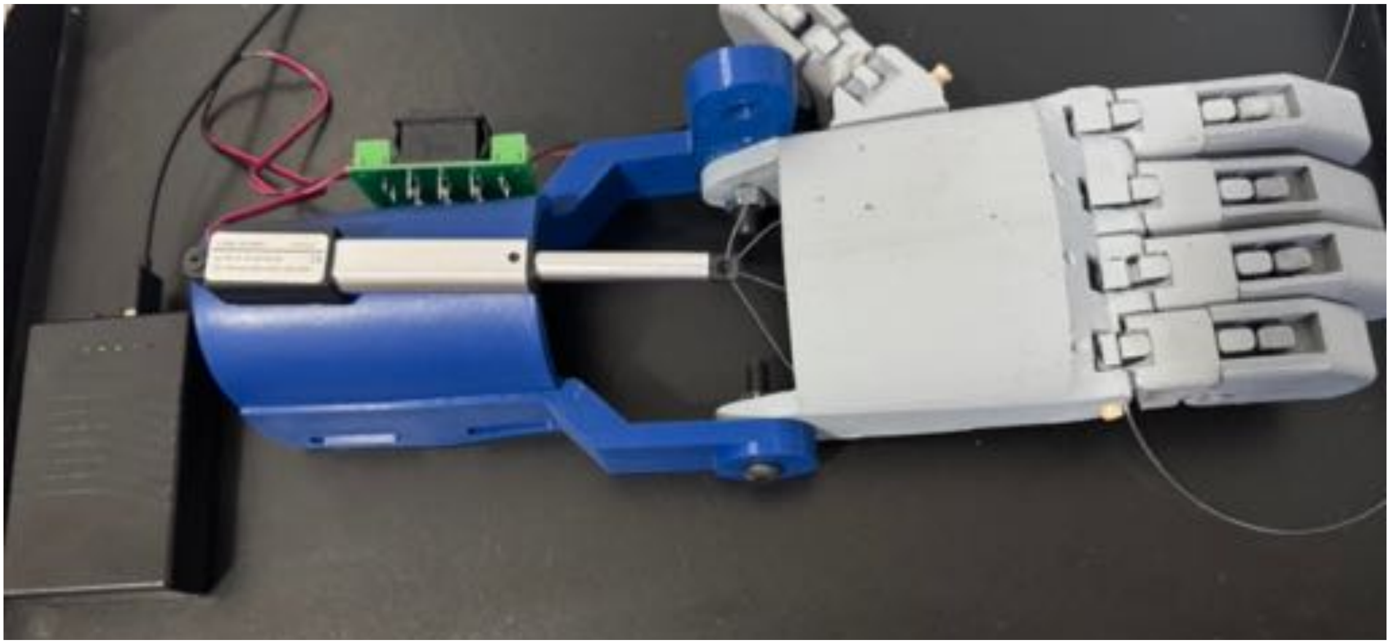
DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

FUNDAMENTALS OF ENGINEERING DESIGN, FED 101-N49



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Instructor: Dr. Swapnil Moon

# Executive Summary

**Problem Statement**: People with missing arms and hands face several challenges in their daily lives. People with such disabilities tend to look for prosthetics that can help improve their lives. Oftentimes, they face pricing and reliability issues. With this in mind, our intention was to develop an innovative, cost-effective, and reliable hand prosthetic that can solve this problem.

**Overall Goal**: The goal of this design project was to develop a functioning linear actuator hand driven prosthetic that can allow the user to replicate real hand movements. Not only that but the hand was developed in such a way that can allow the user to make a fist. The fist motion will allow for the user to grab on to items and will enable them to do basic everyday tasks.

**Solution**: The device that was developed includes a palm, fingers, forearm cuff, and a linear actuator. The device was assembled with the use of custom pins, wooden dowel pins, button head- hex drives, hex-nuts, rubber-bands, and fishing line. Custom pins attached the metacarpals to the phalanges. Wooden Dowel pins attached the metacarpals with the palm. Rubber-bands were used to secure the connections all throughout the palm and fingers. Button head hex-drives and hex nuts attached the palm to the forearm-cuff. The linear actuator was mounted on the forearm cuff with the use of soldering. Lastly, fishing lines were run through the palm and fingers and the string endings were attached to the linear actuator. When the linear actuator runs, it creates tension and forces the fingers to contract to make a fist. This motion enables the user to carry out basic tasks that require grabbing objects.

**Tasks Performed**: Initially, a conceptual design was mapped out to help us envision our final product. The conceptual design was open to all possibilities. After initial designs, we shifted our focus on CAD modeling. All of the main parts were distributed among team members to design on SolidWorks. After the initial CAD modeling, our group carried out our first 3D-printing stage. The initial 3D-printing phase allowed us to see our prototypes and evaluate it for mistakes. Since then, we discovered flaws in our design and adjusted them accordingly.

**Evaluation**: In our initial evaluation, we discovered that our initial prototype had some flaws. The main issue resided with the compatibility of the palm and metacarpals. The initial palm design had rectangular geometry on the top which conflicted with the connection to the round shaped geometry of the metacarpals. Because of this, the palm had to be redesigned to match the round geometry of the metacarpals. After this, a second evaluation was carried out in which the palm and metacarpals were compatible. Since they were compatible and fit, free-motion was achieved, which was something that was possible in the initial evaluation. The metacarpals were able to freely pivot and move around in the palm, which satisfied the goals and requirements of fingers being able to have enough motion to create a fist.

**Recommendations**: Since this project is entirely linear actuator driven, it is important to mount the actuator in a place where it doesn’t negatively affect the function of the device or interfere with the user. With that in mind, it is also important to design a place to mount the battery for the actuator. Another recommendation is to get grip pads that can help the user grab onto objects better. Overall recommendation would be to reduce the weight of the prototype, whether through designing or 3D-printing. Shaving off extra-weight can make the users life easier as it lessens the load for them.

# Introduction

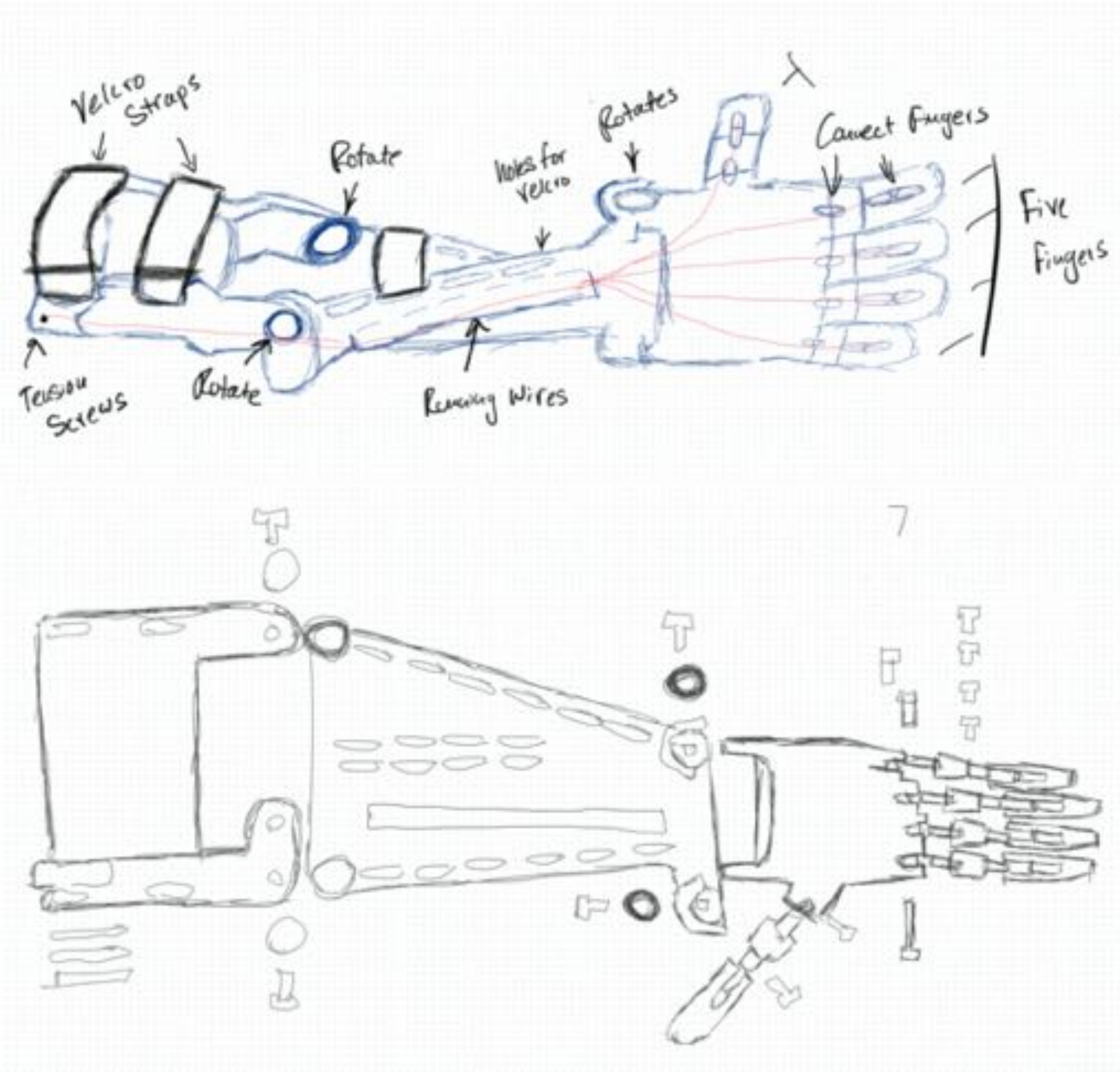
The device is an linear actuator driven hand prosthetic for those that have gone through amputation or for those who are born with a congenital limb. This device will fill in the space for what they lost allowing them to overcome daily challenges and will help in simple daily activities. The prosthetic should be lightweight and sturdy so that it's not heavy and uncomfortable for the user, while using thick rigid wires to make sure the wires are pulling on the fingers properly. The prosthetic consists of a palm, fingers, forearm cuff, and a linear actuator. The palm and the finger must work together for the user to achieve its functional goal. The palm provides the fingers support, while the fingers freely pivot, which allows for the main function. This action will be achieved by running a fishing line through the prosthetic arm and eventually tying it to the actuator. When the actuator functions, it will pull the fish lining, allowing for fingers to contract. It is this exact movement that will enable the user to perform basic everyday tasks. The forearm cuff is attached to the palm and will be used to mount the actuator. Besides that, its primary function is to provide the user connection to the prosthetic. It is a place where the user can insert their limb and wear the device. With this device, the user will be able to have many applications. As stated before the making of a fist, will allow the user to grab/grip any object. Not only that but the dexterity and sturdiness of the device can also enable the user to push and pull objects. The rigid material allows the user to easily push and pull open doors without causing damage to the prosthetic.

# Design Requirements and Specifications

**Main Functional Requirements:** Some of the main functional requirements include free movement and pivot from the fingers. The fingers are very important for this device as the primary function comes from them. Another important feature that is important is the force generated by the actuator. The force from the actuator should be sufficient enough to drive the finger movement. Without the actuator, the device won't be able to function. Durability is another requirement that is essential for the device to function. Since the device is expected to be under heavy use, it can be susceptible to wear and tear. Therefore, one of the design objectives is to make the device durable. On the other hand, the device shouldn't be overly rigid to the point where it impacts the weight. When creating a durable device, the weight can be an issue. Oftentimes, durable objects are heavier but in our case the device must be light in weight so the user can actually function the device with ease.

**Requirements Met by the Design**: To get the desired performance, the palm and the finger have to be designed in a way, where there is little room for error. In a way they must fit perfectly, while at the same time have enough space to not interfere with each other or have friction. The actuator would be responsible for creating adequate tension that doesn't overpower the strings or other parts of the device. At the same time, the fishing line and rubber-bands must be responsible for handling immense tension and not snapping.

**Specifications**: The price range needed to replicate this device would be anywhere from $100-$120. The bulk of the price is used up by the linear actuator while 3D-printing parts take up the rest. Given that a human sized hand is being replicated, the prosthetic should represent realistic palm, finger, and forearm measurements. Typically, an average weight of a palm, fingers, and a forearm range from 4-6 lbs. Since a battery and linear actuator are being implemented, the whole device should weigh about 5 lbs to give the user comfort. The rubber-bands will perform like springs as they help with steady movement of the fingers. The material for the device will be PLA. The PLA will need to be durable and flexible at the same time. Since the foundation of the device is the palm, it will require higher durability. For the palm, the infill density would have to be higher since it's carrying the weight of the fingers, forearm, and actuator. The forearm will need to be flexible for molding, therefore it cannot have the same durable structure as the palm. Additional features include a secure place to mount the actuator. The actuator must be secured and fixed as it cannot have vigorous movements. Vigorous movements can cause the device to malfunction.



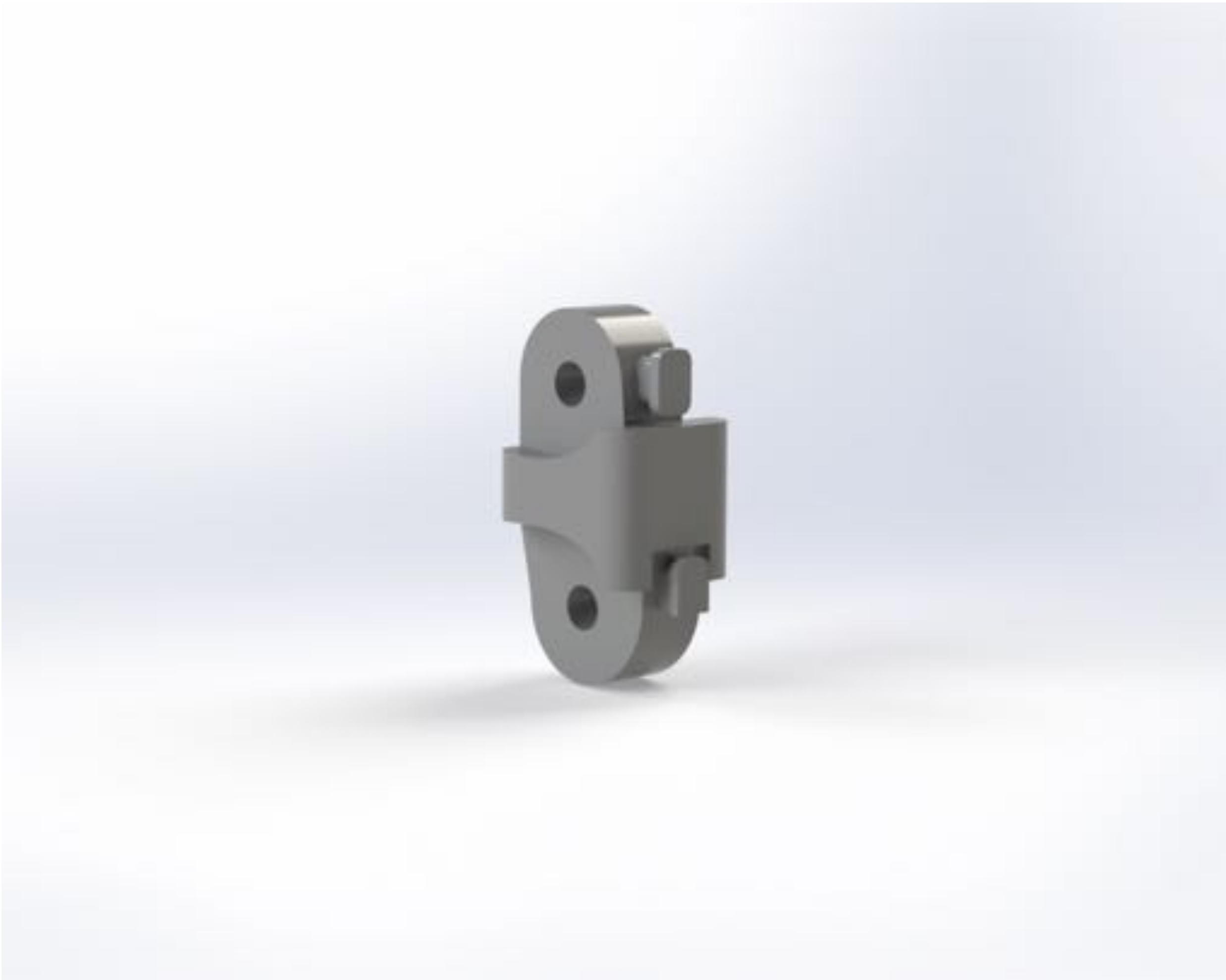

Note: The final prototype has changed from the conceptual design. The conceptual design is of an elbow-driven prosthetic. We have adapted to a linear actuator driven prosthetic. In our final prototype we have also eliminated the forearm and used the elbow-cuff as our new forearm to reduce the weight.

# CAD Models and Assemblies

**Rendered Images**:

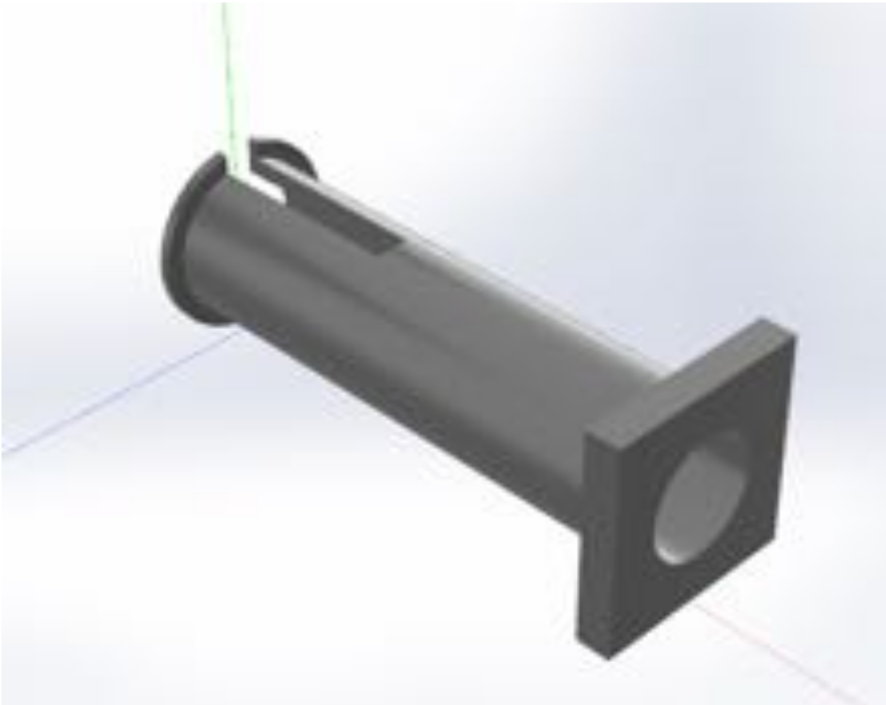
Palm


Forearm/Elbow Cuff



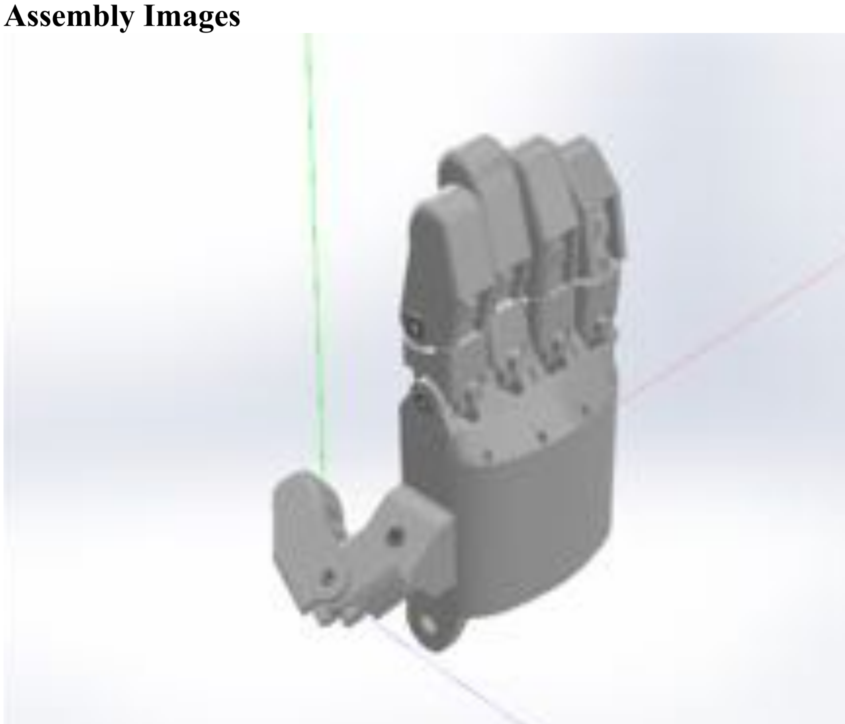
Metacarpals (Finger 1/2)

Phalanges (Finger 2/2)

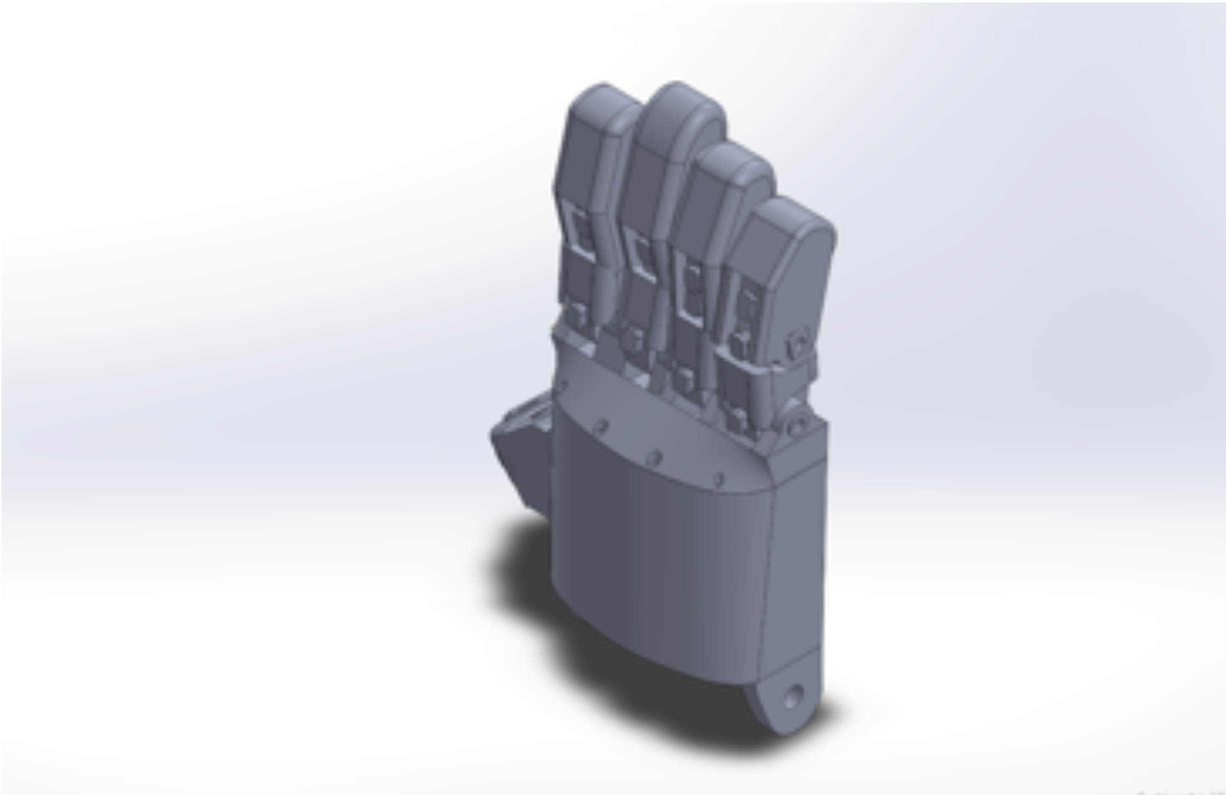


Pins

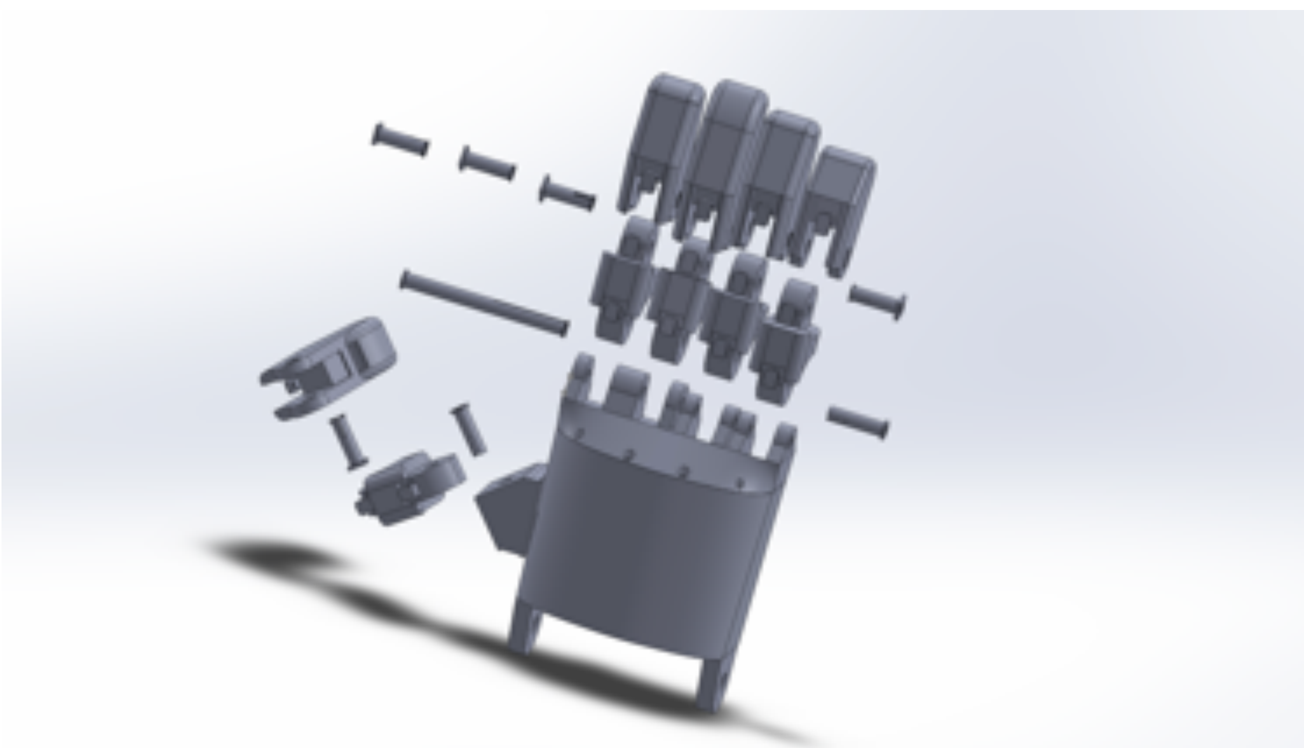
**Assembly Images**



Rendered Image of Assembly

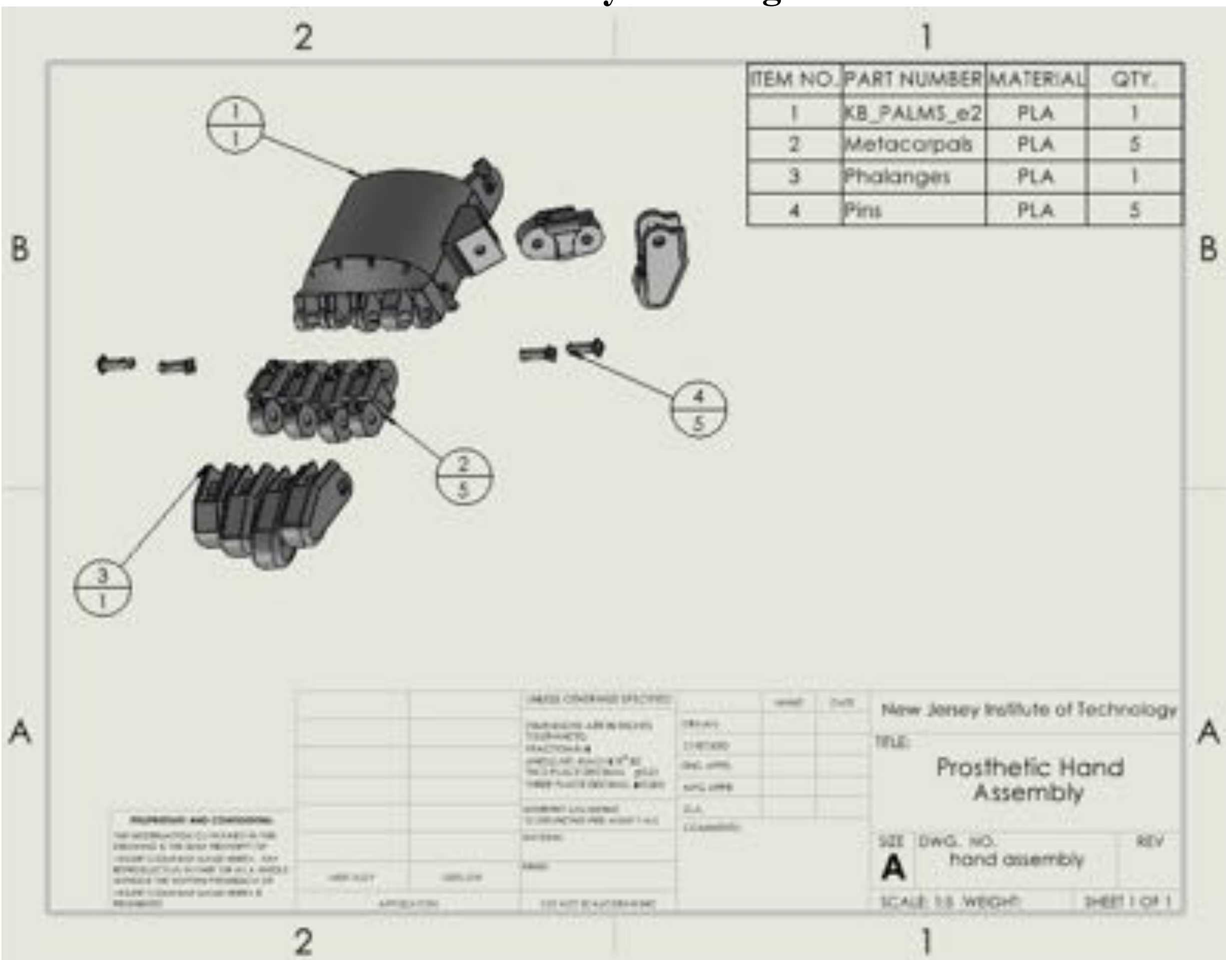


Unexploded View

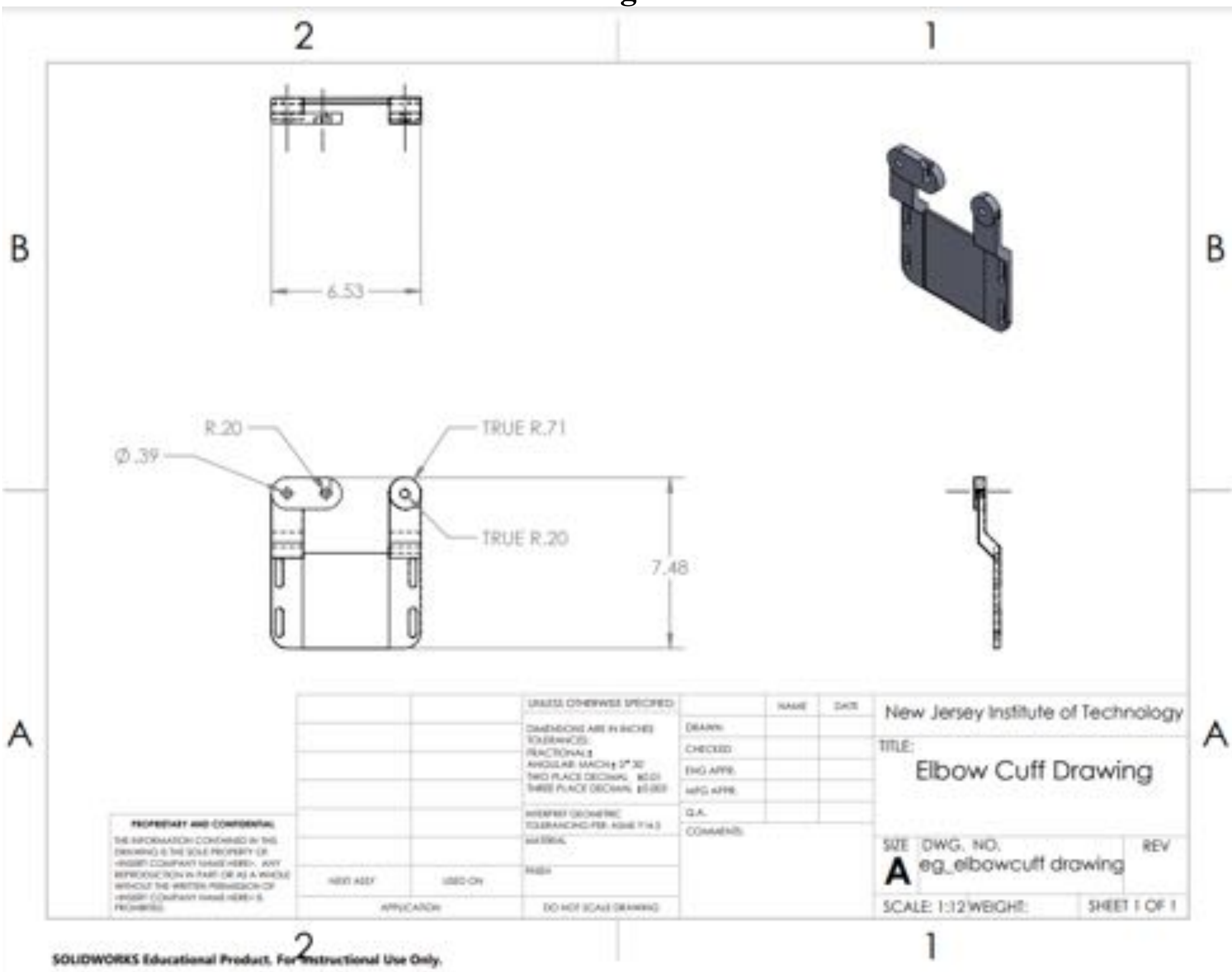


Exploded View

# Assembly Drawing



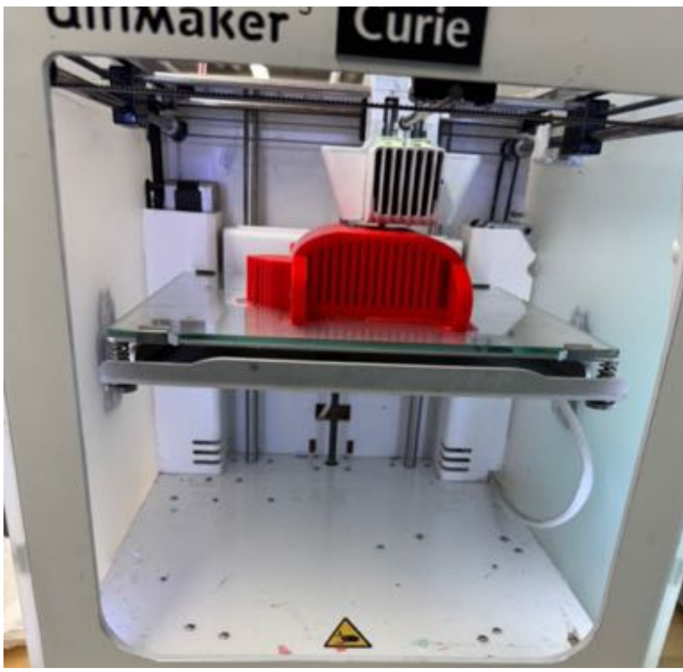
# Part Drawings

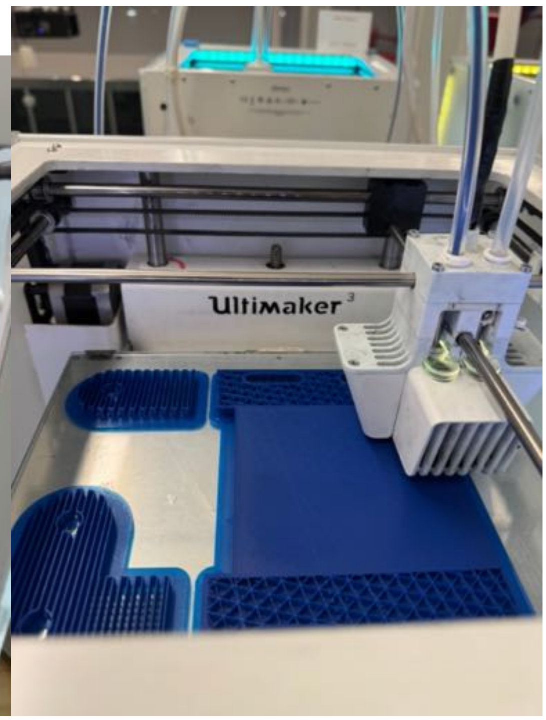



Forearm/Elbow Cuff Drawing

## Prototype Manufacturing

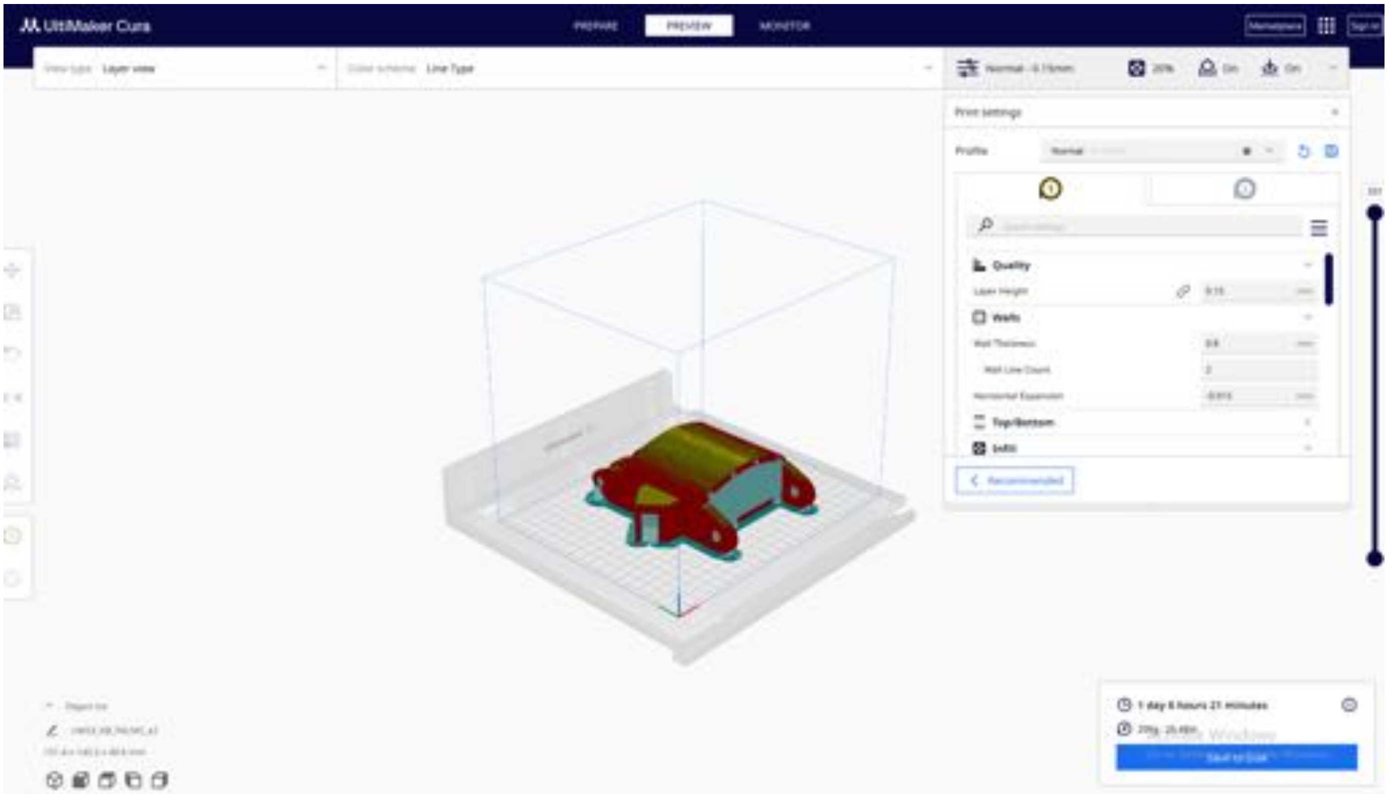
Manufacturing the prototype mainly consisted of 3D-printing. All of the important parts like the palm, metacarpals, phalanges, forearm-cuff, and pins were 3D-printed at NJIT's Makerspace. Another process that was used to manufacture the prototype was soldering. To connect the linear actuator to the forearm, soldering had to be done. Upon PLA being melted, a nut was added to the forearm. The actuator was secured by adding a screw, which attached the actuator to the surface of the forearm.



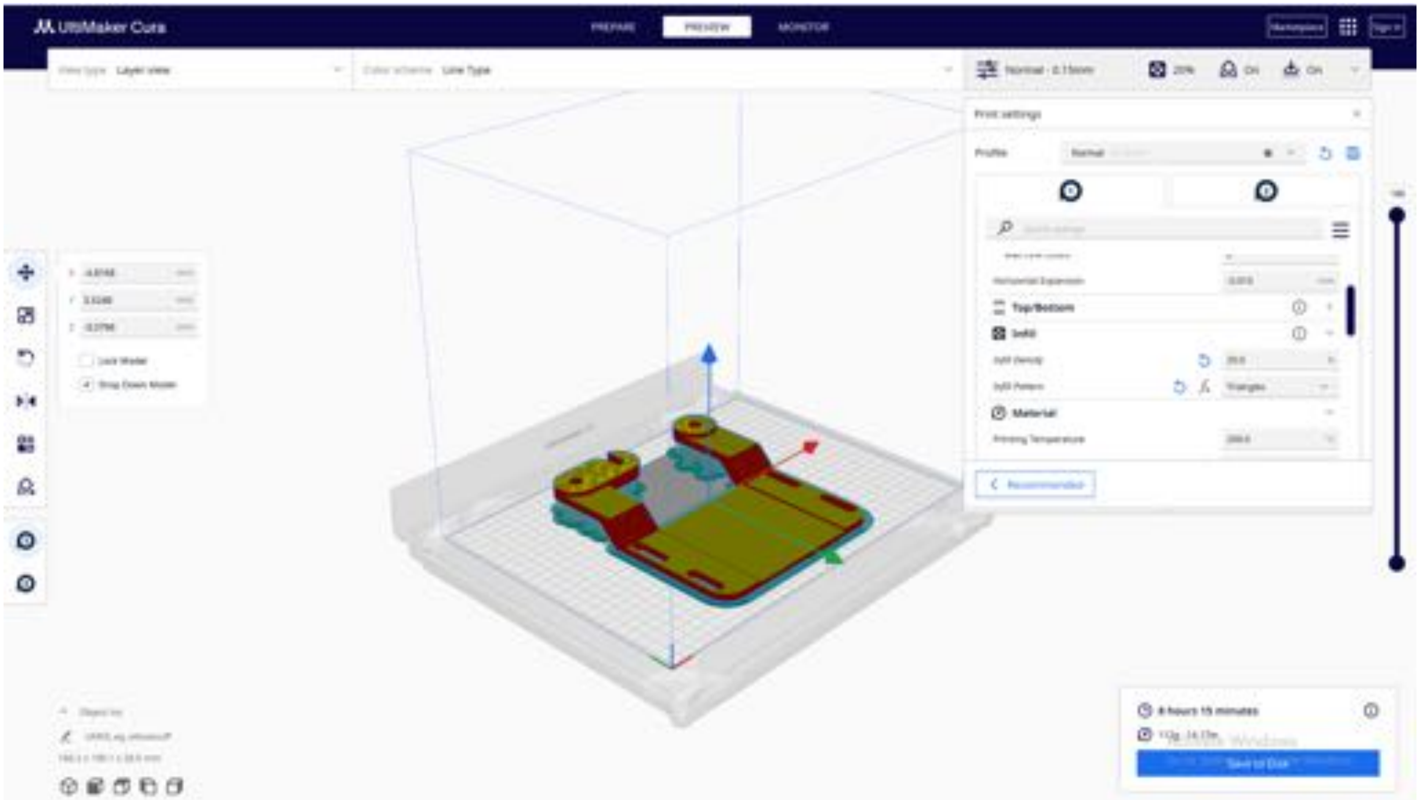

The palm and forearm are being printed on Ultimaker 3 at NJIT's Makerspace. The printing process was simple. Convert the sldprt file into an stl file. From the stl file, adjust the print settings and download the print to a usb. Attach the usb to an available printer.

**Print Preview Screenshots**

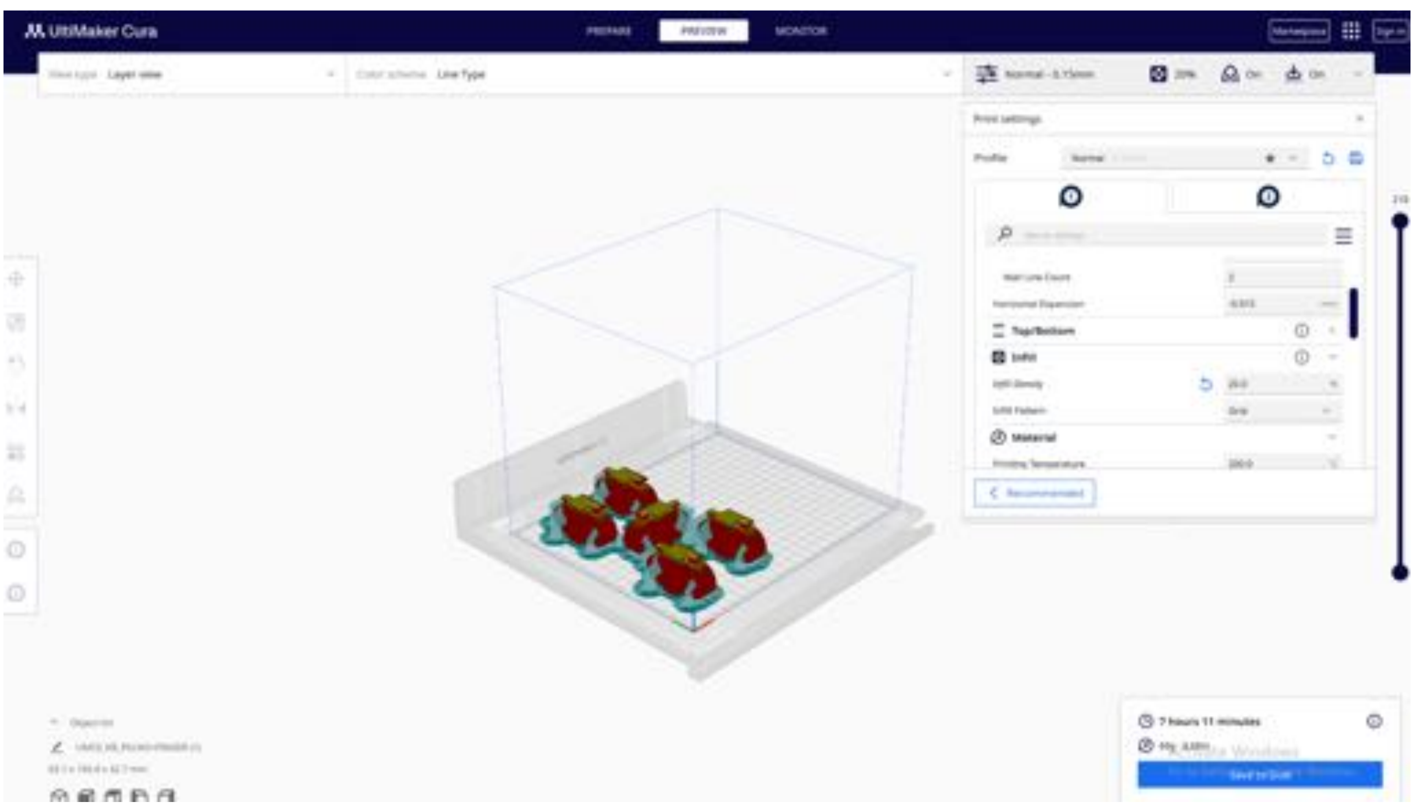



Palm

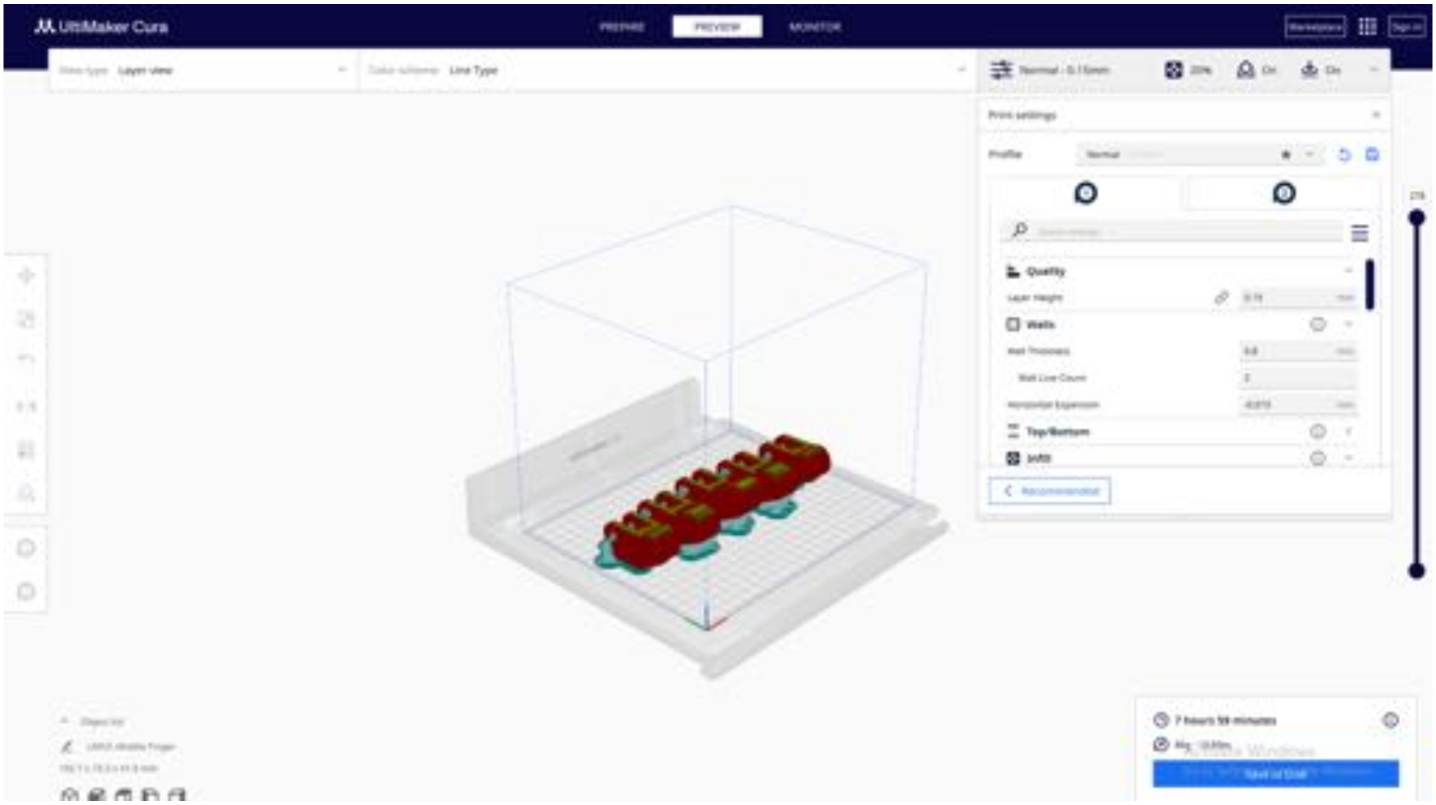
Material: PLA



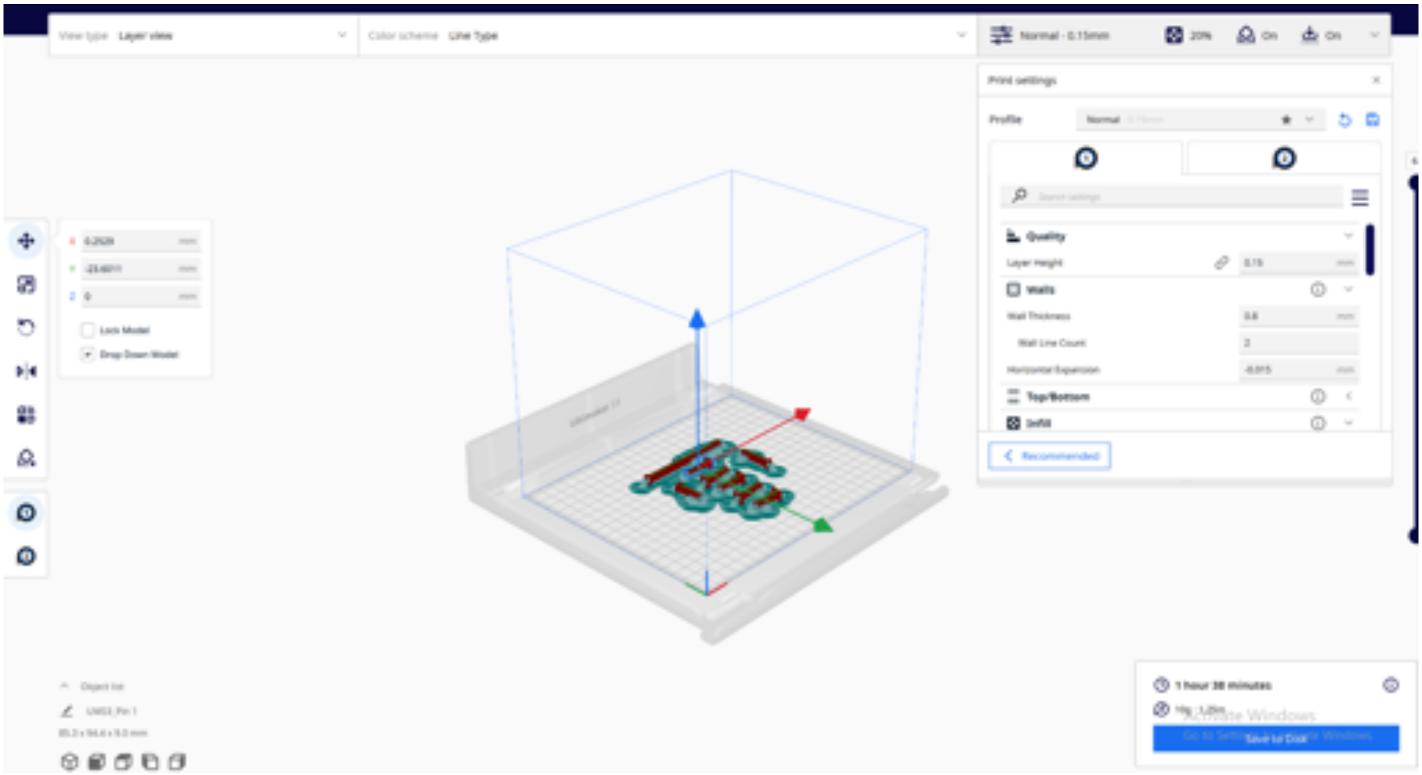

Forearm/Elbow-Cuff
Material: PLA



Metacarpals (1/2) (5)
Material: PLA




Phalanges (2/2) (5)
Material: PLA



Pins (8)
Material: PLA

**Materials Used for Prototype**: PLA was the material that was primarily used for all of our prints. PLA is strong, reliable, flexible, and comfortable. All of these attributes made PLA a great choice for our prosthetic. Our prosthetic is going to be used a lot, therefore PLA would provide longevity and durability to the user. The strong material wouldn’t be susceptible to damage caused by the environment or everyday tasks.

Fishing line was also a great choice for string that can be run throughout the prosthetic. The fishing line that was used can hold up to 40lbs of weight, which is more than enough for our device. On top of that, rubber bands were a great addition to our device. Rubber bands were used to connect the palm and the metacarpals and the metacarpals to the phalanges. The rubber bands allowed for good tension and helped to secure the objects in place. The flexibility of the rubber-bands also favored the pivot of the fingers.

In addition to that, wooden dowel pins were used to attach the metacarpals to the palm. The wooden dowel pins were a great alternative to plastic 3D-printed pins because they are more durable. Majority of the weight fell on the palm, therefore wooden dowel pins had to be substituted to ensure better support.

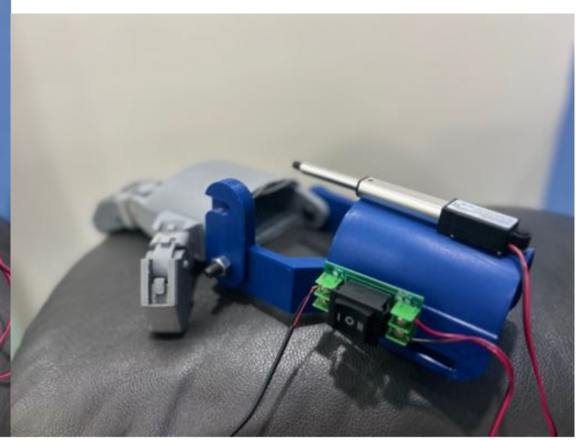
Metal Fasteners like the button head-hex drives and hex-nuts were also used instead of 3D-printed pins to connect the palm and forearm-cuff. The forearm had to support the weight of the palm, fingers, and the actuator, meaning that the connection from palm to forearm must be strong. 3D-printed plastic pins can simply not keep up with this demand, therefore metal fasteners were used to ensure support.

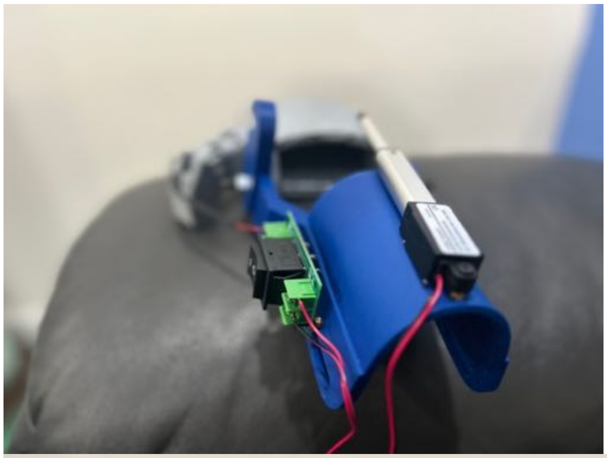
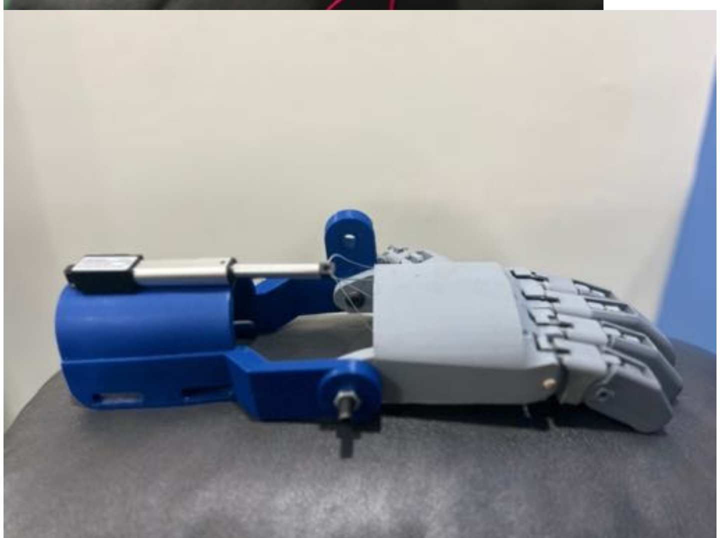
**All Components in Assembly (including “Off the Shelf”)**

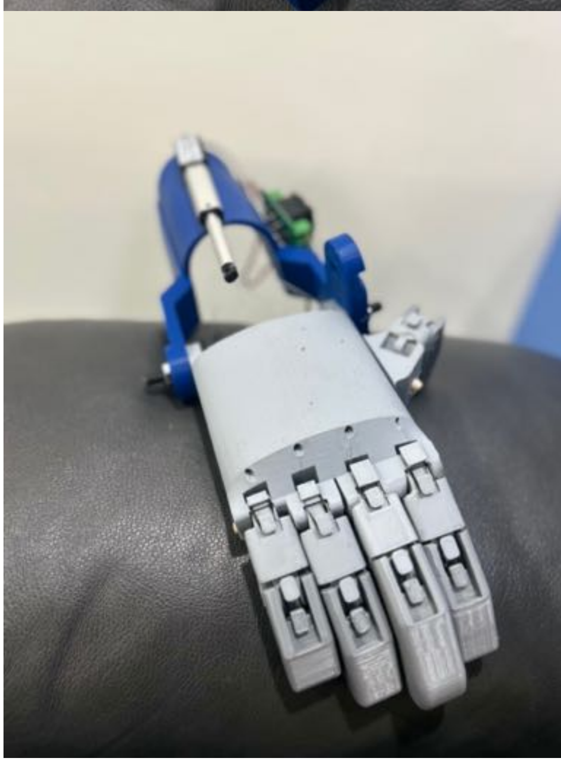
1. Palm (1)
2. Metacarpals (5)
3. Phalanges (5)
4. Forearm-Cuff (1)
5. Linear Actuator (1)
6. TalentCell 12V Lithium ion power bank (1)
7. Rocker Switch (1)
8. Fishing Line
9. Pack of Small Rubber-Bands
10. ¼ Wooden Dowel Pins (5) (Palm-Metacarpals)
11. ¼ Custom 3D Printed PLA Pins (5) (Metacarpals-Phalanges)
12. 5/16-18 x 1-½’’ Button Head, Hex Drive, Black Oxide (2) (Palm-Forearm)
13. 5/16-24, Hex Nut, Stainless 18-8 (2)  (Palm-Forearm)

**Images of the Prototype**



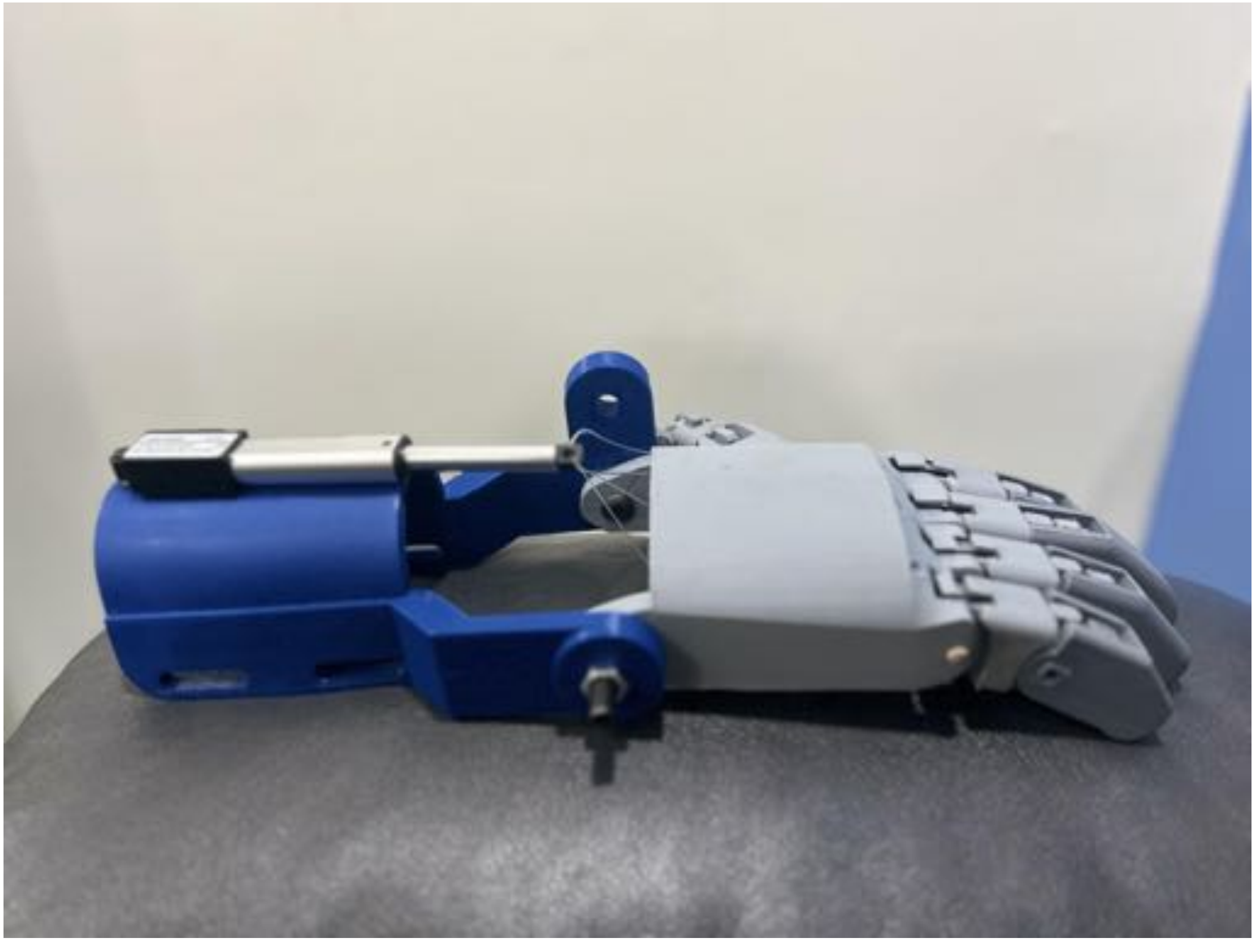



# Testing and Evaluation of The Prototype

**Functional Issues:**
This is the hand of our first prototype, once it was printed we immediately realized that it was going to need remodeling in its CAD file. The top part of the hand where each finger would be held at, had a rectangular geometry that wouldn't allow the finger to rotate completely without it colliding with the top of the hand, limiting its range of motion. As seen in the first image the finger would be limited at that position once it made contact with the top of the hand, not allowing it to fulfill its purpose of the hand closing completely.



**Design changes:**
This issue with the hand led us to recognize the need for a rounded geometry at the top of the slot where the finger fits. This adjustment allowed the finger to achieve a full range of motion without colliding with any obstacles, enabling it to close completely. Another modification we made to the model involved reducing the number of parts in the prototype. Initially, the design consisted of three components: the hand, forearm, and elbow cuff. However, we realized that the combined weight of these parts made the prototype too heavy for practical use by someone missing a hand. To address this, we removed the forearm component and reconfigured the elbow cuff to serve as the forearm cuff, significantly reducing the overall weight.

**Recommendations for future design improvements:**
Future improvements could include adding grip pads to the palm and fingertips, enabling the prosthetic to securely hold objects like a water bottle without requiring excessive contraction. This would allow for a gentle yet firm grip. Another potential change is increasing space on the forearm cuff to accommodate the battery that powers the device. Currently, the user must keep the battery in their pocket, which can lead to disconnections. By creating a designated spot on the forearm cuff for the battery, such issues could be minimized. Alternatively, finding a smaller power source for the actuator could make it possible to mount the battery directly on the cuff, reducing complications and enhancing usability.

# Conclusion

Conclusively, this experience offered invaluable insights into the intricate processes of design, development, and manufacturing. From conceptualizing initial prosthetic designs and ensuring precise alignment of parts to experimenting with materials and performing durability tests, each step deepened understanding and enhanced technical skills. The most rewarding moments came from collaborative brainstorming, merging ideas, and seeing the designs evolve into functional prototypes through CAD modeling and physical testing. Along the way, key lessons such as the importance of material selection, attention to detail in CAD designs, and the balance between simplicity and functionality were learned. This journey not only strengthened technical expertise but also underscored the value of teamwork and innovation in creating impactful solutions.