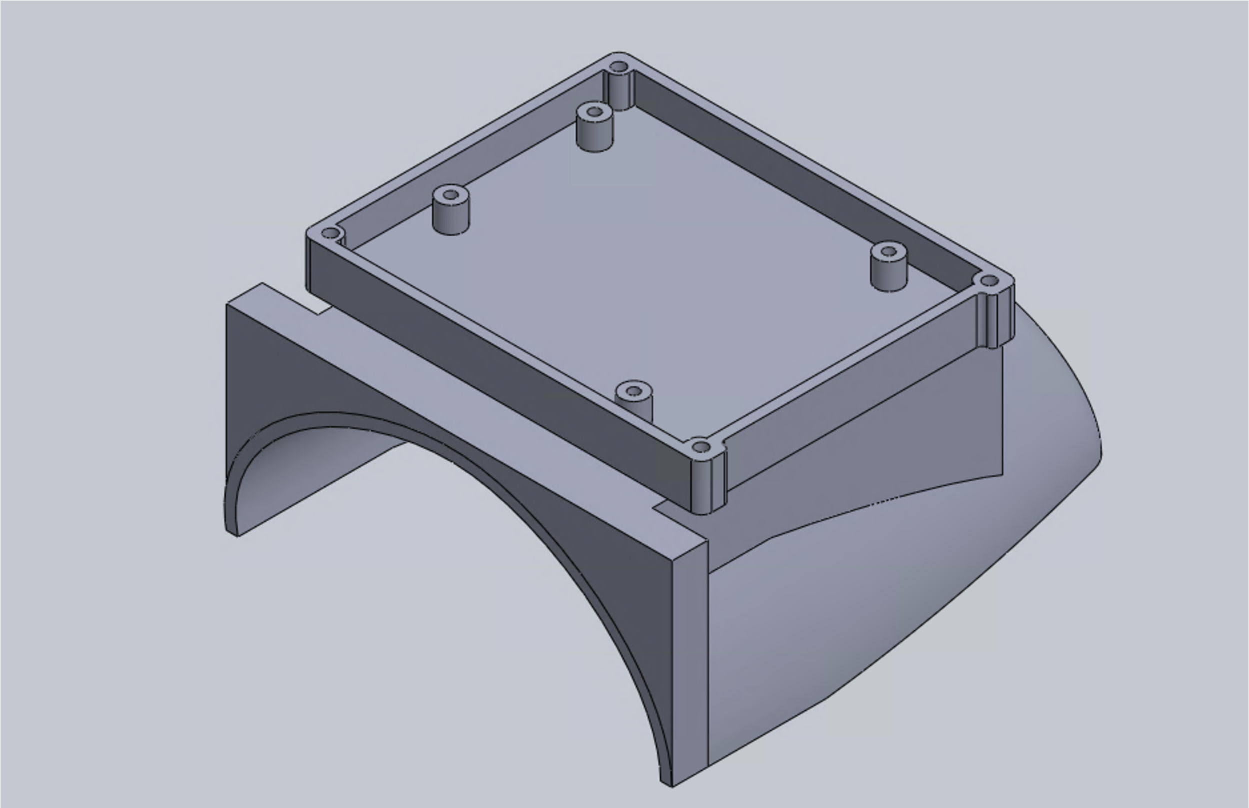
Concluding Remarks: it was a good experience to go through some turbulence in the process. I now know the solidworks software better and am more comfortable with it. This will help for future models of the prosthesis. Next up is combining the two edited parts I made today.

## Entry 9: Modeling of first prototype, 1/18/23,

Introduction: integrated the two parts from the previous entry in solidworks.

Methods/Materials: solidworks, remote desktop, Global Protect VPN, grabCAD

Observations and Experimental Data: in order to combine the parts, I had to mate the two in a solidworks assembly and then export the assembly as a solidworks part file. Mating the two pieces was the hardest part of this process, as I had to sketch two circles on the faces which I wanted to connect before concentrically mating them.



The two parts combined as a solidworks part file.

Calculations and Data Analysis: n/a

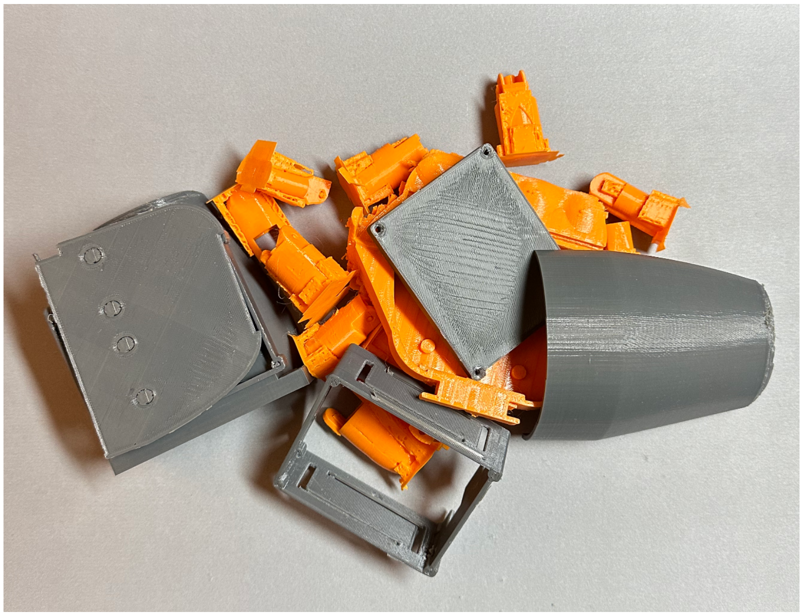
Concluding Remarks: this was one of the only parts I had to modify to implement my movement method for this prosthesis. I am ready to print the first iteration of the first prototype.

## Entry 10: Printing of the first prototype, 1/27/23,

Introduction: Converted all of the solidworks part files to the form STL to 3D print. Emailed Dr. C. to get print ready.

Methods/Materials: solidworks, remote desktop, Global Protect VPN, grabCAD

Observations and Experimental Data:



The 3D printed parts for the first prototype

Calculations and Data Analysis: infill level to be 35% for this prototype. 35% is a good balance between strength and weight. From previous experience with 3D printing, I have found 20% to be too light and research has shown that >50% infill level brings diminishing returns to strength while compromising weight greatly.

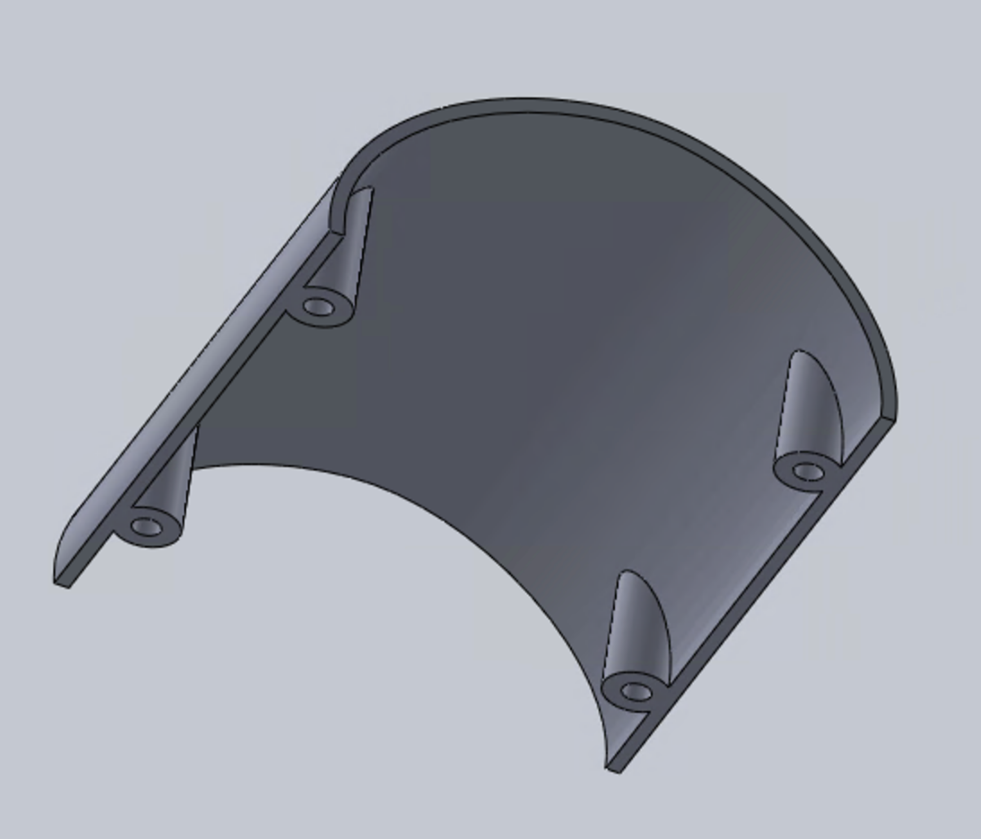
Concluding Remarks: I am excited to see my first print of the project and will have to work on the software/Arduino/sensor part of the equation before testing and comparing to the preliminary Backyard Brains model and a regular human arm's performance. IRB approval was received so I can now go through with this.

## Entry 11: Modeling of the Second Prototype, 1/30/23,

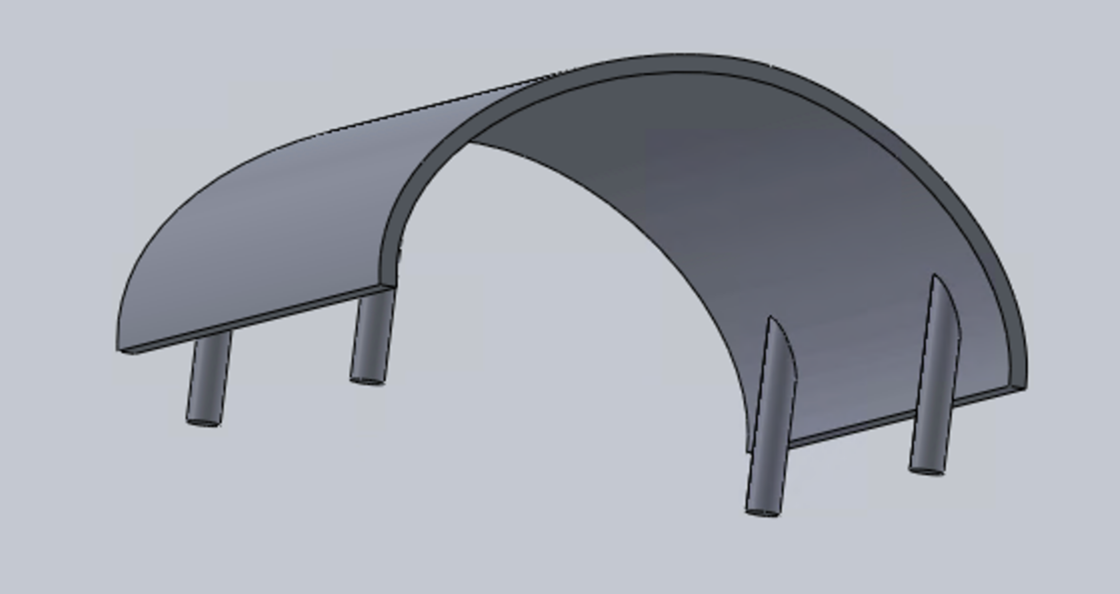
Introduction: As the last model focused more on the functionality of the prosthesis, in this entry and prototype, I will be focusing more on the modularity aspect of the prosthesis as well as the fine details of the moving hardware. The last prototype had modular fingers, so this model will focus on the socket (making it more modular).

Methods/Materials: solidworks, remote desktop, Global Protect VPN, grabCAD

Observations and Experimental Data: To make the socket modular, the original 2 half-socket pieces were taken and extended (the spline) in Solidworks. From there, the longer piece was split in half and pegs/holes were put on the respective half pieces.



1/2 of the prototyped extended socket



The other half of the prototyped extended socket

Calculations and Data Analysis: n/a

Concluding Remarks: This finishes, for now, the modularity aspect of the design. The assembly, Arduino coding, and mechanical aspects of the two prototypes are up next.

## Entry 12: Testing of Human Arm, 2/1/23,

Introduction: to compare all of the test results of the prototypes, I will test the functionality of a single normal human arm in all of the applicable categories.

Methods/Materials: listed in detail in

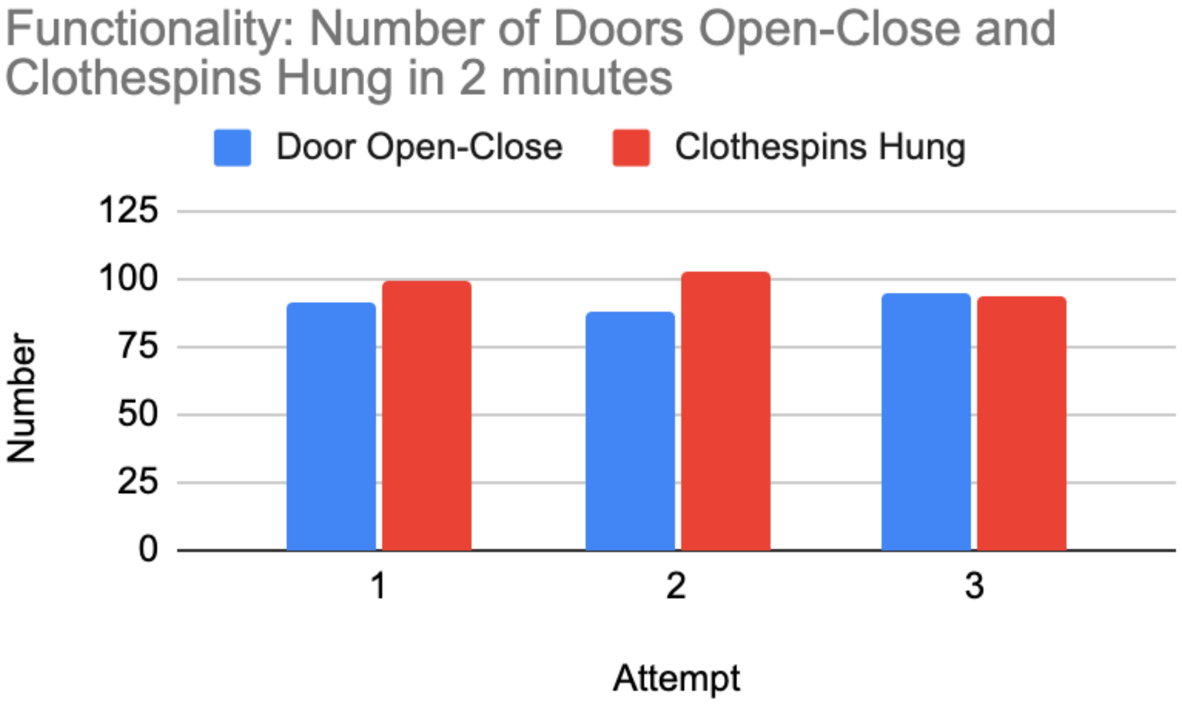
Tran Grant Proposal 2022v3

Observations and Experimental Data:

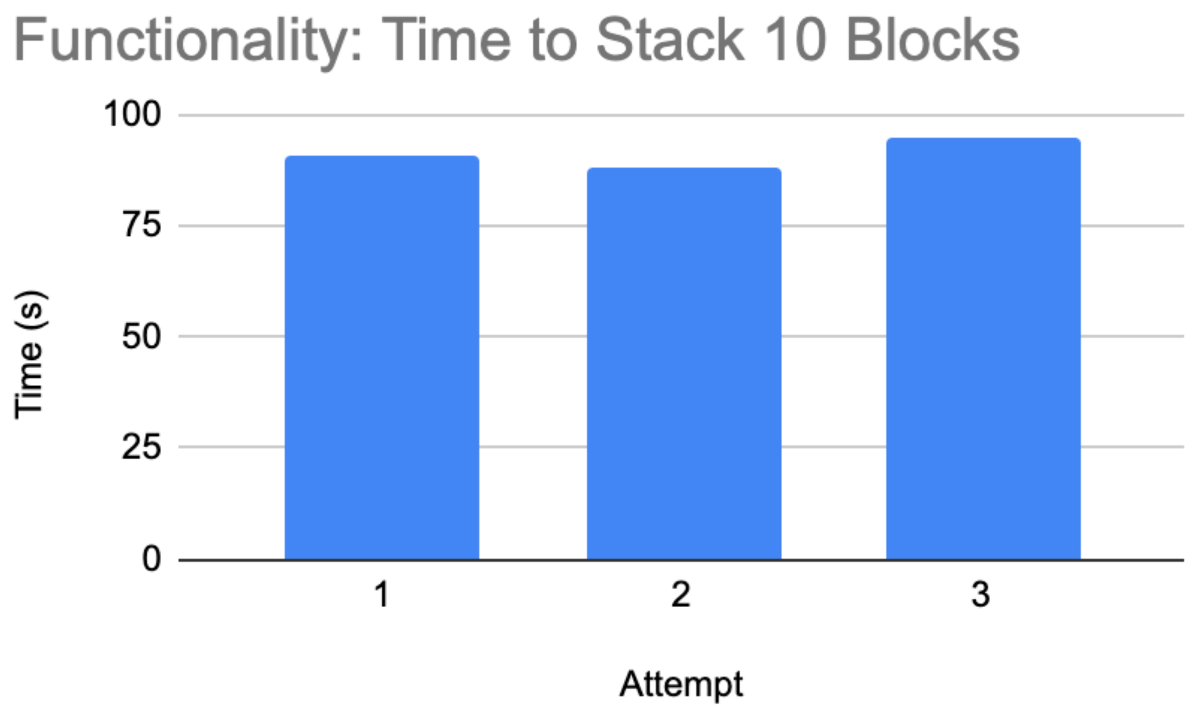
STEM data

Calculations and Data Analysis:

Done in the engineering matrix in STEM data



Graph of both of the 2-minute trials for a normal human arm



Graph of the time to stack 10 blocks for a normal human arm

Decision Matrix:

| Criteria (Rank) | Singular Human Arm | Reasoning |
|---|---|---|
| Safety - how safe the user feels when using the prosthesis; how well the user trusts the prosthesis (10) | 10 | no danger at all |
| Functionality - determined from functionality methodology (9) | 10 | completely functional |
| Modularity - determined from modularity methodology (9) | 0 | Not modular |
| Comfort - determined from comfort methodology (7) | 10 | Had to be held in the other hand, not comfortable |
| Durability - determined from durability methodology (7) | 10 | human arm is very durable |
| Cost-effectiveness - determined from cost-effectiveness | 10 | no cost |

| | | |
|---|---|---|
| methodology (6) | | |
| Control - how well the user can manipulate the prosthesis to do desired actions (8) | 10 | total control |
| Sensory Feedback - how well the prosthesis conveys the sense of touch to the user (8) | 10 | total sensory feedback |
| Total (Max 640) | 550 - best matrix score | |

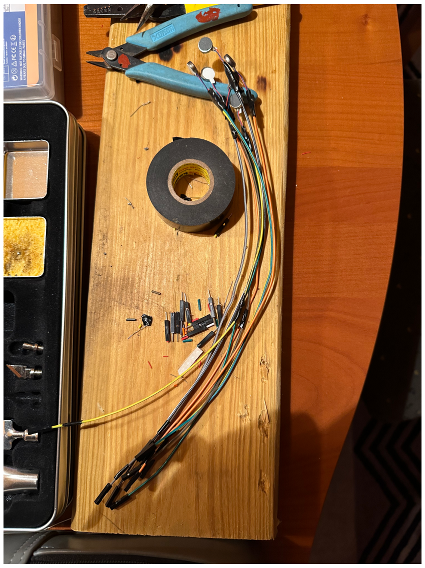
Concluding Remarks: Images not applicable, it is just a human arm doing the tasks such as stacking blocks or hanging clothespins. From the results in the table, the human arm, as expected, performed substantially better than the baseline. The baseline Backyard Brains apparatus only performed around 20-25% of the human arm. This sets the goal for the prototypes at around 30% as a starting point for improvement. The design matrix has my scores according to the specific criteria.

## Entry 13: Assembly of the First Prototype, 2/1/23,

Introduction: this entry includes a lot of troubleshooting, C++ code and mechanical workings. It describes the process of with the parts, how the first prototype was created and coded.

Methods/Materials: 3D printed parts, arduino and accompanying attachments, aluminum wire, arduino IDE (C++)

Observations and Experimental Data:



Soldered wires and transistors onto vibration motors

```

  https://www.arduino.cc/en/Tutorial/BuiltInExamples/Button
*/
#include <Servo.h>

Servo myservo;  // create servo object to control a servo
// twelve servo objects can be created on most boards

int pos = 0;    // variable to store the servo position

// constants won't change. They're used here to set pin numbers:
const int buttonPin = 12;  // the number of the pushbutton pin
const int ledPin = 8;    // the number of the LED pin

// variables will change:
int buttonState = 0;  // variable for reading the pushbutton status

void setup() {
  // initialize the LED pin as an output:
  pinMode(ledPin, OUTPUT);
  // initialize the pushbutton pin as an input:
  pinMode(buttonPin, INPUT);
  myservo.attach(9);
}

void loop() {
  // read the state of the pushbutton value:
  for (pos = 0; pos <= 180; pos += 1) { // goes from 0 degrees to 180 degrees
    // in steps of 1 degree
    myservo.write(pos);
    buttonState = digitalRead(buttonPin);
      // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
  if (buttonState == HIGH) {
    // turn LED on:
    digitalWrite(ledPin, HIGH);
  } else {
    // turn LED off:
    digitalWrite(ledPin, LOW);
  }             // tell servo to go to position in variable 'pos'
    delay(6);
                    // waits 15 ms for the servo to reach the position
  }
  for (pos = 180; pos >= 0; pos -= 1) { // goes from 180 degrees to 0 degrees
    myservo.write(pos);
    buttonState = digitalRead(buttonPin);
      // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
  if (buttonState == HIGH) {
    // turn LED on:
    digitalWrite(ledPin, HIGH);
  } else {
    // turn LED off:
    digitalWrite(ledPin, LOW);
  }         // tell servo to go to position in variable 'pos'
    delay(6);                       // waits 15 ms for the servo to reach the position
  }
}


```

Code used to implement the prototype

Assembled first prototype

Calculations and Data Analysis: n/a

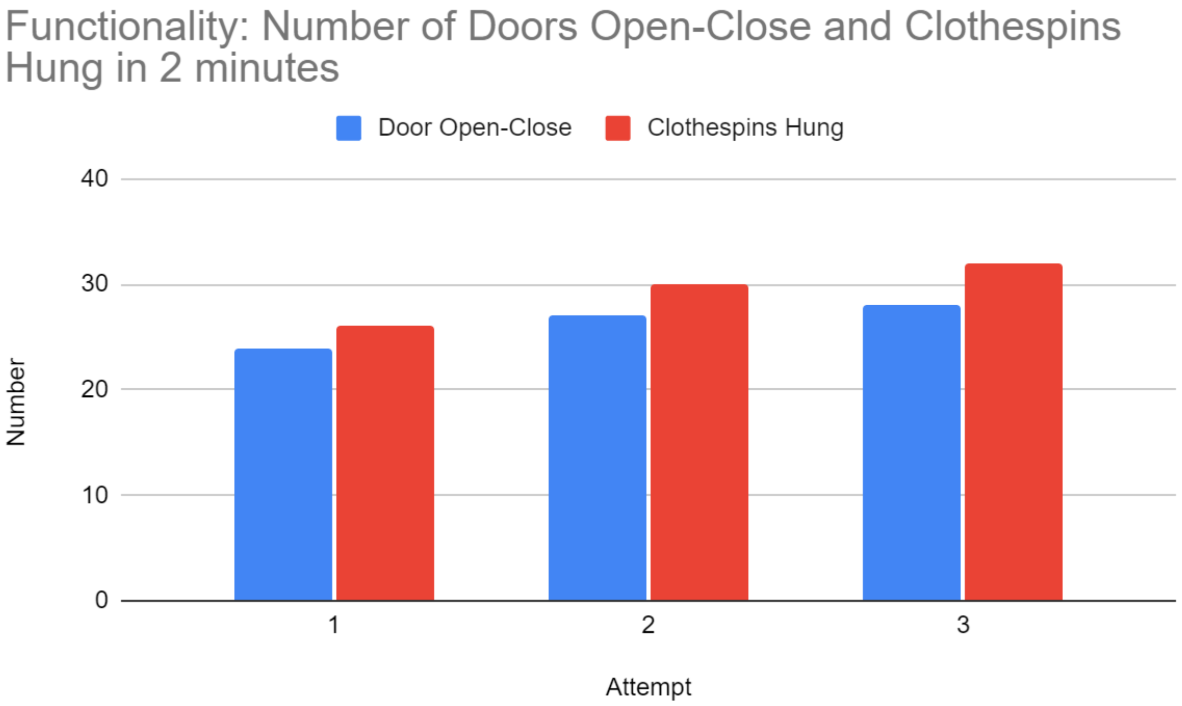
Concluding Remarks: this first prototype was constructed fairly slowly because of the vast amount of sanding and scaffolding removal needed. Testing this first prototype will be the next priority.

## Entry 14: Testing of the First Prototype, 2/6/23,

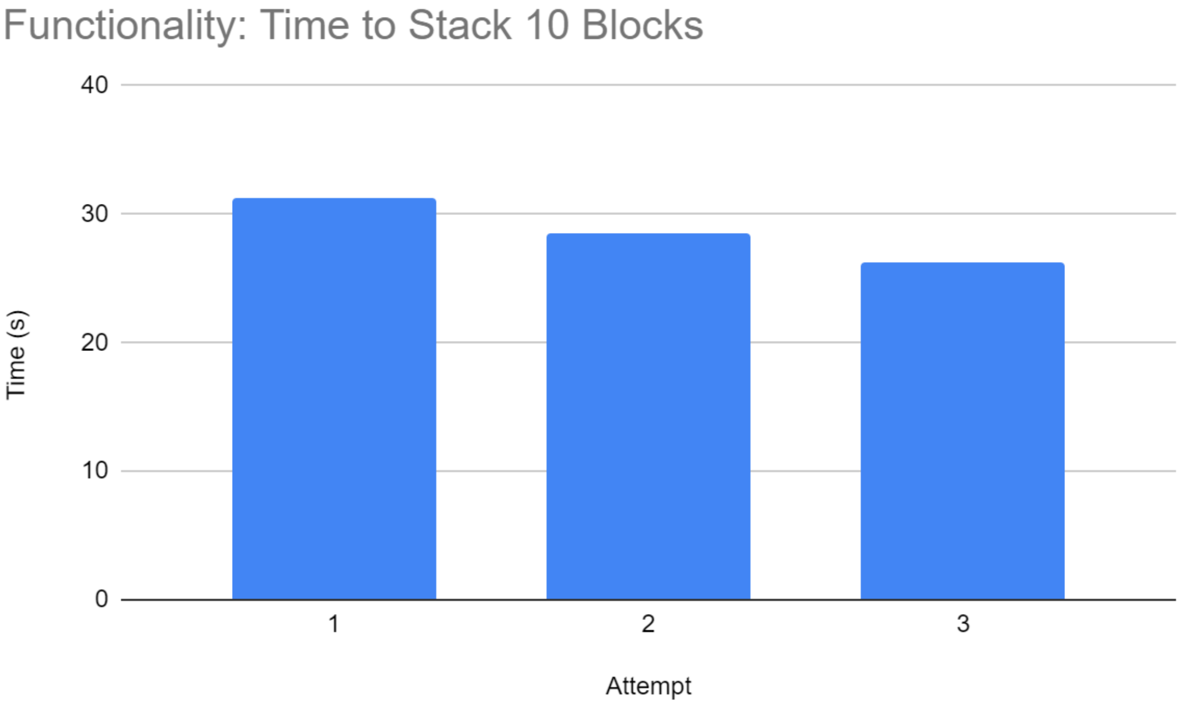
Introduction: this testing is explained in the methodology of the Tran, Travis - 2022-2023 Project Thesis in detail and tests for the 5 specific aims

Methods/Materials: prototype 1, listed in detail in Tran Grant Proposal 2022v3

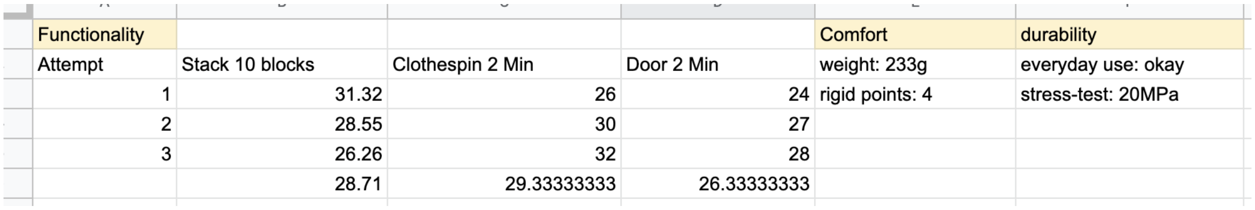
Observations and Experimental Data: done in STEM data



Graph of both the 2-minute trials for the first prototype



Graph of time to stack 10 blocks for the first prototype



| | | | | | |
|---|---|---|---|---|---|
| Functionality | | | | Comfort | durability |
| Attempt | Stack 10 blocks | Clothespin 2 Min | Door 2 Min | weight: 233g | everyday use: okay |
| 1 | 31.32 | 26 | 24 | rigid points: 4 | stress-test: 20MPa |
| 2 | 28.55 | 30 | 27 | | |
| 3 | 26.26 | 32 | 28 | | |
| | 28.71 | 29.33333333 | 26.33333333 | | |

Raw data

Calculations and Data Analysis: done in STEM data

Decision matrix:

| Criteria (Rank) | Prototype 1 | Reasoning |
|---|---|---|
| Safety - how safe the user feels when using the prosthesis; how well the user trusts the prosthesis (10) | 9 | Very safe, almost no potential sources of harm |
| Functionality - determined from functionality methodology (9) | 7 | Performed in the trials fairly well |
| Modularity - determined from modularity methodology (9) | 5 | Fingers are modular, but the socket is not, performed similarly when fingers shortened |
| Comfort - determined from comfort methodology (7) | 6 | Decent, but the design is a little bulky |
| Durability - determined from durability methodology (7) | 8 | 20MPa is fairly durable compared to the baseline |
| Cost-effectiveness - determined from cost-effectiveness methodology (6) | 9 | 3D printing out of plastic is much cheaper than buying a whole prosthesis system |
| Control - how well the user can manipulate the prosthesis to do desired actions (8) | 6 | Controlling the prosthesis had a learning curve and was hard to control at times, especially for fine motor movements |
| Sensory Feedback - how well the prosthesis conveys the sense of touch to the user (8) | 6 | Vibration from motor was the only sensory feedback |
| Total (Max 640) | 446 | |

Concluding Remarks: this data was really impressive for a first prototype, and statistical analyses must be done on it to determine if it is statistically significant. Modularity and sensory feedback are things that must be focused on for the next prototype because they underperformed in this prototype according to the engineering design matrix.

# Entry 15: Printing of the Second Prototype, 2/9/23,

Introduction: Converted all of the solidworks part files to the form STL to 3D print. Emailed Dr. C. to get print ready.

Methods/Materials: solidworks, remote desktop, Global Protect VPN, grabCAD

Observations and Experimental Data:

Parts of the second prototype

Calculations and Data Analysis: infill level to be 35% for this prototype. 35% is a good balance between strength and weight. From previous experience with 3D printing, I have found 20% to be too light and research has shown that >50% infill level brings diminishing returns to strength while compromising weight greatly.

Concluding Remarks: This print came out better than the previous one and will need less work sanding the edges and taking off the scaffolding.

# Entry 16: Assembly of the Second Prototype, 2/12/23,

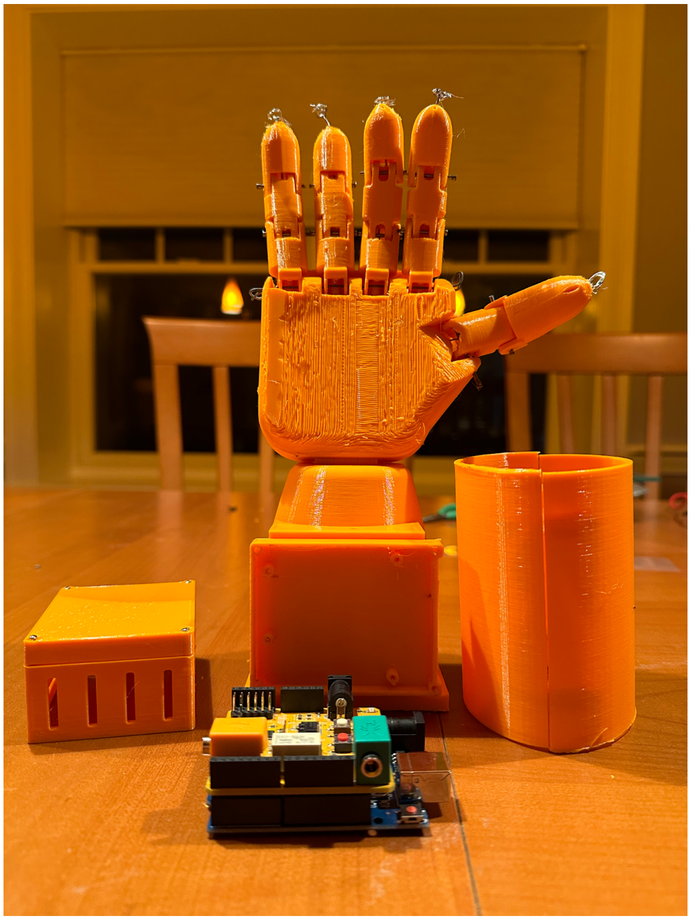
Introduction: this entry contains the mechanical workings, code, and assembly of the second prototype. Many of the parts/methods are shared with the first prototype; the only thing that is different is the modularity of the socket/the socket extension.

Methods/Materials: 3D printed parts, arduino and accompanying attachments, aluminum wire, arduino IDE (C++)

Observations and Experimental Data:

```
  https://www.arduino.cc/en/Tutorial/BuiltInExamples/Button
*/
#include <Servo.h>

Servo myservo;  // create servo object to control a servo
// twelve servo objects can be created on most boards

int pos = 0;    // variable to store the servo position

// constants won't change. They're used here to set pin numbers:
const int buttonPin = 12;  // the number of the pushbutton pin
const int ledPin = 8;    // the number of the LED pin

// variables will change:
int buttonState = 0;  // variable for reading the pushbutton status

void setup() {
  // initialize the LED pin as an output:
  pinMode(ledPin, OUTPUT);
  // initialize the pushbutton pin as an input:
  pinMode(buttonPin, INPUT);
  myservo.attach(9);
}

void loop() {
  // read the state of the pushbutton value:
  for (pos = 0; pos <= 180; pos += 1) { // goes from 0 degrees to 180 degrees
    // in steps of 1 degree
    myservo.write(pos);
    buttonState = digitalRead(buttonPin);
      // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
  if (buttonState == HIGH) {
    // turn LED on:
    digitalWrite(ledPin, HIGH);
  } else {
    // turn LED off:
    digitalWrite(ledPin, LOW);
  }             // tell servo to go to position in variable 'pos'
    delay(6);
                    // waits 15 ms for the servo to reach the position
  }
  for (pos = 180; pos >= 0; pos -= 1) { // goes from 180 degrees to 0 degrees
    myservo.write(pos);
    buttonState = digitalRead(buttonPin);
      // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
  if (buttonState == HIGH) {
    // turn LED on:
    digitalWrite(ledPin, HIGH);
  } else {
    // turn LED off:
    digitalWrite(ledPin, LOW);
  }         // tell servo to go to position in variable 'pos'
    delay(6);                           // waits 15 ms for the servo to reach the position
  }
}
```

Code used to implement the prototype



Assembled second prototype

Calculations and Data Analysis: n/a

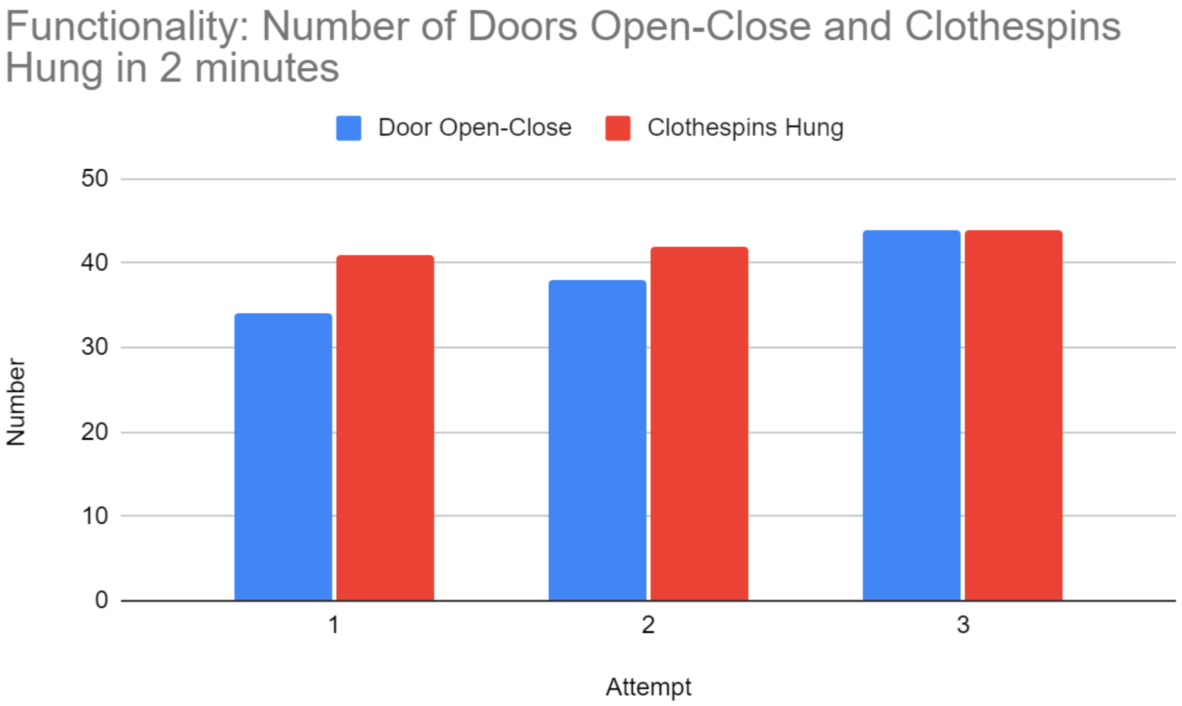
Concluding Remarks: this was similar to the assembly of the first prototype, and even the fingers were the same. Sanding the parts and feeding the wires/servo motors through the small hole cutouts has become easier. I am excited to see how this prototype will perform, as the mechanical movement is a little different (the wire arrangement changed).

## Entry 17: Testing of the Second Prototype, 2/12/23,

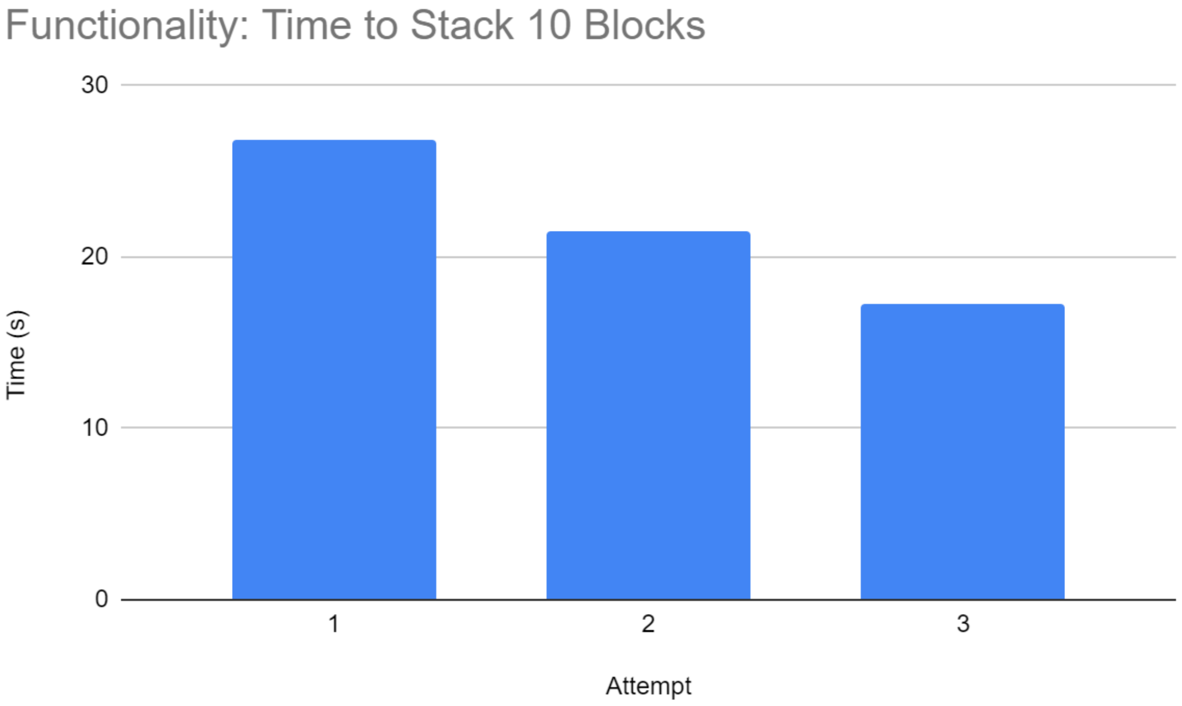
Introduction: this testing is explained in the methodology of the Tran, Travis - 2022-2023 Project Thesis in detail and tests for the 5 specific aims

Methods/Materials: prototype 2, listed in detail in Tran Grant Proposal 2022v3

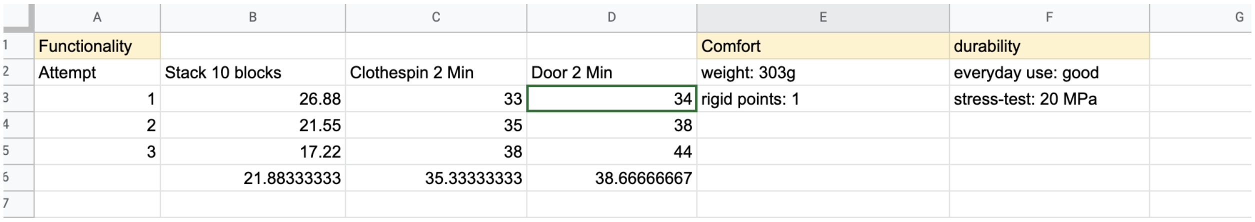
Observations and Experimental Data: done in STEM data



Graph of both the 2-minute trials for the second prototype



Graph of time t stack 10 blocks for the second prototype



| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | Functionality | | | | Comfort | durability | |
| 2 | Attempt | Stack 10 blocks | Clothespin 2 Min | Door 2 Min | weight: 303g | everyday use: good | |
| 3 | 1 | 26.88 | 33 | 34 | rigid points: 1 | stress-test: 20 MPa | |
| 4 | 2 | 21.55 | 35 | 38 | | | |
| 5 | 3 | 17.22 | 38 | 44 | | | |
| 6 | | 21.88333333 | 35.33333333 | 38.66666667 | | | |
| 7 | | | | | | | |

Raw data

Calculations and Data Analysis:

Decision Matrix:

| Criteria (Rank) | Prototype 2 | Reasoning |
|---|---|---|
| Safety - how safe the user feels when using the prosthesis; how well the user trusts the prosthesis (10) | 9 | Very safe, almost no potential sources of harm |
| Functionality - determined from functionality methodology (9) | 7 | Performed in the trials fairly well |
| Modularity - determined from modularity methodology (9) | 7 | Fingers are modular, but the socket is not, performed similarly when fingers/socket shortened |
| Comfort - determined from comfort methodology (7) | 6 | Decent, but the design is a little bulky |
| Durability - determined from durability methodology (7) | 8 | 20MPa is fairly durable compared to the baseline |
| Cost-effectiveness - determined from cost-effectiveness methodology (6) | 9 | 3D printing out of plastic is much cheaper than buying a whole prosthesis system |
| Control - how well the user can manipulate the prosthesis to do desired actions (8) | 6 | Controlling the prosthesis had a learning curve and was hard to control at times, especially for fine motor movements |
| Sensory Feedback - how well the prosthesis conveys the sense of touch to the user (8) | 6 | Vibration from motor was the only sensory feedback |
| Total (Max 640) | 464 | |

Concluding Remarks: note, as the best design according to the engineering design matrix, this prototype was compared directly to to the functionality of a human arm and performed at 42% of the productivity. I think that 42% is a great figure for this statistic and think that the modularity of the prosthesis improved greatly from the first model. All in all, a great improvement. Future work can be geared toward adding sensory feedback inside of the actual prosthesis.

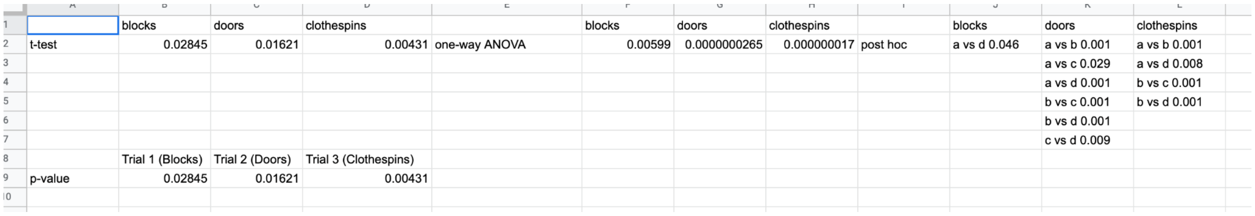
## Entry 18: Analysis of the Prototypes, 2/12/23,

Introduction: the analysis in this entry is described in detail in Tran, Travis - 2022-2023 Project Thesis . Three statistical tests were used

Methods/Materials: ti-nSpire ii, standard t-test, one-way ANOVA test, post hoc test (after the one-way ANOVA test, and depending on the one-way ANOVA test)

Observations and Experimental Data: n/a

Calculations and Data Analysis:



| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | blocks | doors | clothespins | | blocks | doors | clothespins | | blocks | doors | clothespins |
| t-test | 0.02845 | 0.01621 | 0.00431 | one-way ANOVA | 0.00599 | 0.0000000265 | 0.000000017 | post hoc | a vs d 0.046 | a vs b 0.001 | a vs b 0.001 |
| | | | | | | | | | | a vs c 0.029 | a vs d 0.008 |
| | | | | | | | | | | a vs d 0.001 | b vs c 0.001 |
| | | | | | | | | | | b vs c 0.001 | b vs d 0.001 |
| | | | | | | | | | | b vs d 0.001 | |
| | | | | | | | | | | c vs d 0.009 | |
| | Trial 1 (Blocks) | Trial 2 (Doors) | Trial 3 (Clothespins) | | | | | | | | |
| p-value | 0.02845 | 0.01621 | 0.00431 | | | | | | | | |

P-values of the 3 different statistical tests. Note: a corresponds to the baseline, b to the human arm, c to prototype 1, and d to prototype 2

Concluding Remarks: it was great to see that all of my data from the prototypes was statistically significant compared to the baseline and that prototype 2 was statistically significant compared to prototype 1 (alpha value of 0.05). It was expected that the human arm would be statistically different compared to all of the other baseline/prototypes because of how it performed.