

Actuator Modification Guide

Therabot - TABUi

Related resources shared at:

https://mstate-my.sharepoint.com/:f:/g/personal/zmh68_msstate_edu/En2XXLOMWtdLvaSsHwflpL4BX48qFGRJdlpGywvzB6qZGg?e=wipjJq

Last updated: 2023-04-10

About this guide

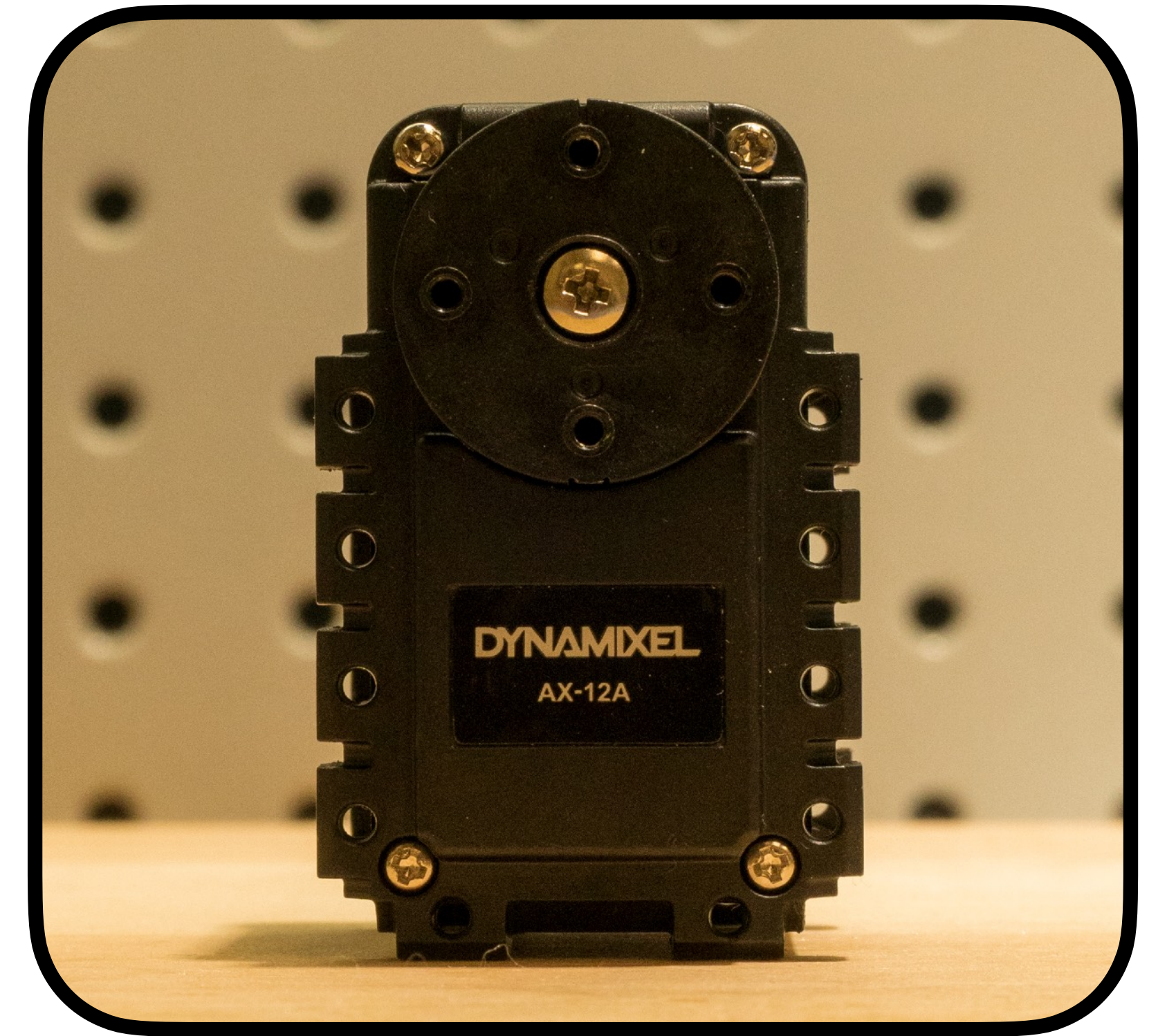
- This guide describes how to perform physical modifications to the eight Dynamixel AX-12A smart actuators used on the Therabot robotic platform.
 - This guide is for the **TBAUi** version of Therabot (released December 2022).
- Additional resources, including a video demonstrating the full modification process, are available at:
 - **Test Bench Setup & Use:** https://youtu.be/mDhoN_q8Mc
 - **Actuator Modification Process:** <https://youtu.be/Kbht8eGN3tQ>
 - **All video files:** https://mstate-my.sharepoint.com/:f:/g/personal/zmh68_msstate_edu/En2XXLOMWtdLvaSsHwflpL4BX48qFGRJdIpGywwzB6qZGg?e=wipjJq
- Separate guides describe Therabot's printed parts and the assembly process.
- For the latest information and links to other guides, visit the shared **TBAUi Fabrication Clearinghouse Google Slides** document.
 - **Link:** <https://docs.google.com/presentation/d/169Mv3hVGqsospuk8Mh-GBcdvckYeu8nqdFovMiNCWts/edit?usp=sharing>

Required Parts and Tools

CONTENT SHARED OR MADE ACCESSIBLE VIA THIS DOCUMENT IS INTENDED FOR USE BY AUTHORIZED MEMBERS OF THE THERABOT RESEARCH PROJECT. ALL OTHER ACCESS IS PROHIBITED.

8 Robotis Dynamixel AX-12A Actuators

- TBAUi uses a total of 8 AX-12A actuators.
- The Dynamixel AX-12A is a “smart servo” produced by Robotis.
 - 🇰🇷: https://www.robotis.com/shop/item.php?it_id=902-0003-001
 - 🇺🇸: <https://www.robotis.us/dynamixel-ax-12a/>
- Each actuator must be modified to allow the heat it generates to be more efficiently dissipated via the robot’s cooling fans.

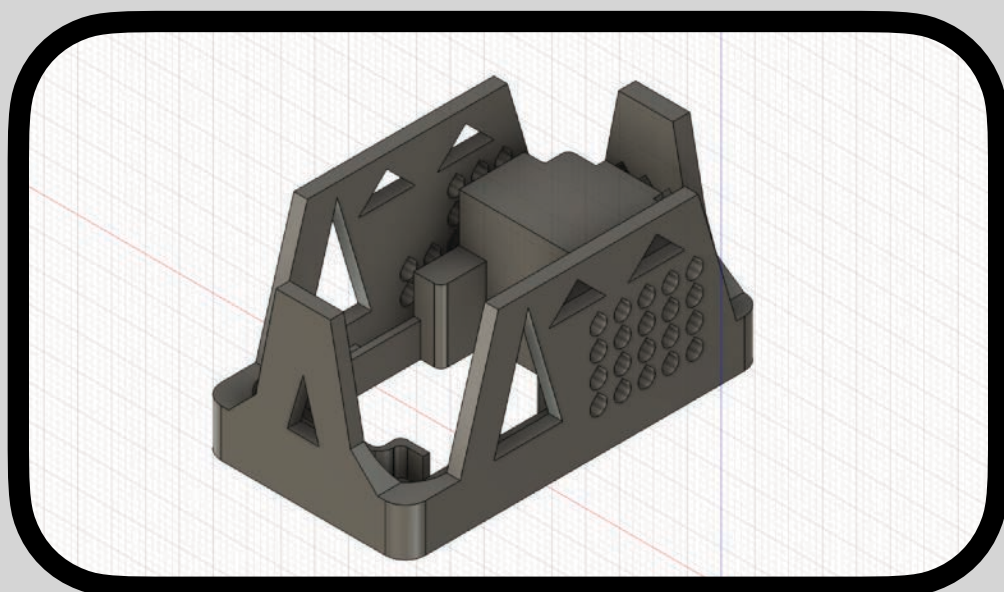


The front of an AX-12A purchased in 2023.

Required Parts and Tools:

3D-Printed Actuator Modification Parts

The actuator modification process is completed with assistance from three 3D-printed parts. These parts can be printed using any material with moderate durability and dimensional accuracy (e.g., PLA, ABS, ASA, etc.).

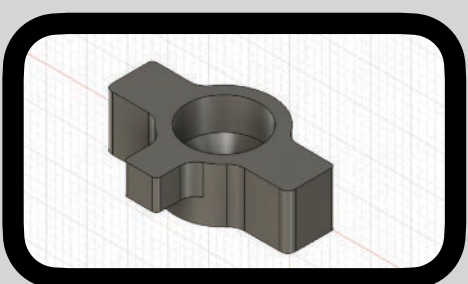


Hole Template

3D Part: *Jigs/AX12-Jig-Hole-Template-V27*

The hole template fits into the AX-12A actuator and acts like a stencil to provide consistent placement of the ventilation holes drilled into to the actuator. After printing, 4 M2 heat-set threaded inserts are added to the part to allow it to be fastened to the actuator.

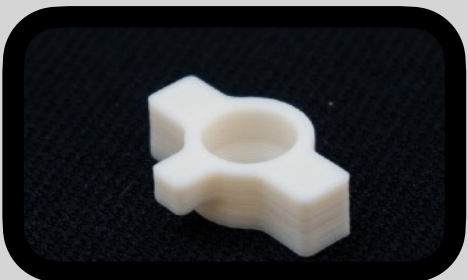
A printed hole template part can be used repeatedly to modify more than one actuator, but due to wear on the part we typically dispose of the part after it has been used twice.



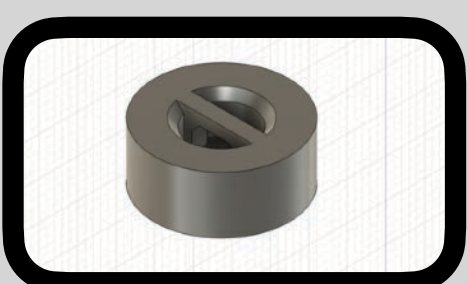
Spanning Cap

3D Part: *Jigs/AX12-Jig-Spanning-Cap-V2*

The spanning cap fits inside the AX-12A actuator during modification to protect the gearbox.



A single spanning cap can be used repeatedly to modify more than one actuator.



Motor Plug

3D Part: *Jigs/AX12-Jig-Motor-Plug-V5*

The motor plug fits inside the AX-12A actuator during modification to protect the gearbox.



A single motor plug can be used repeatedly to modify more than one actuator.



Parts Included in Kit

Parts for actuator modification are provided in the TBAUi kit within the “**Jigs, Kits, SD Card**” bag, grouped into smaller bags:

#601 - Includes 4 hole template parts with threaded inserts and 8 M2 x 30mm screws

#602 - Includes 2 spanning caps and 2 motor plugs

Required Parts and Tools:

Materials & Tools



Jig Parts & Screws

- Jig Parts (included in Bag #601 & Bag #602)
- 4x 30mm M2 screws (included in Bag #601)
- If self-printing: 4x M2 threaded inserts per hole template



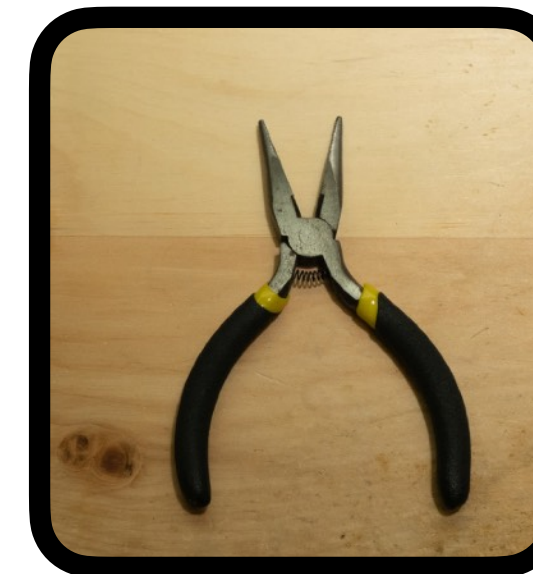
Vise / clamps

- A vise is used to hold the actuator firmly in place while drilling holes into it.
- Any equivalent system for holding the actuator is acceptable.
- The vise pictured here is a low-cost model available at hardware stores in the US, see [\[P3\]](#)



Power Drill or Drill Press

- A standard power drill or drill press
- A low-end/basic power drill that can hold a 1.5mm and 2.5mm drill bit is sufficient.
- The drill pictured here is similar to the product at [\[P1\]](#)



Pliers / grabbing tool

- Standard pliers or other grabbing tool
- Useful for grasping small parts of the actuator during the modification process.



Drill Bits

- 1.5 mm drill bits
- 2.5 mm drill bits
- Bag #603 includes 2 of each size drill bit.
- The drill bits pictured here are from [\[P2\]](#)



Vacuum and/or compressed air

- A wet/dry or “shop” vacuum capable of capturing plastic debris. Example: [\[P4\]](#)
- Compressed air either from a small air compressor (~80 PSI) [Ex: [P5](#)] or another source like canned air [Ex: [P6](#)].

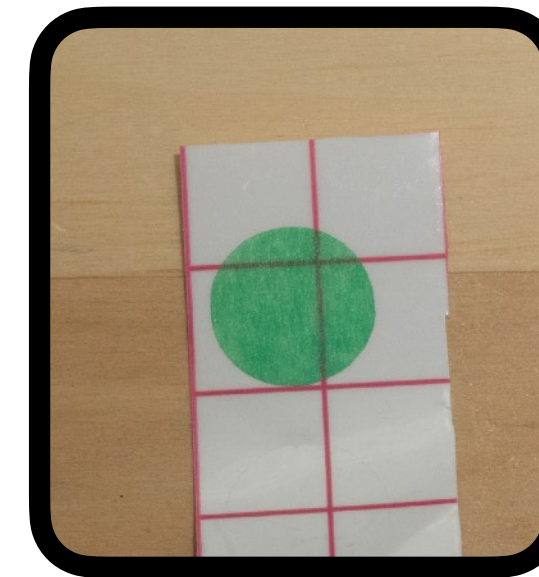
Required Parts and Tools:

Materials & Tools



Tweezers: regular and blunt

- Precision tweezers for electronics / hobby work
- Both fine tip (pointed) and rounded spade tip (blunt)
- Product example: [\[P7\]](#)



Masking Tape Circles

- Masking/painter's tape cut into roughly 16mm diameter circles (2 per actuator modified)
- Does not need to be cut into an exact circle, only needs to cover openings.



Phillips screw drivers

- Phillips head screw drivers for M2 and smaller screws
- Recommended sizes: PH0 and PH00
- Product example: [\[P8\]](#)



Bags

- Sealable plastic bags to hold the parts of the actuator while it is being modified.
- Three bags for each actuator, one of which should be an anti-static/ESD bag to hold electronic components.



Utility knife & files

- A utility knife with a fine point blade (e.g., #11)
 - Product example: [\[P9\]](#)
- Small needle files for smoothing rough edges
 - Product example: [\[P10\]](#)



Microfiber shop cloth (large and small)

- Reusable or washable non-fiber shedding cloths
- Larger cloth to clean tools and larger surfaces
- Smaller cloths used to wipe away grease within actuator.

Required Parts and Tools:

Materials & Tools



99.9% Isopropyl Alcohol (IPA)

- Pure isopropyl alcohol
- <99.9% is acceptable if no additives (like glycerin)
- 99.9% IPA is usually marketed for electronics work and does not contain additives.



Respiratory Protection

- The modification process may result in small plastic particles from the actuator being suspended in the air.
- Use proper respiratory protection (like an N95 respirator) and an acceptably ventilated workspace.



Disposable nitrile gloves

- Disposable gloves to protect hands from grease inside of actuators.
- Nitrile recommended, but any material acceptable.



Work Surface Protector

- When opening the actuator gearbox, grease will escape onto the work surface.
- Use a disposable sheet of paper or cloth so that your primary work surface does not become contaminated.



Safety glasses

- An acceptable form of eye protection is needed when modifying actuators.
- Eye protection is important when using the drill and when working with IPA.



IMPORTANT SAFETY NOTE

- Safety regulations differ by locality and organization.
- Please identify and follow all appropriate local safety guidance when completing actuator modifications.

Required Parts and Tools:

Example Product Links

P1: <https://www.amazon.com/BLACK-DECKER-LDX120C-Lithium-Driver/dp/B005NNF0YU>

P2: <https://www.amazon.com/gp/product/B078YLRFRD>

P3: <https://www.lowes.com/pd/IRWIN-4-in-Cast-Iron-Drill-Press-Vise/1003168306>

P4: <https://www.amazon.com/Shop-Vac-2021005-Vacuum-Gallon-1-Pack/dp/B09GQVKYBQ>

P5: <https://www.amazon.com/gp/product/B07KHHDJGD>

P6: <https://www.amazon.com/Dust-Off-Disposable-Compressed-Duster-Cans/dp/B073R4LKW9>

P7: <https://www.amazon.com/Precision-Anti-Static-Electronics-Laboratory-Jewelry-Making/dp/B07RNVXXV1>

P8: <https://www.amazon.com/gp/product/B015HUBA4M>

P9: <https://www.amazon.com/X-Acto-No-Roll-Rubber-Replaceable-X3724/dp/B0006HVRPO>

P10: <https://www.amazon.com/gp/product/B07QYYLH4T>



Creating a Test Bench

Video Guide: https://youtu.be/_mDhoN_q8Mc

Summary



In order to test actuator functionality before and after modification, you will need to setup a basic test bench for Dynamixel AX-12A actuators.

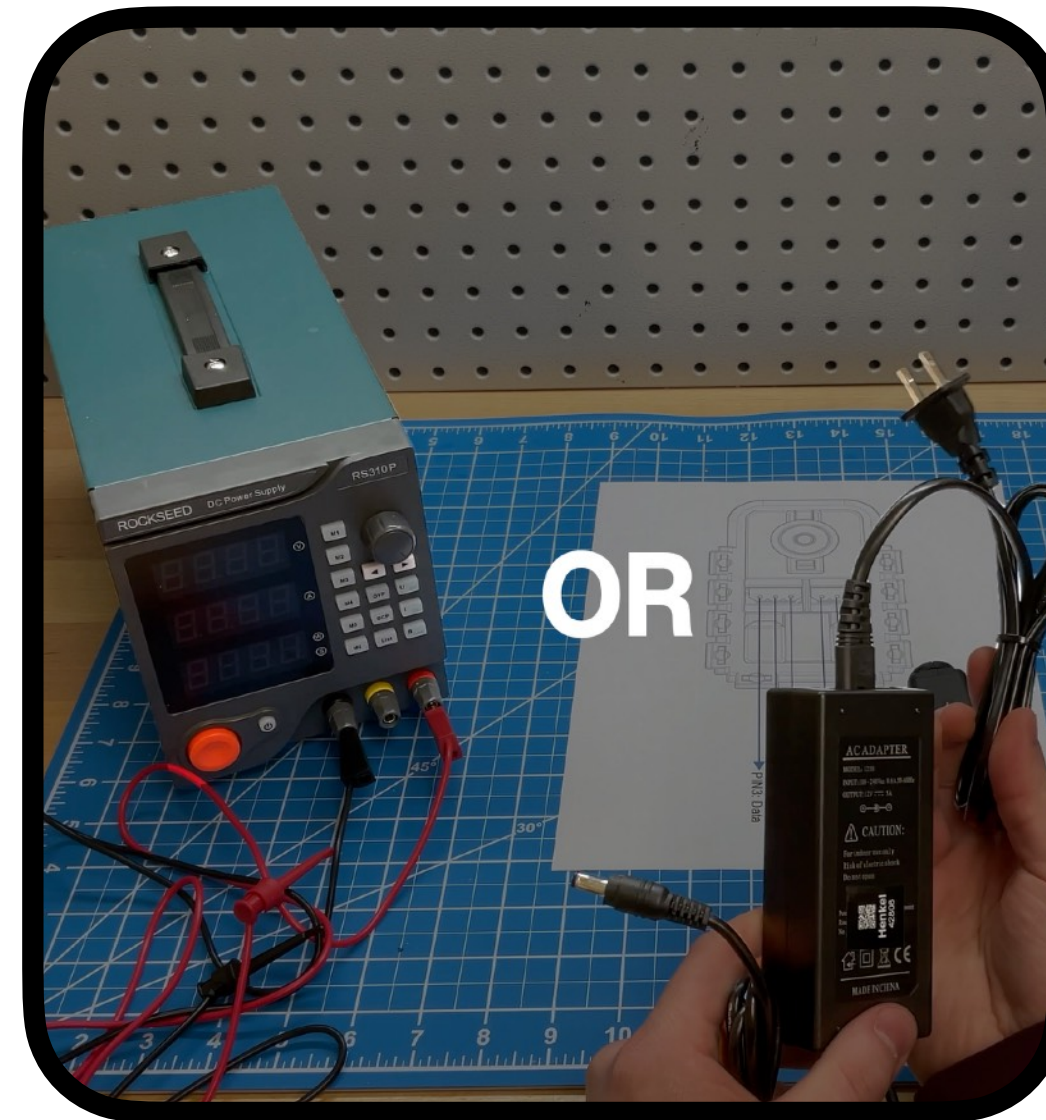
The test bench will allow you to connect an actuator to a computer and interact with it via the DynamixelWizard2 software made by Robotis.

Creating the test bench involves gathering the required parts and assembling them to connect the actuator to the control software.

Required Components



U2D2 Adapter



Power Supply



Dynamixel Cables



DynamixelWizard2

The required components include:

U2D2 Adapter: An interface for connecting Dynamixel actuators to a computer via USB (micro USB cable also required).

Power Supply: Either an adjustable or fixed power supply capable of providing DC power between 9-12V at 2A minimum.

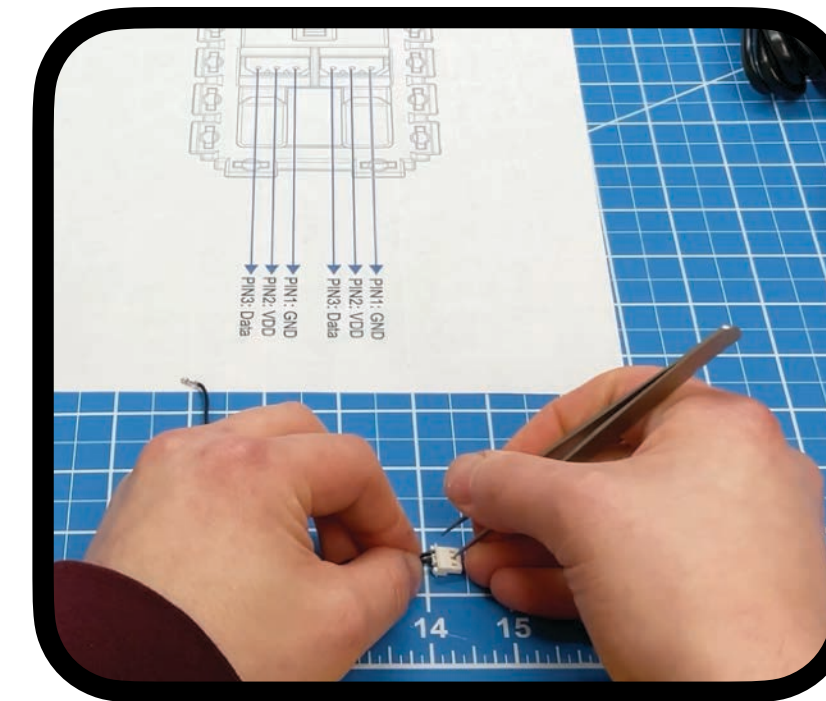
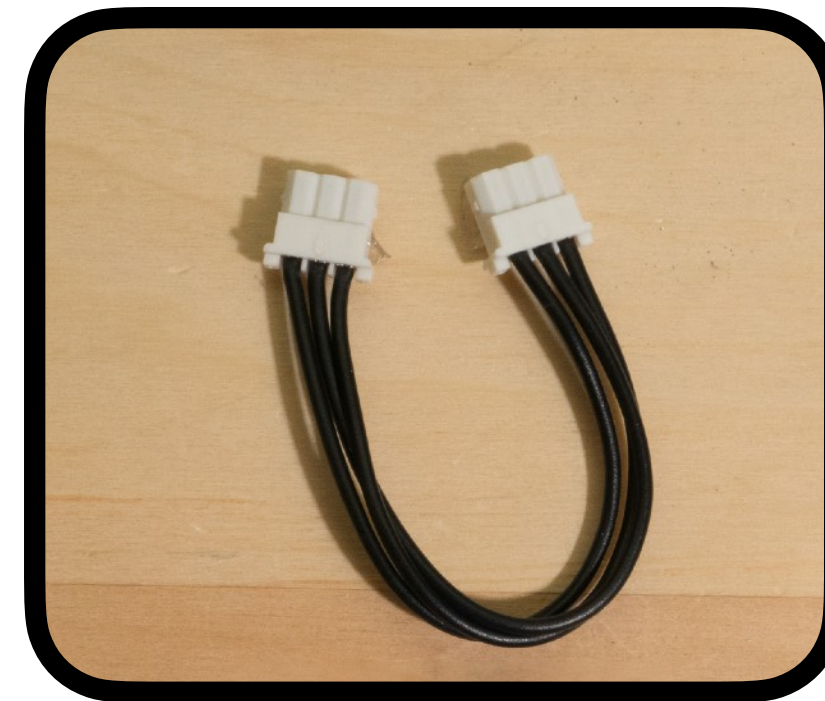
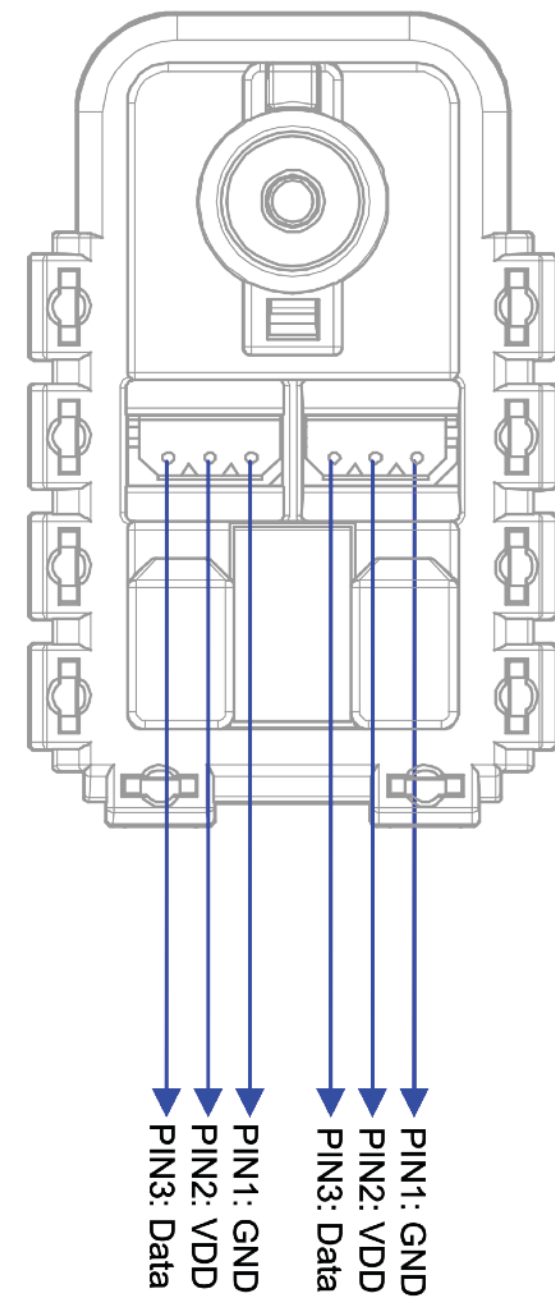
Dynamixel Cables: 1 standard 3-pin to 3-pin Mini-Spox Dynamixel cable, 1 3-pin Mini-spox to JST converter cable (included with U2D2)

DynamixelWizard2: Robotis control software installed on a computer with a USB port, downloadable from:

https://emanual.robotis.com/docs/en/software/dynamixel/dynamixel_wizard2/

Creating the necessary cables

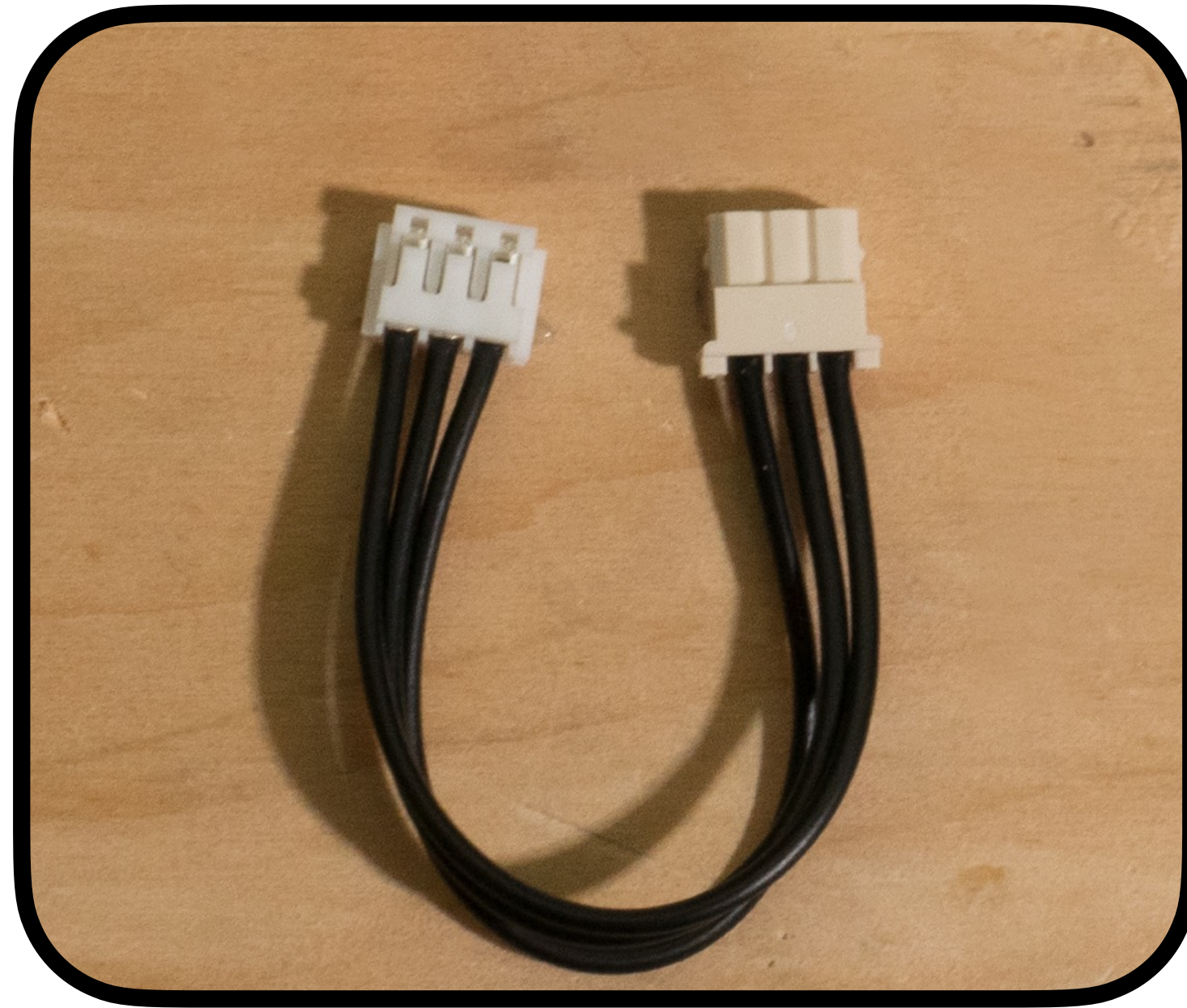
Modify a standard 3-pin Mini-Spox Dynamixel cable for supplying power.



- #1:** From a standard 3-pin Mini-Spox Dynamixel cable, use tweezers to remove the Data wire (see illustration) from the housing on one end of the wire.
- #2:** Use tweezers to remove all wires from the housing on the opposite end of the wire.
- #3:** The remaining connector with two wires (+11.1V and GND) will be used for supplying power to the actuator.

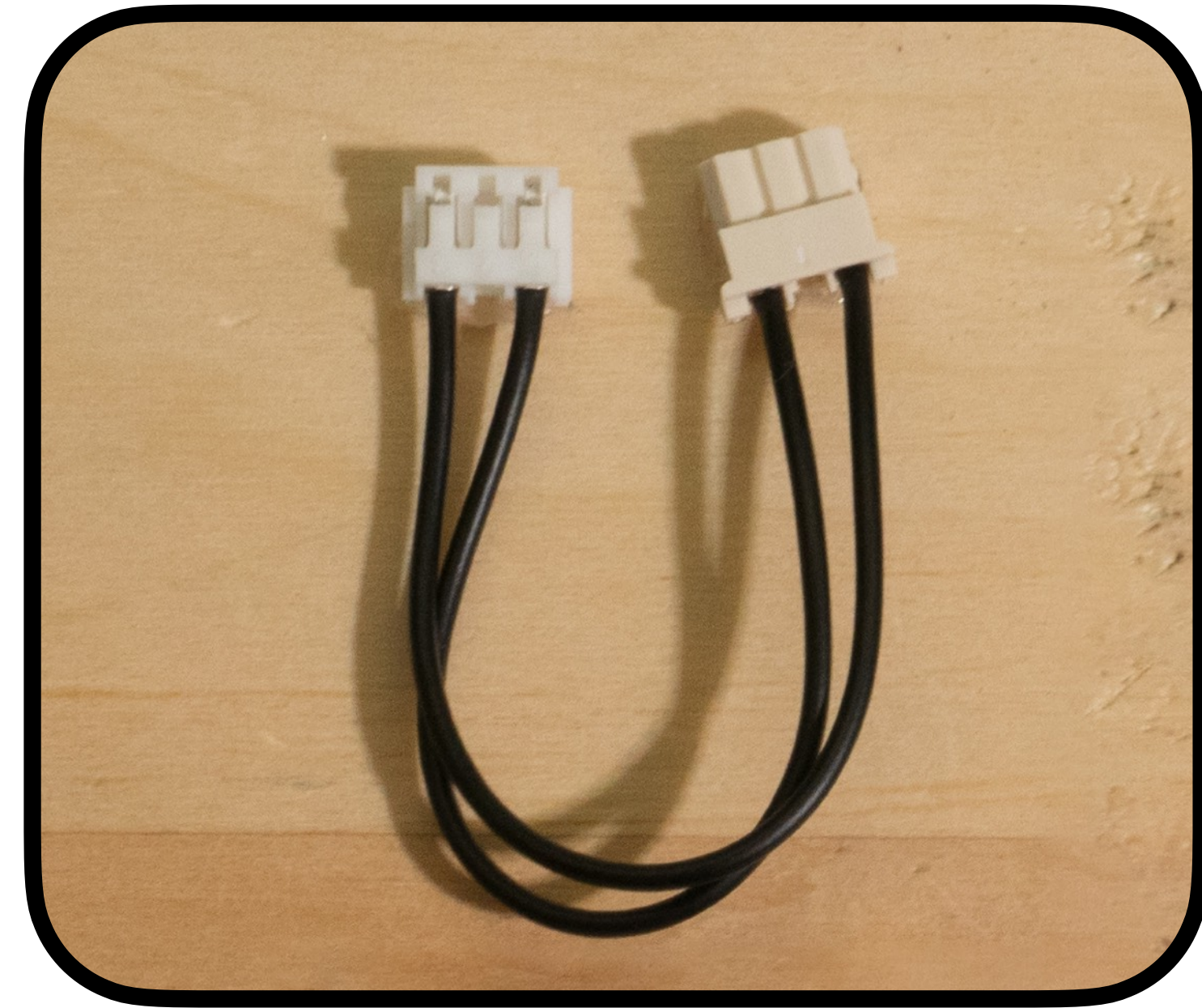
Creating the necessary cables

Optional: remove the center conductor from the 3-pin Mini-Spox to 3-pin JST converter cable



Mini-spox to JST with all three wires.

OR



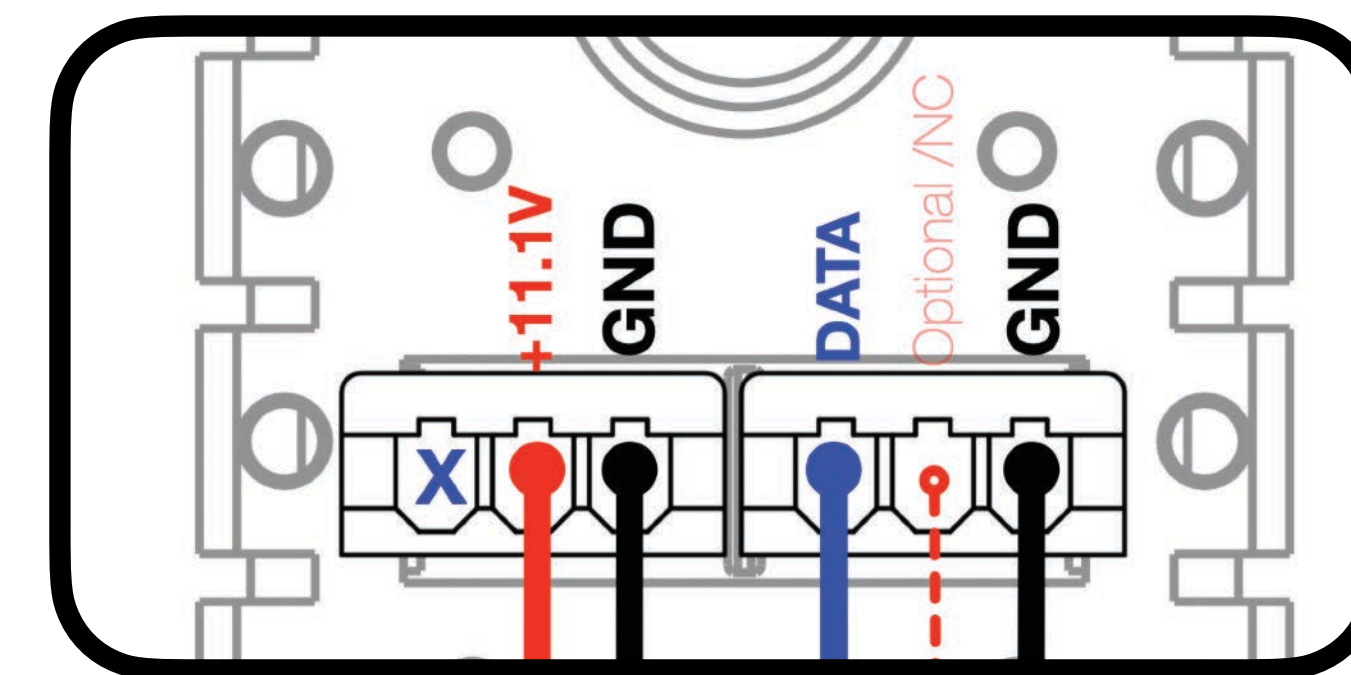
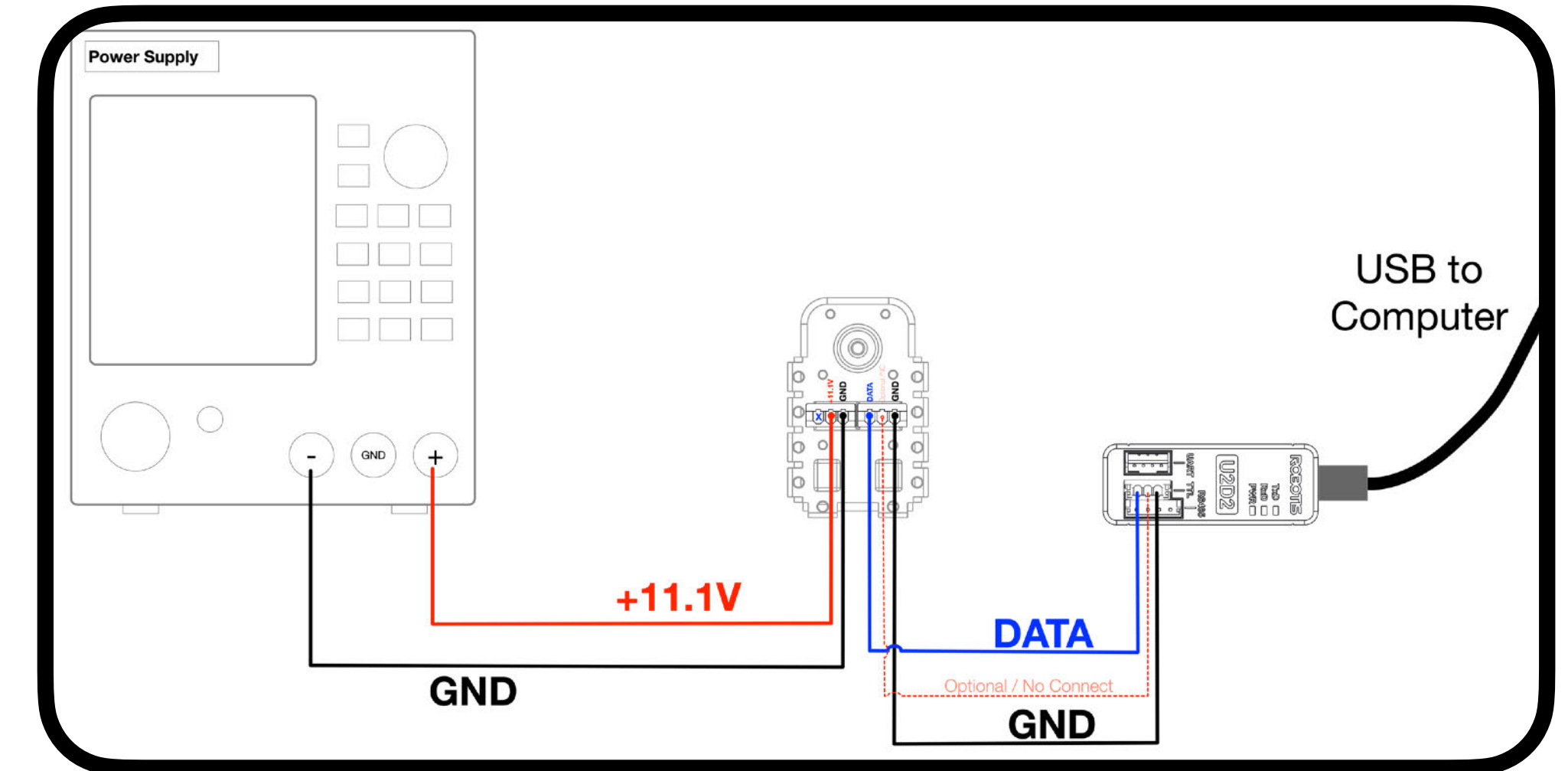
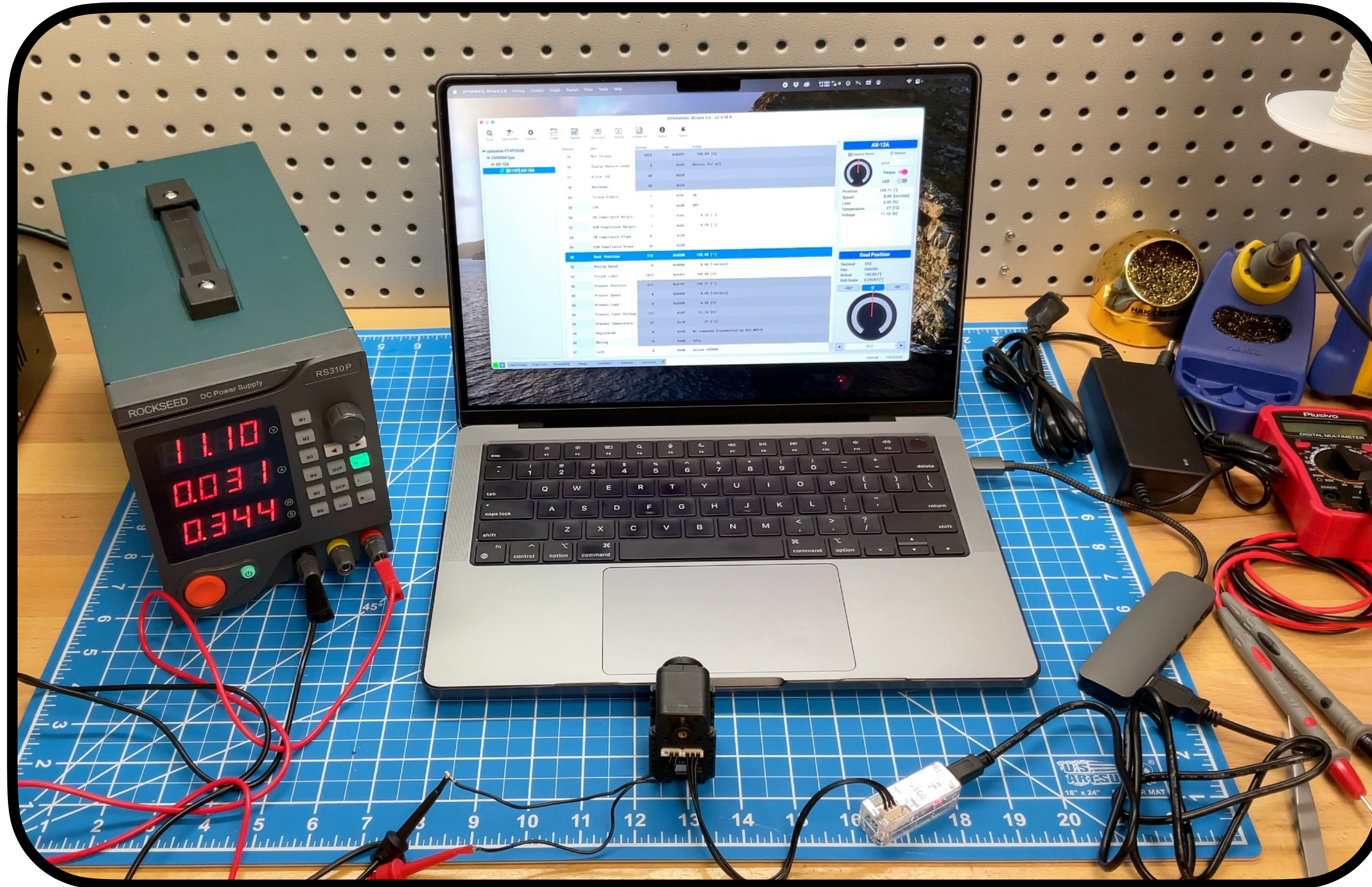
Mini-spox to JST with center (+11.1V) wire removed.

#1: Since the U2D2 does not supply power to the actuators, its middle wire can be removed if desired.

NOTE: Internally the middle wire/center (+11.1V) pin on the U2D2 is not connected, so it should not be affected by the presence or absence of the middle (+11.1V) wire. In our documentation we sometimes remove this wire for clarity.

Creating a Test Bench

System Configuration



NOTE: The center position (+11.1V) can be connected between the actuator and U2D2.

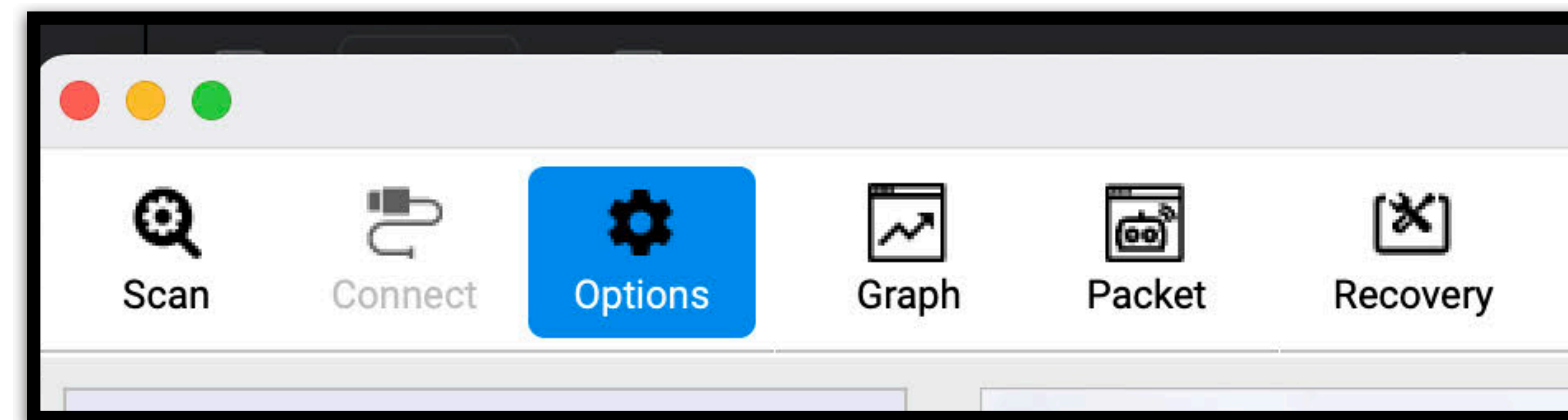
It is not connected internally on the U2D2 board and will not affect operation of the system.

Connect the system as shown here.

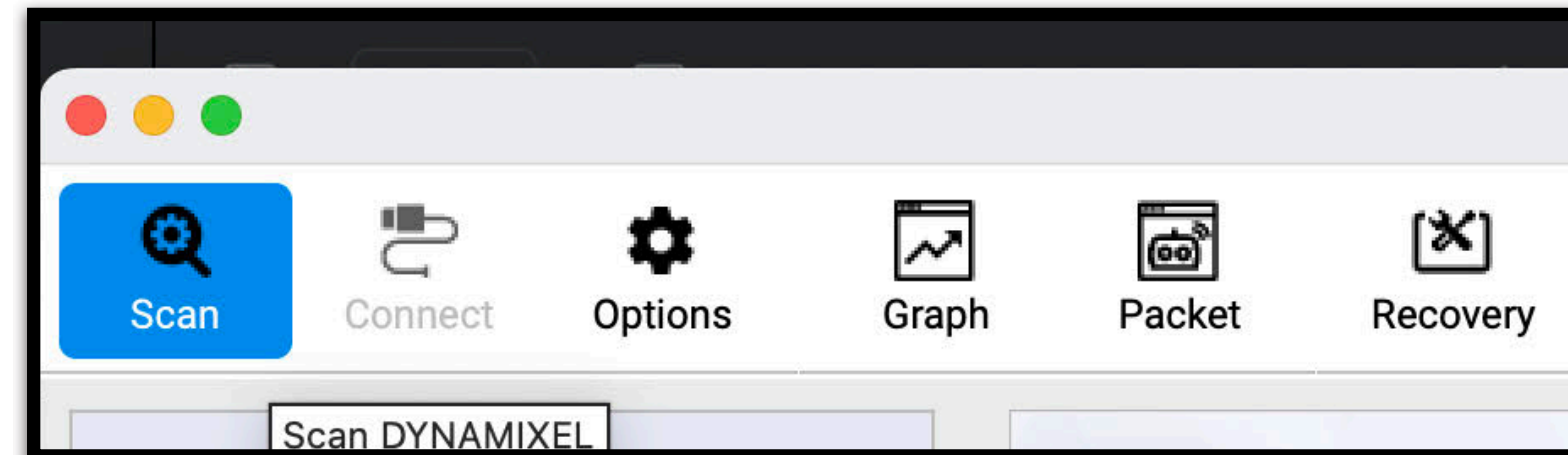
Upon applying power to the actuator its red LED (top center back) should illuminate briefly.

Scanning for actuators

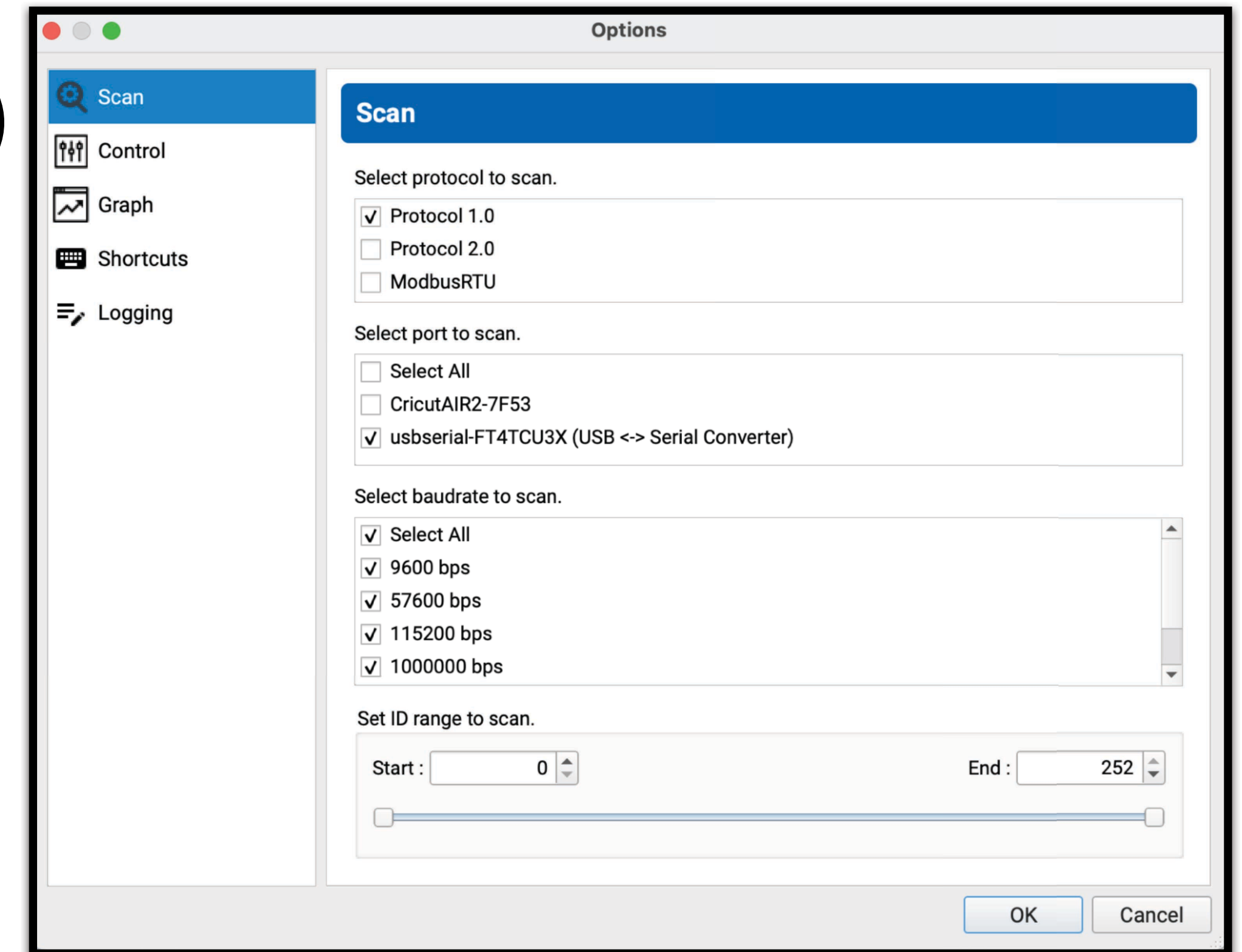
2



4



3



#1: Plug the U2D2 into the computer and connect it to a single powered Dynamixel actuator.

#2: Launch the DynamixelWizard2 and click the “Options” button in the top menu.

#3: Ensure “Protocol 1.0” is checked, the serial port associated with the U2D2 is checked, and “Select All” for baud rates is checked. Click “Ok”.

#4: Scan for actuators by clicking the “Scan” button in the top menu. The U2D2’s LED will blink as the scanning progresses.

Creating a Test Bench

Testing actuators

1 Select the actuator in the left column.

2 Select the "goal position" entry in the list of registers.

3 Use the buttons on the right to move between -90° and +90°.

Address	Item	Decimal	Hex	Actual
6	CW Angle Limit	0	0x0000	0.00 [°]
8	CCW Angle Limit	1023	0x03FF	299.71 [°]
11	Temperature Limit	70	0x46	70 [°C]
12	Min Voltage Limit	60	0x3C	6.00 [V]
13	Max Voltage Limit	140	0x8C	14.00 [V]
14	Max Torque	1023	0x03FF	100.00 [%]
16	Status Return Level	2	0x02	Return for all
17	Alarm LED	36	0x24	
18	Shutdown	36	0x24	
24	Torque Enable	0	0x00	OFF
25	LED	0	0x00	OFF
26	CW Compliance Margin	1	0x01	0.29 [°]
27	CCW Compliance Margin	1	0x01	0.29 [°]
28	CW Compliance Slope	32	0x20	
29	CCW Compliance Slope	32	0x20	
30	Goal Position	511	0x01FF	149.71 [°]
32	Moving Speed	0	0x0000	0.00 [rev/min]
34	Torque Limit	1023	0x03FF	100.00 [%]
36	Present Position	511	0x01FF	149.71 [°]
38	Present Speed	0	0x0000	0.00 [rev/min]
40	Present Load	0	0x0000	0.00 [%]
42	Present Input Voltage	113	0x71	11.30 [V]

AX-12A

Factory Reset Reboot

Joint

Torque

LED

Position 149.71 [°]
Speed 0.00 [rev/min]
Load 0.00 [%]
Temperature 28 [°C]
Voltage 11.30 [V]

Goal Position

Decimal 511
Hex 0x01FF
Actual 149.71 [°]
Unit Scale 0.29297 [°]

+90° 0° -90°

Interval: 100.0 [ms]

Test the actuator by selecting it in the left column, selecting to the “goal position” entry in the list of registers, and using the buttons on the right to move between -90° and +90°.

Be sure to return the actuator to 0° when finished.



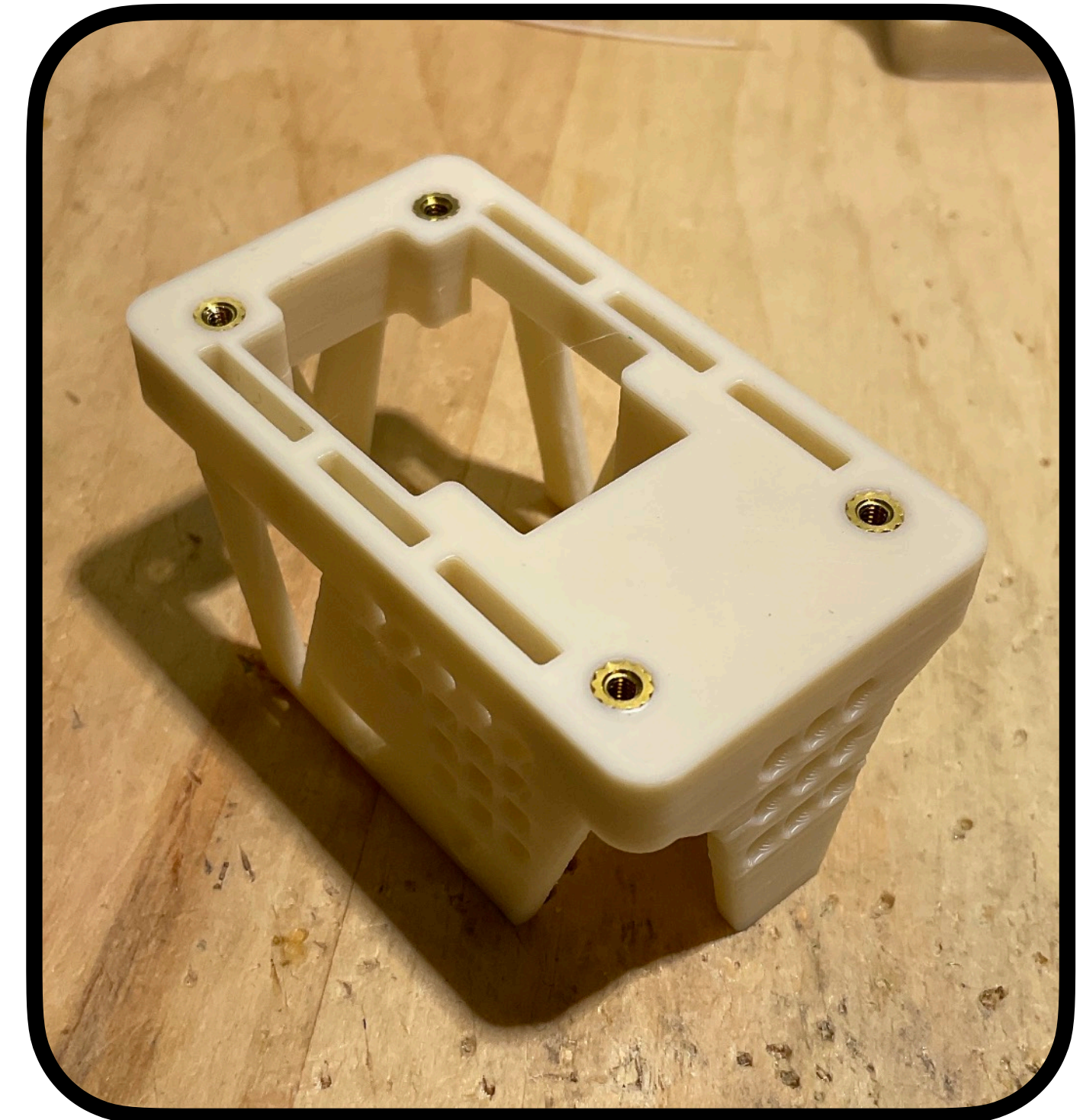
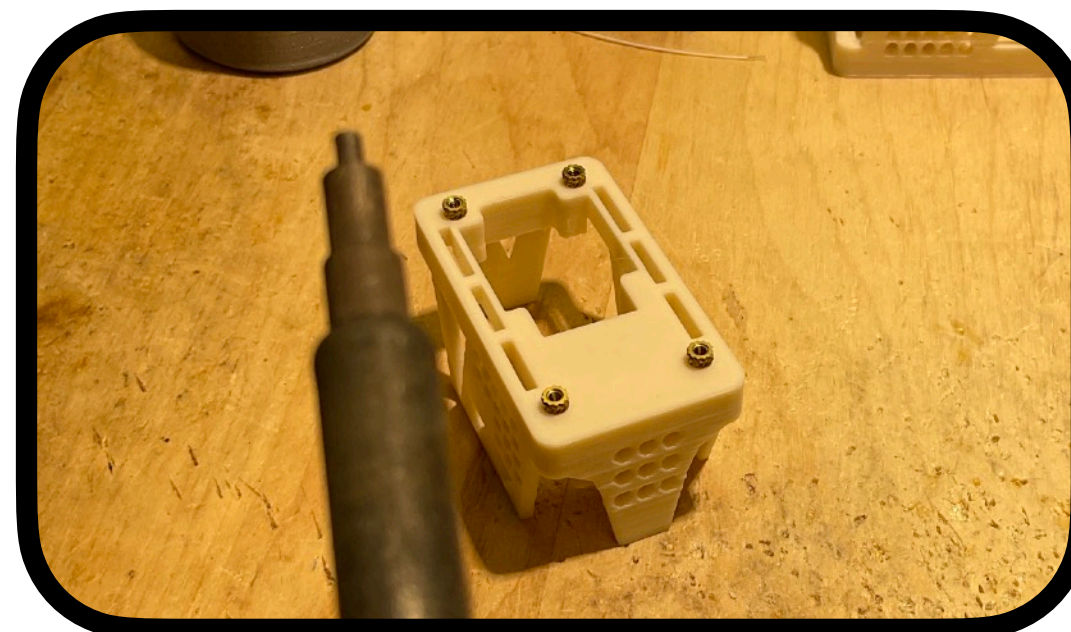
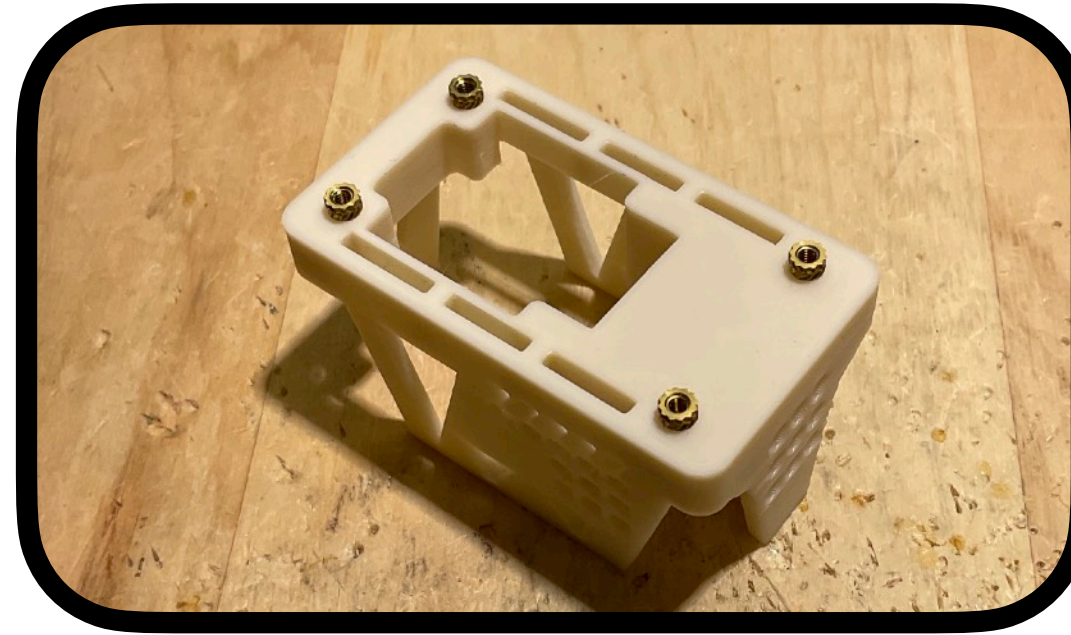
Actuator Modification Process

Video Guide: <https://youtu.be/Kbht8eGN3tQ>

Actuator Modification Process

Step #00:

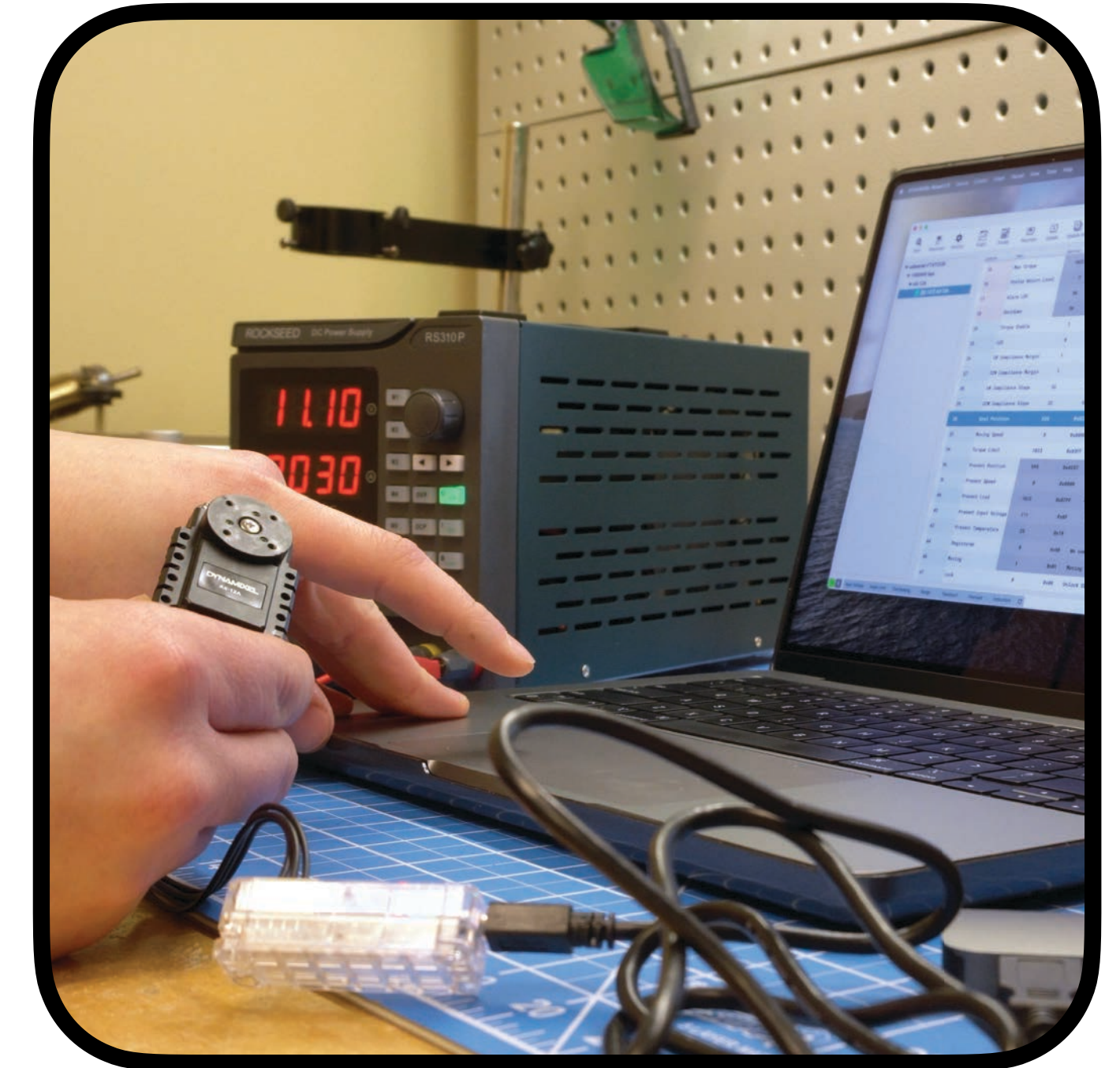
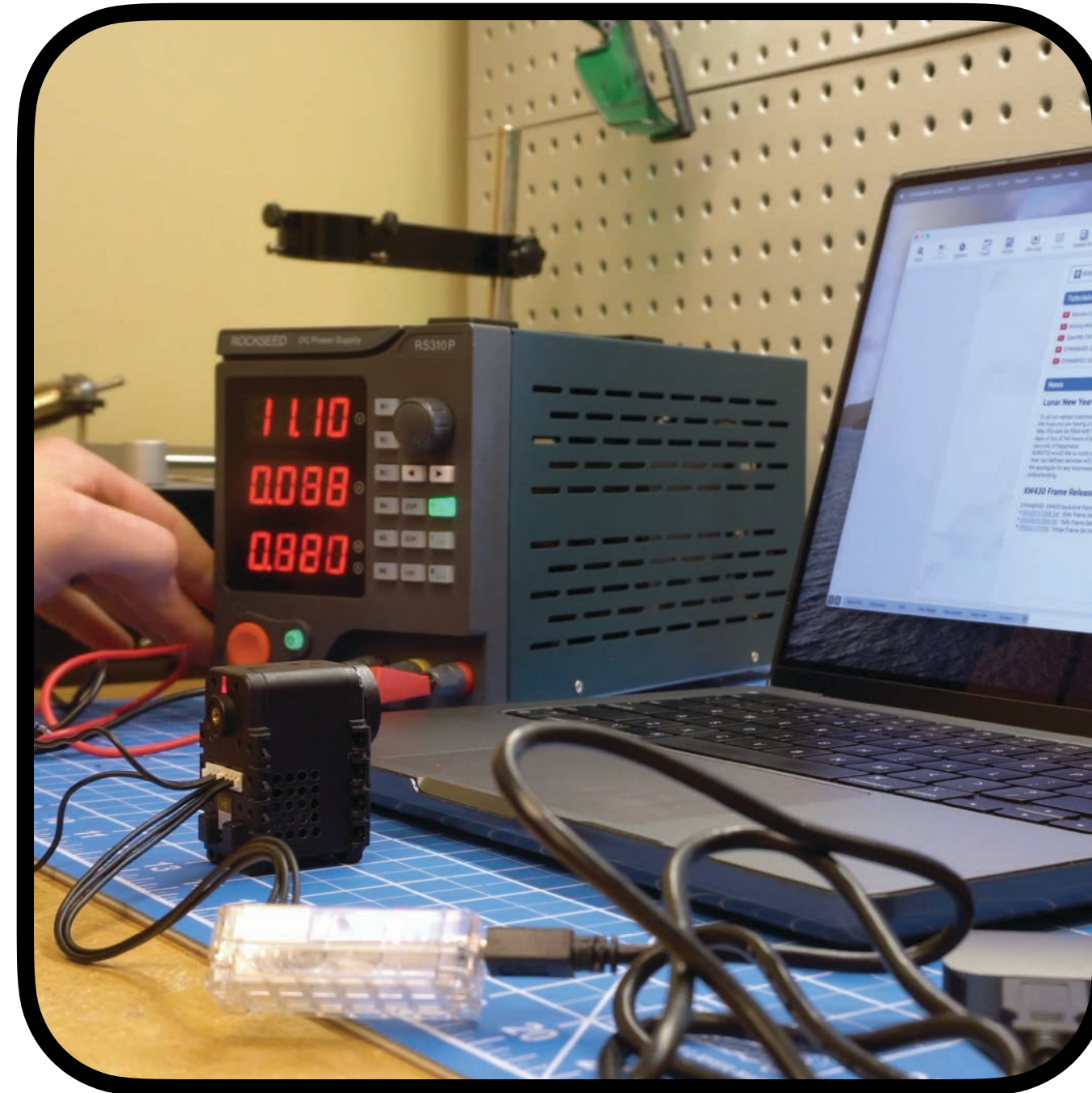
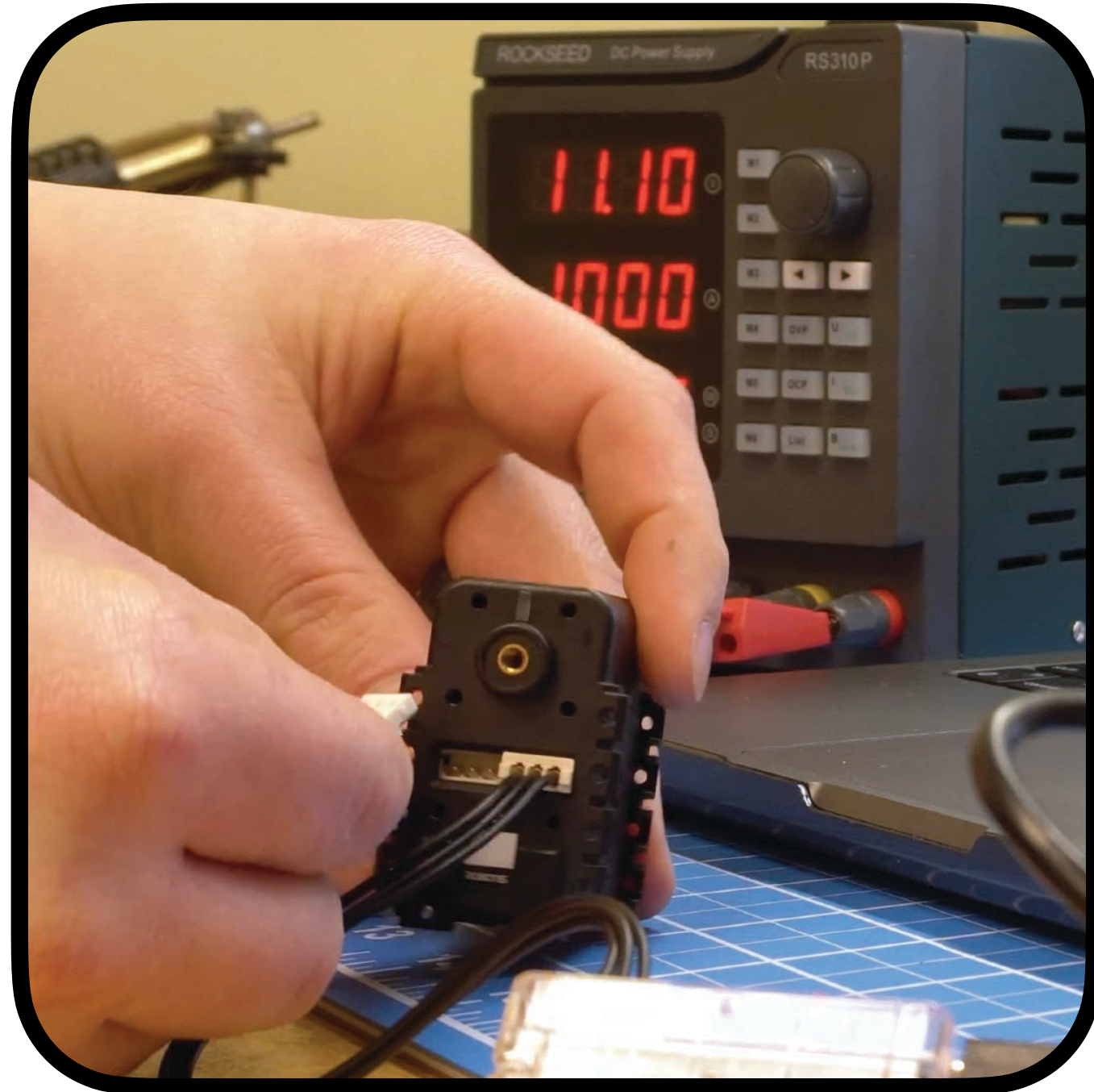
Optional: If printing your own hole templates, add 4 heat-set threaded inserts to the part.



Actuator Modification Process

Step #01:

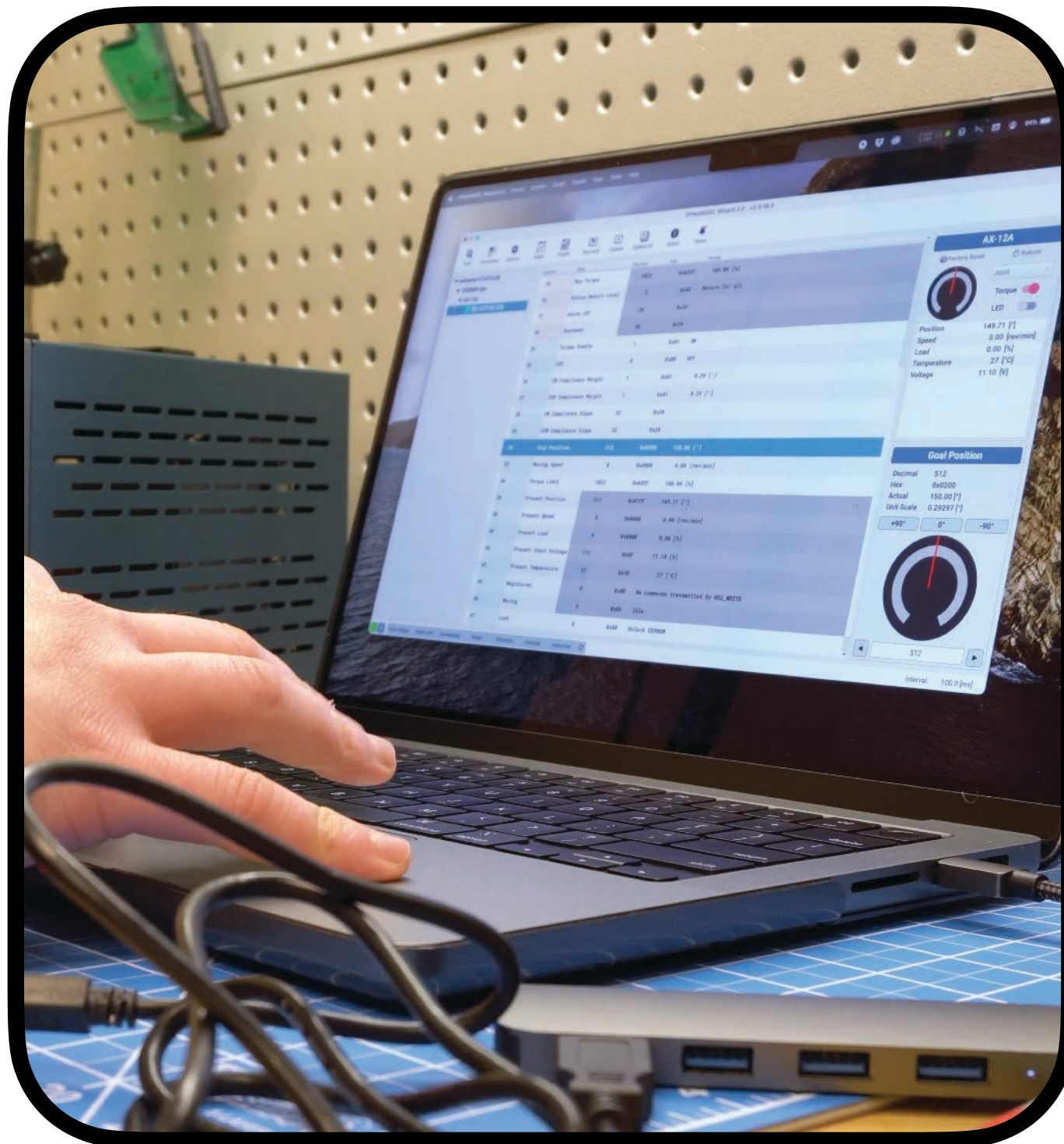
Connect the motor to a test setup and verify it functions normally.



- Connect the actuator to power and to the U2D2 connected to the computer.
- Use the DynamixelWizard2 application to find the actuator.
- Manipulate the actuator's goal position and verify that it operates properly.

Step #02:

Optional: Configure the actuator settings, verify, and disconnect from test setup.



- This can be a convenient time to configure the actuator for later use.
- The properties typically changed for TBAUi use are:
 - Set the ID to the appropriate joint ID (1 to 8)
 - Set the Baud Rate to 1 Megabit (0x01)
 - Set the Return Delay Time to 64 microseconds (0x20)
 - Set the Status Return Level to Return for Read (0x01)
 - Set the Alarm LED to Overheat only (0x04)
 - Set the Shutdown register to Overheat only (0x04)

Actuator Modification Process

Step #03:

Prepare the work surface, remove the actuator sticker, and clean the outside casing

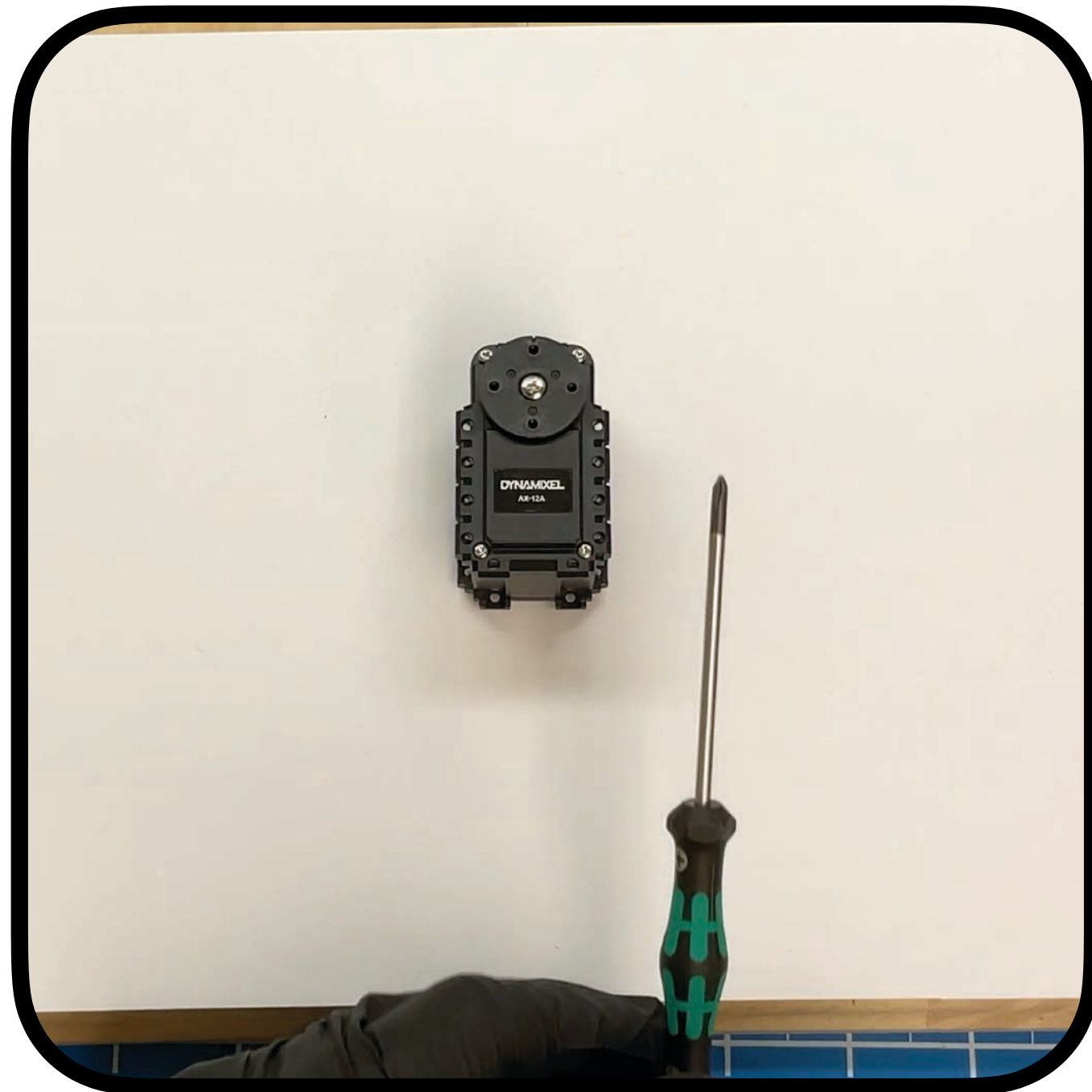


- Put on gloves.
- Cover workspace with paper or cloth for grease.
- Remove QC sticker from bottom of actuator using tweezers and clean with Isopropyl alcohol (IPA).
- Wipe all sides of motor with IPA to ensure drilling surfaces are clean.

Actuator Modification Process

Step #04:

Remove the center screw from the actuator horn

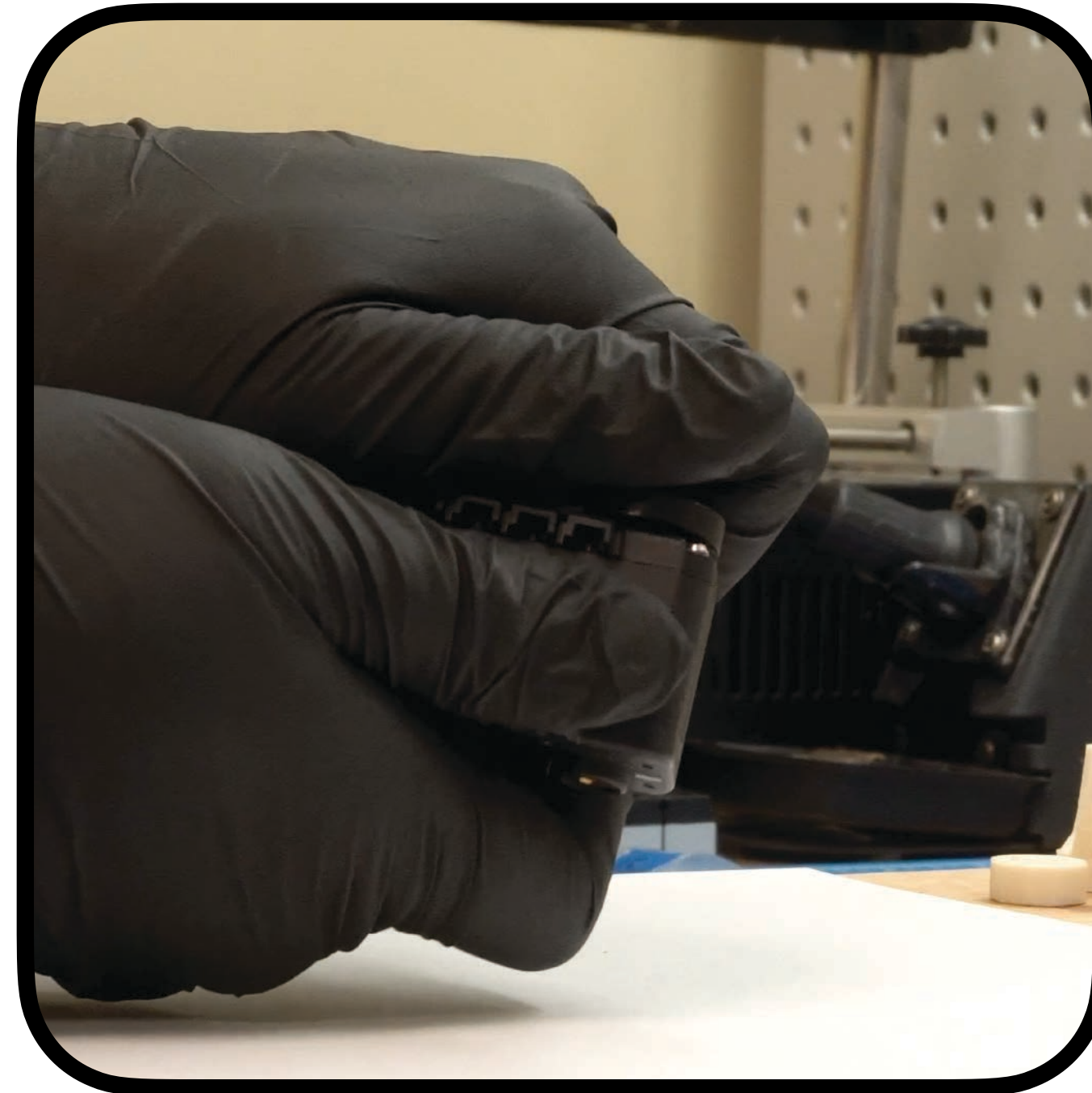


- Place the motor's back side (where wires connect) on the work surface.
- Ensure motor is in zero/home position using scored line.
- Remove center screw.
- Be careful not to turn too much from home position.

Actuator Modification Process

Step #05:

Remove the actuator's horn

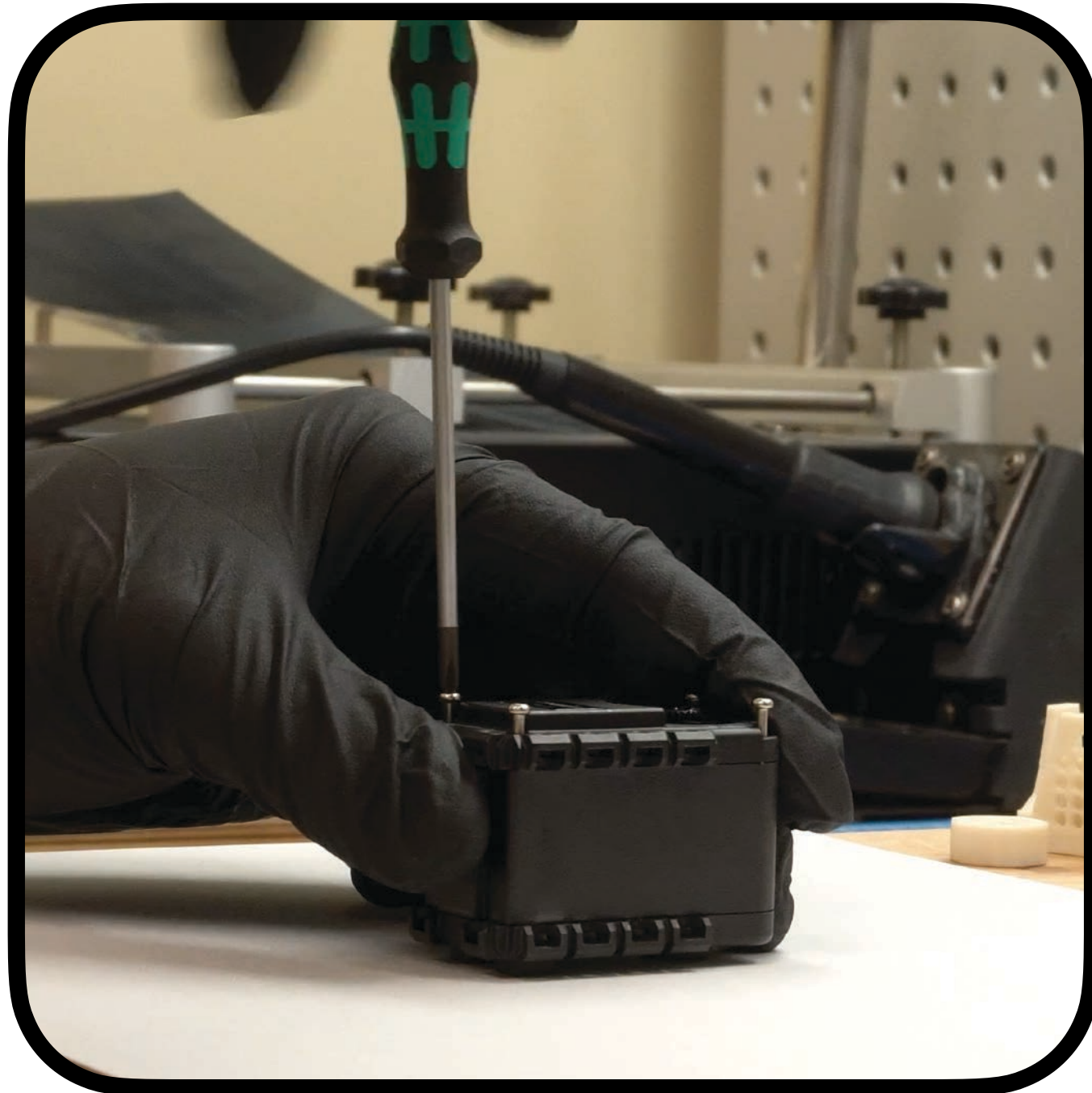


- Gently lift the horn (round disc that rotates) away from the serrated axle.
 - This may take some slow prying.
 - A thin rigid plastic (or metal) tool can be used to help start this process.
- Once removed, place the horn in a plastic bag for non-greasy parts.

Actuator Modification Process

Step #06:

Open the front casing of the actuator to expose the gearbox.



- **WARNING:** the front section of the motor contains gearbox and grease.
- Remove the four long screws that hold the full motor assembly together.
 - Note: these are only threaded at the far end.
- Place the four long screws into the plastic bag for non-greasy parts.
- Carefully **remove the front case** of the actuator, exposing the gear box.
- Set the front case's exterior face onto the work surface so that the interior is facing upward.
- Use tweezers to re-seat any gears that have moved from their original locations.

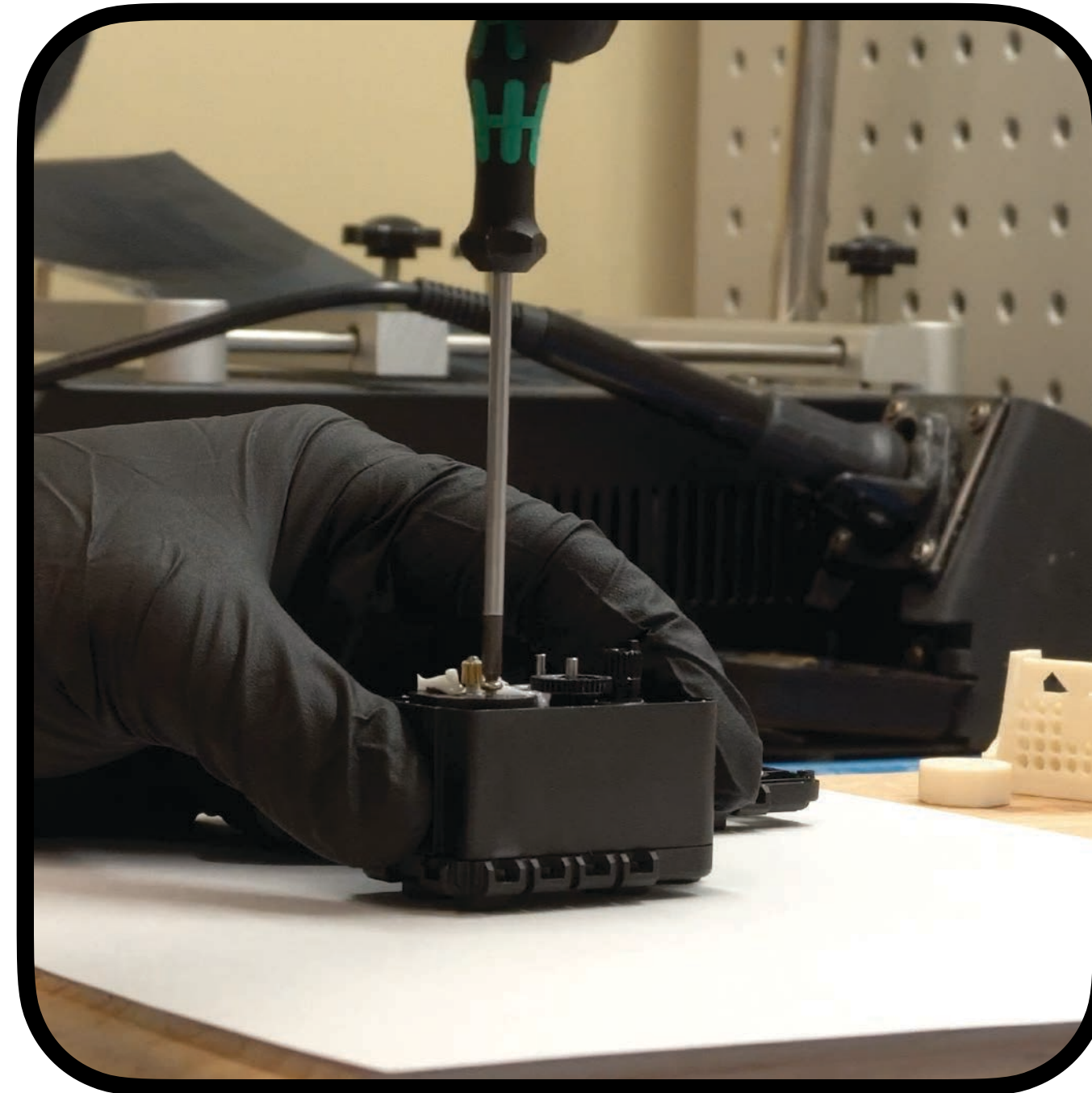
Removing the front case:

- Grasp the middle section of the actuator with one hand and hold it in place so that the actuator does not lift from the work surface.
- Use one finger to apply downward holding force on the serrated axle that the horn was attached to.
- Use your free hand to grasp the actuator's top casing around the edges and lift it directly upward away from the actuator.

Actuator Modification Process

Step #07:

Remove the two screws attached to the DC motor.

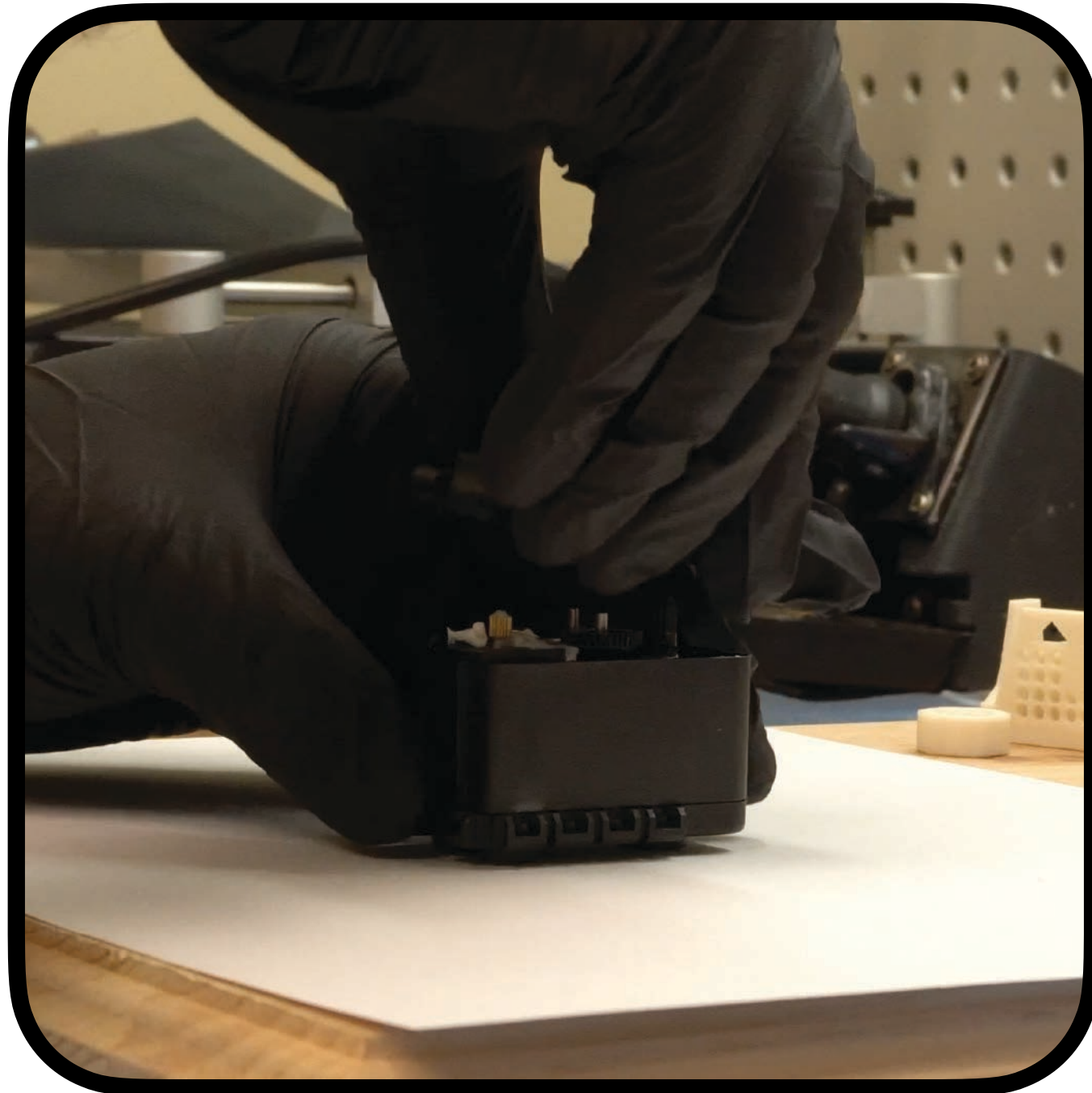


- Note that Gear #1 (the gear closest to the DC motor output shaft) and associated axle may be affixed to either the inside of the front casing or to the middle casing. Either location is acceptable at this point in the process.
- Remove the two short screws that hold the DC motor in place (located towards the bottom of the gear box).
- Place the two screws into a plastic bag for greasy parts, seal it, and set aside.

Actuator Modification Process

Step #08:

Replace the actuator's front casing.

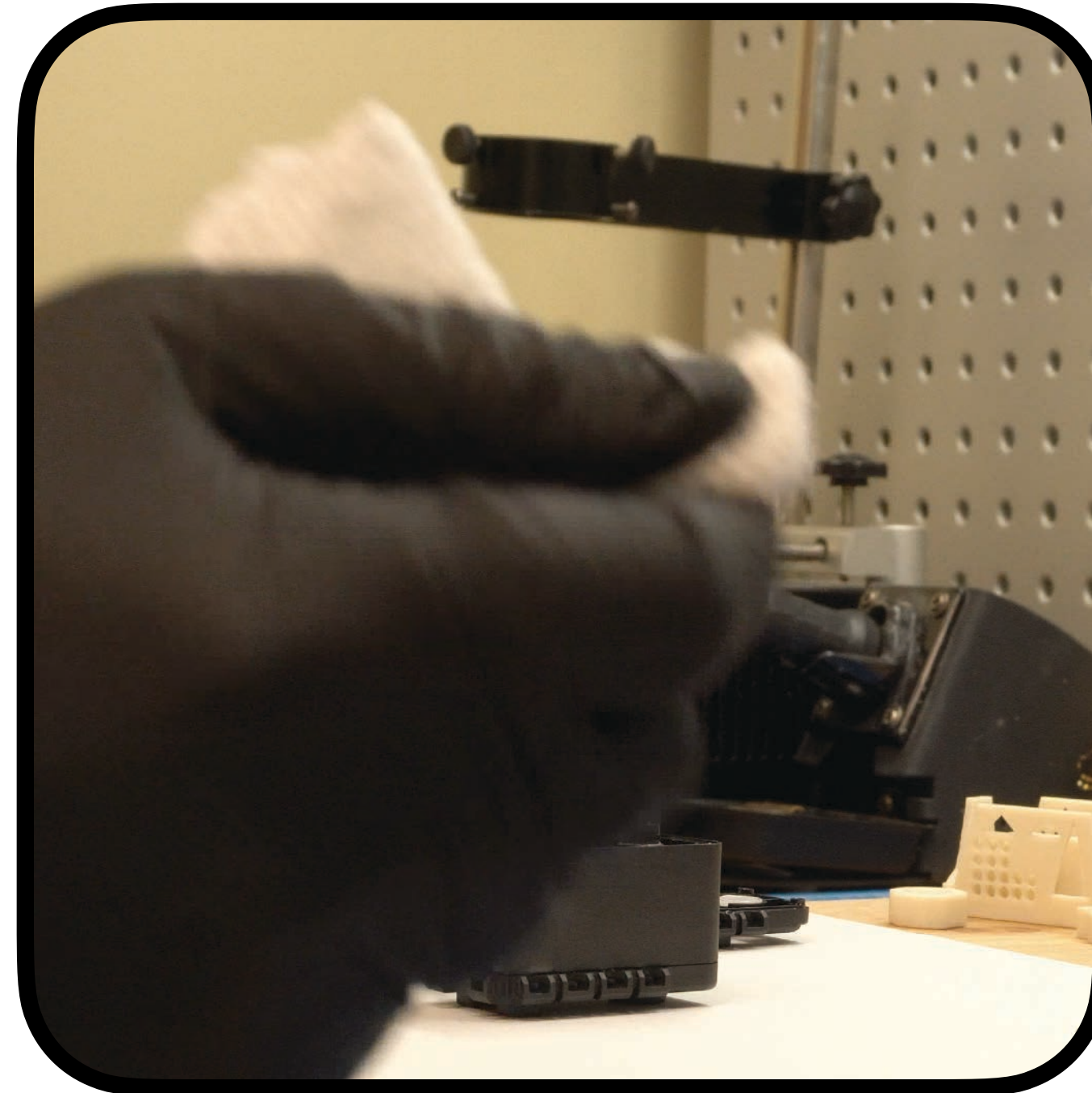
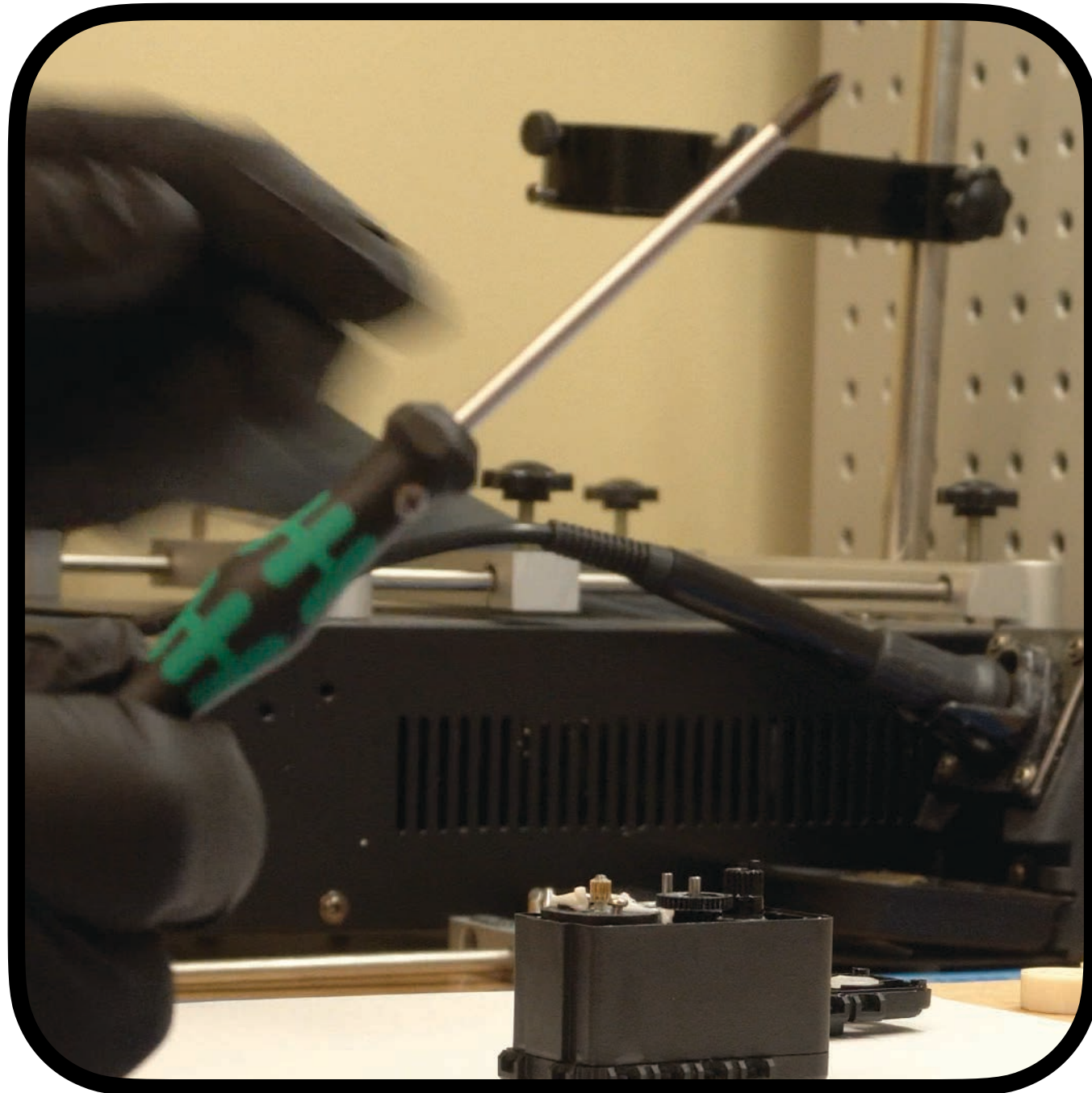


- Carefully put the front casing back onto the actuator by first holding it above the actuator, aligning it to the actuator, and slowly lowering it into position.
 - If Gear #1 is on the front casing be extra careful that it properly aligns as the front casing is placed back onto the actuator.
- Once the front casing is on the actuator, apply force to its four corners until it snaps fully into position.
 - The seam between it and the middle section of the actuator looks the same as it did prior to removal.
- If Gear #1 or any other gear has fallen out of place refer to the Robotis AX-12A Gear Replacement video to reposition them:
<https://www.youtube.com/watch?v=W1sOavdmlus>

Actuator Modification Process

Step #09:

Clean tools and flip the actuator over.



- Clean your tools to ensure they are free from grease before working in non-greasy sections of the actuator.
- Flip the actuator over so that its front exterior casing is set on the work surface.
- **Remember:** There are no screws holding the pieces of the actuator together, so use caution when moving and manipulating it.

Actuator Modification Process

Step #10:

Remove the actuator's back casing.



- Use one hand to gently hold the middle section of the actuator so that it does not lift from the work surface.
- Use your free hand to grasp the edges of the back casing and lift it away from the actuator.
- The back casing is easier to remove than the front, and the section it covers does not contain gears or grease.
- Once removed you should see the actuator's electronics and DC motor.
- Place the back casing in the grease-free plastic bag.

Actuator Modification Process

Step #11:

Remove the electronics and DC motor from the actuator.



- Remove the single screw that holds the PCB to the actuator.
 - The screw is located towards the upper left section of the actuator.
- Place the screw in non-greasy part plastic bag.
- **Remove the PCB and connected DC motor assembly** from the actuator casing.
- Place the PCB and DC motor assembly in an electrostatic discharge bag and set it aside.

Removing the PCB and DC motor assembly:

- Using your fingers, gently pull upward on the edges of the DC motor. If necessary, carefully grasp the DC motor's electrical leads to help pull it away.
- If the PCB and DC motor are not easily released, use small tweezers or pliers to grab one of the edges of the 3-pin electrical connectors and pull it away from the actuator casing.

Actuator Modification Process

Step #12:

Inspect the interior back section of the actuator and clean away excess grease.

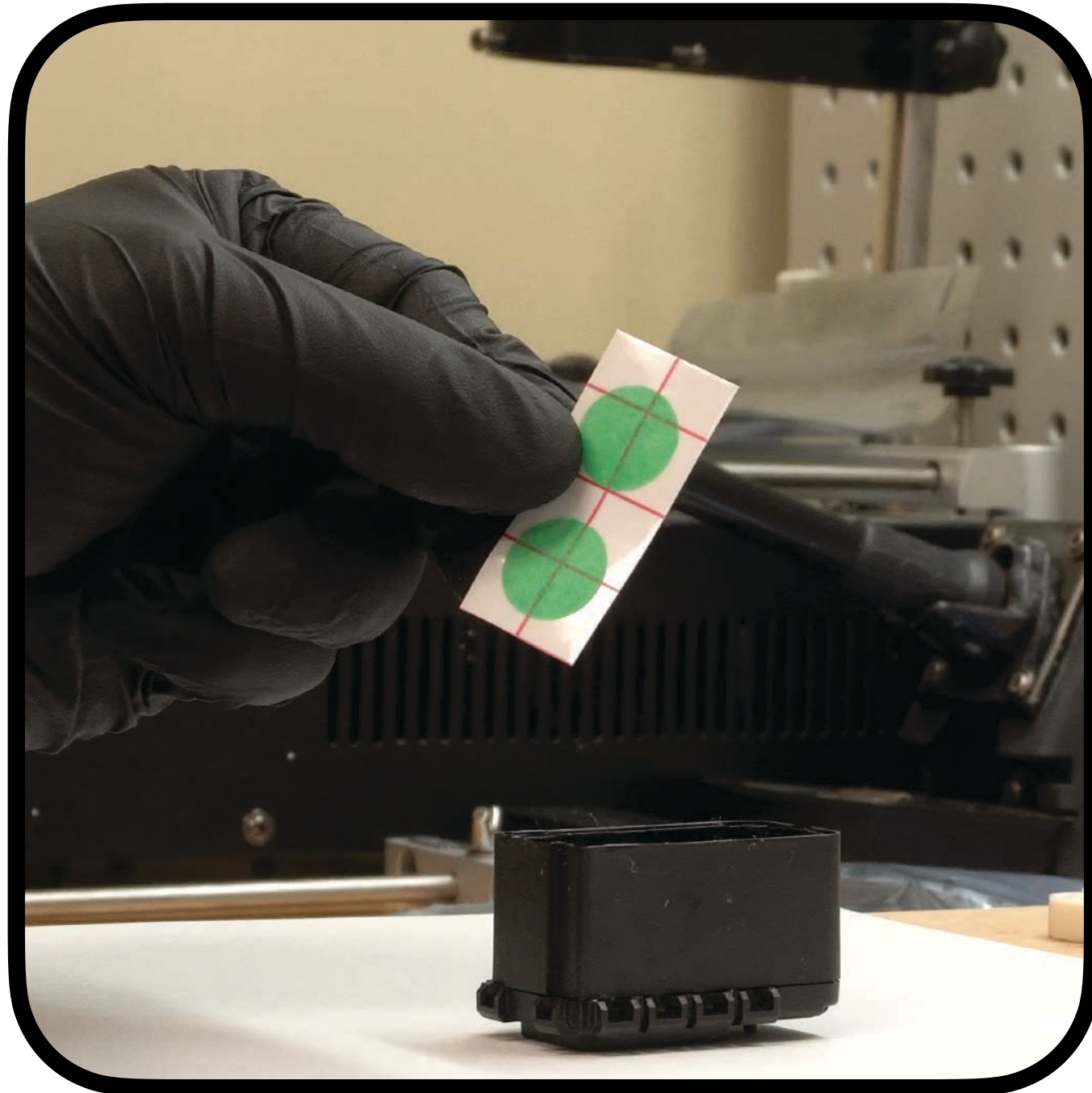


- Examine the area around the potentiometer axle and identify any grease that has passed through from the front gearbox.
- Remove any grease or debris by using a small piece of microfiber cloth to wipe the area clean.
- Examine the opening for the DC motor's axle and identify any grease that has passed through from the front gearbox.
- Remove any grease or debris by using tweezers to hold a small piece of microfiber cloth and wipe the area clean.

Actuator Modification Process

Step #13:

Apply masking tape around the potentiometer axle.



- Use masking tape to seal the area where the potentiometer axle enters into the electronics area from the front gearbox.
- Begin by placing the center of the tape on the protruding axle and then use your fingers to lightly adhere the edges of the tape to the casing that surrounds the axle.
- Use blunt tweezers ensure a seal all the way around the axle.
- Small wrinkles in the tape are acceptable.

Actuator Modification Process

Step #14:

Seal the opening for the DC motor with masking tape.

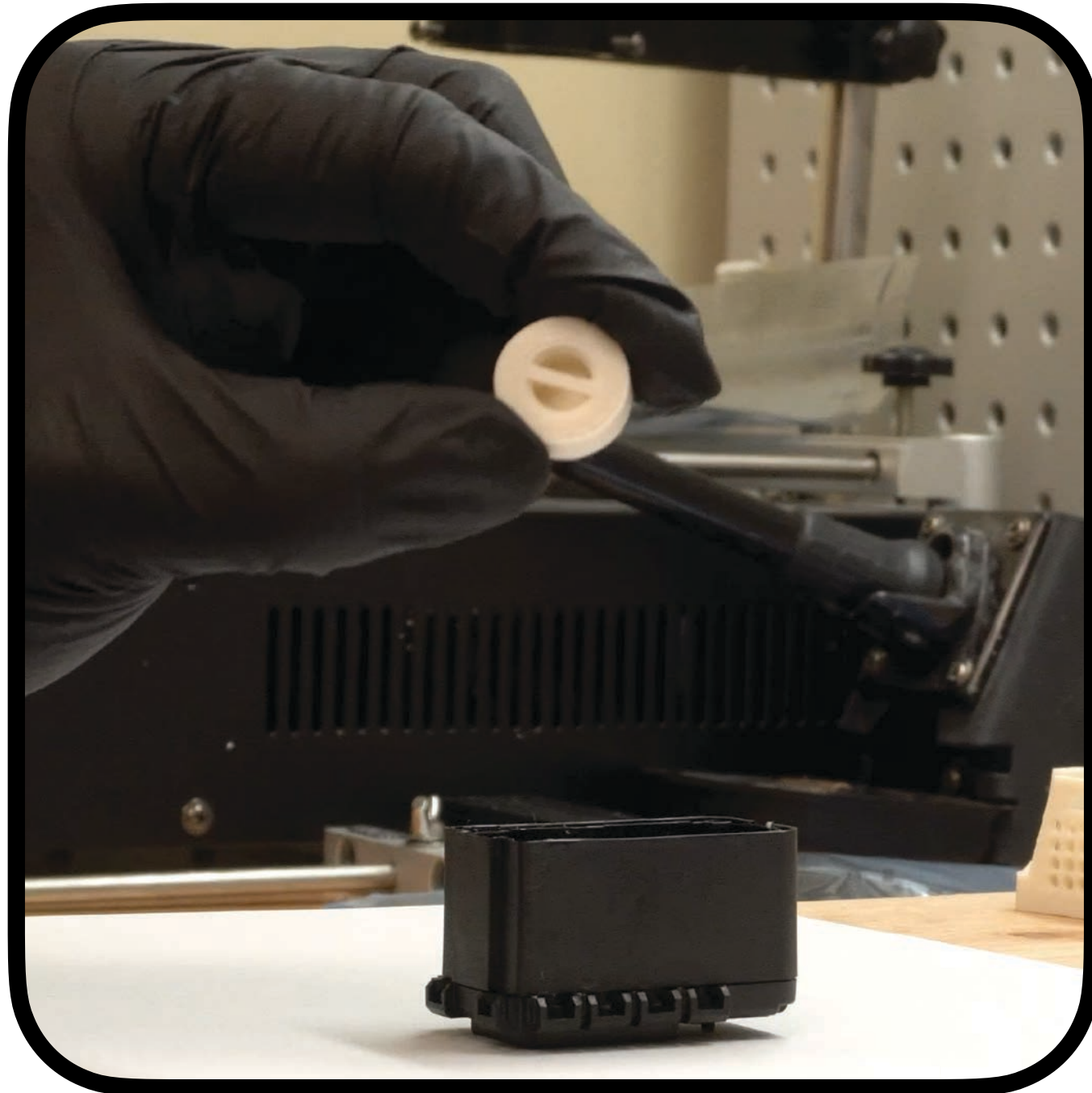


- Use tweezers to place a piece of masking tape over the opening for the DC motor, sealing the back section from the front gearbox.
- Ensure the tape is smoothly adhered and fully seals the holes that connect back section to the front gearbox.

Actuator Modification Process

Step #15:

Insert the 3D-printed motor plug into the casing.

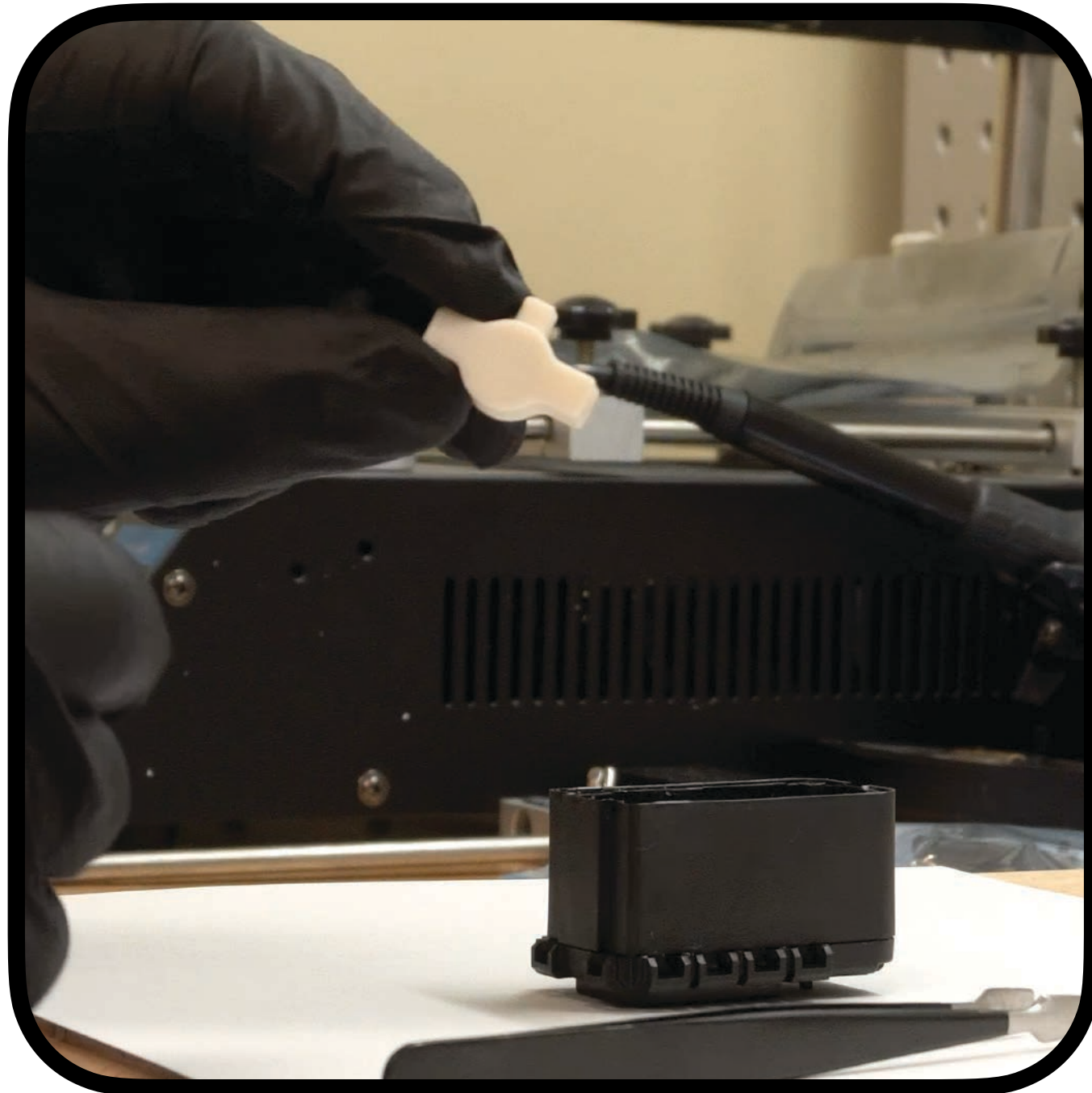


- Using tweezers and your fingers, align and insert the 3D-printed motor cap into the area that previously held the DC motor.
 - The motor cap should fit snugly into the enclosure.
- Push the cap all the way down so that it is in contact with the masking tape seal applied previously.

Actuator Modification Process

Step #16:

Insert the spanning cap over the potentiometer axle.

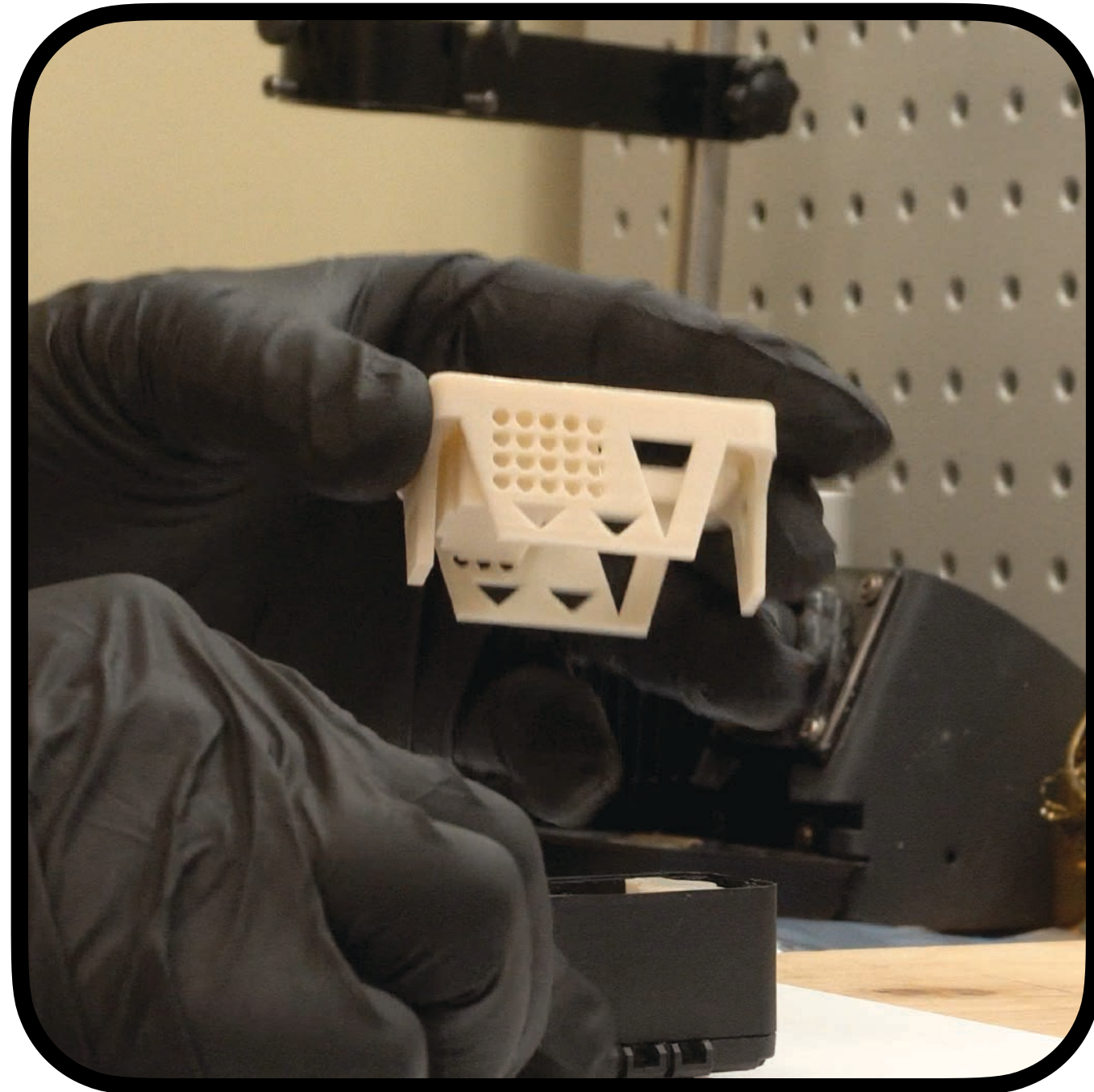


- Align the spanning cap to the actuator's casing and lower it into position over the masking tape sealing the potentiometer axle.
- There are tabs on the inside of the actuator casing that will hold the spanning cap snugly in place.

Actuator Modification Process

Step #17:

Align and attach the 3D-printed hole template to the actuator casing.

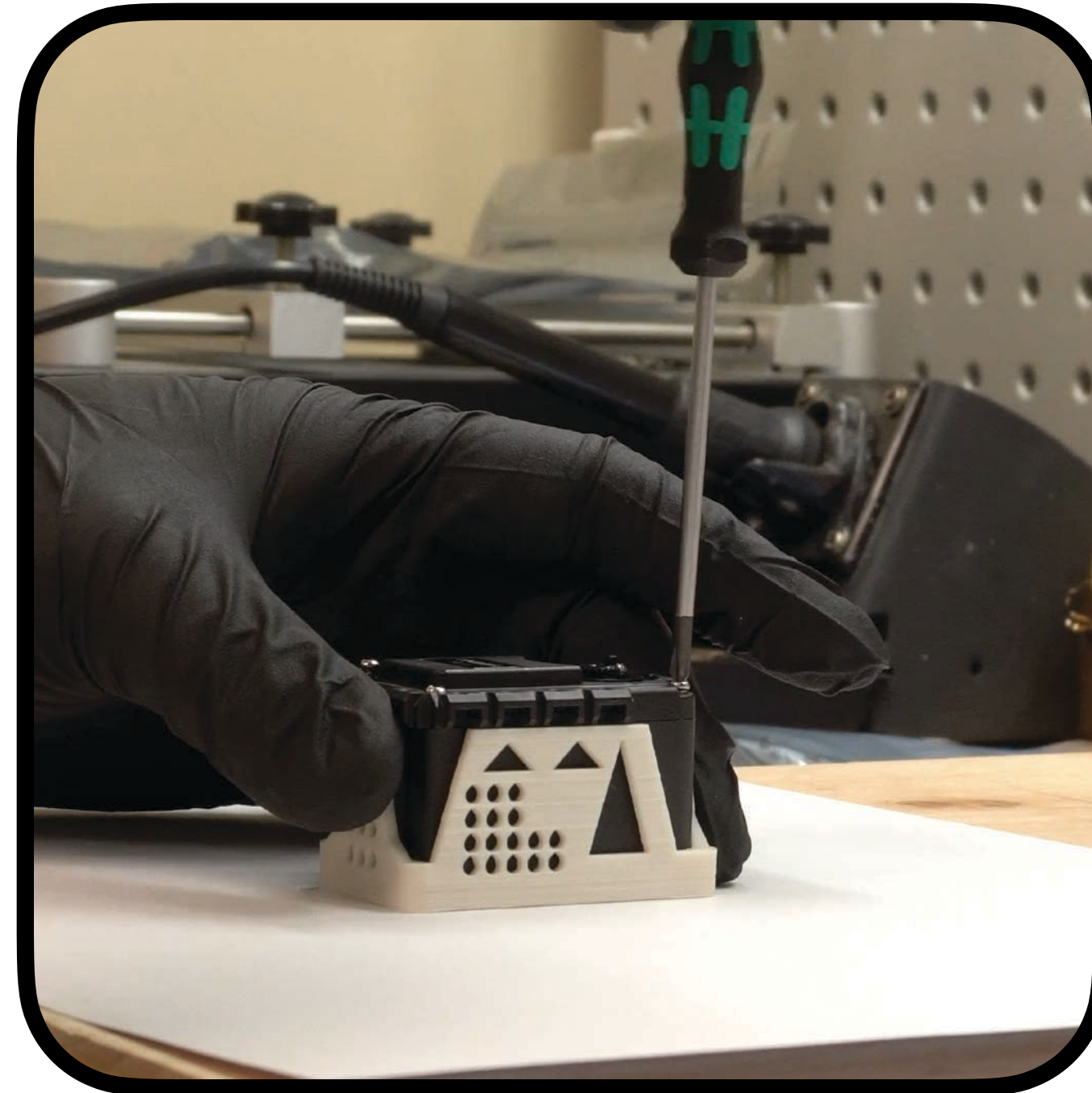


- Orient the 3D-printed hole template part over the actuator and lower it gently and evenly onto the actuator.
- Perform this process carefully and ensure the actuator's casing is properly aligning and fitting with the hole template part as it is lowered.
- Using your hands apply moderate force to the hole template part until it snaps fully into place.
- **WARNING:** If you experience difficulty achieving a proper fit with moderate force, you may need to use a utility knife or small file to remove material from the 3D-printed hole template to allow a good fit.

Actuator Modification Process

Step #18:

Secure the hole template to the actuator using 4 M2 x 30mm screws.



- Orient the actuator so that the front is facing upwards.
- Insert a 30mm M2 machine screw into each of the four corners of the front of the actuator such that they pass through the front and middle casing and connect with the 3D-printed hole template part.
- Partially tighten each of the four screws by turning it a few (i.e., three) times.
- Since the fully tightened screws will protrude beyond the back of the hole template part, hold the assembly in one hand and fully tighten each of the four screws.
- **Note:** Ensure all screws protrude a similar amount and that the hole template is properly aligned.

Actuator Modification Process

Step #19:

Safety reminder

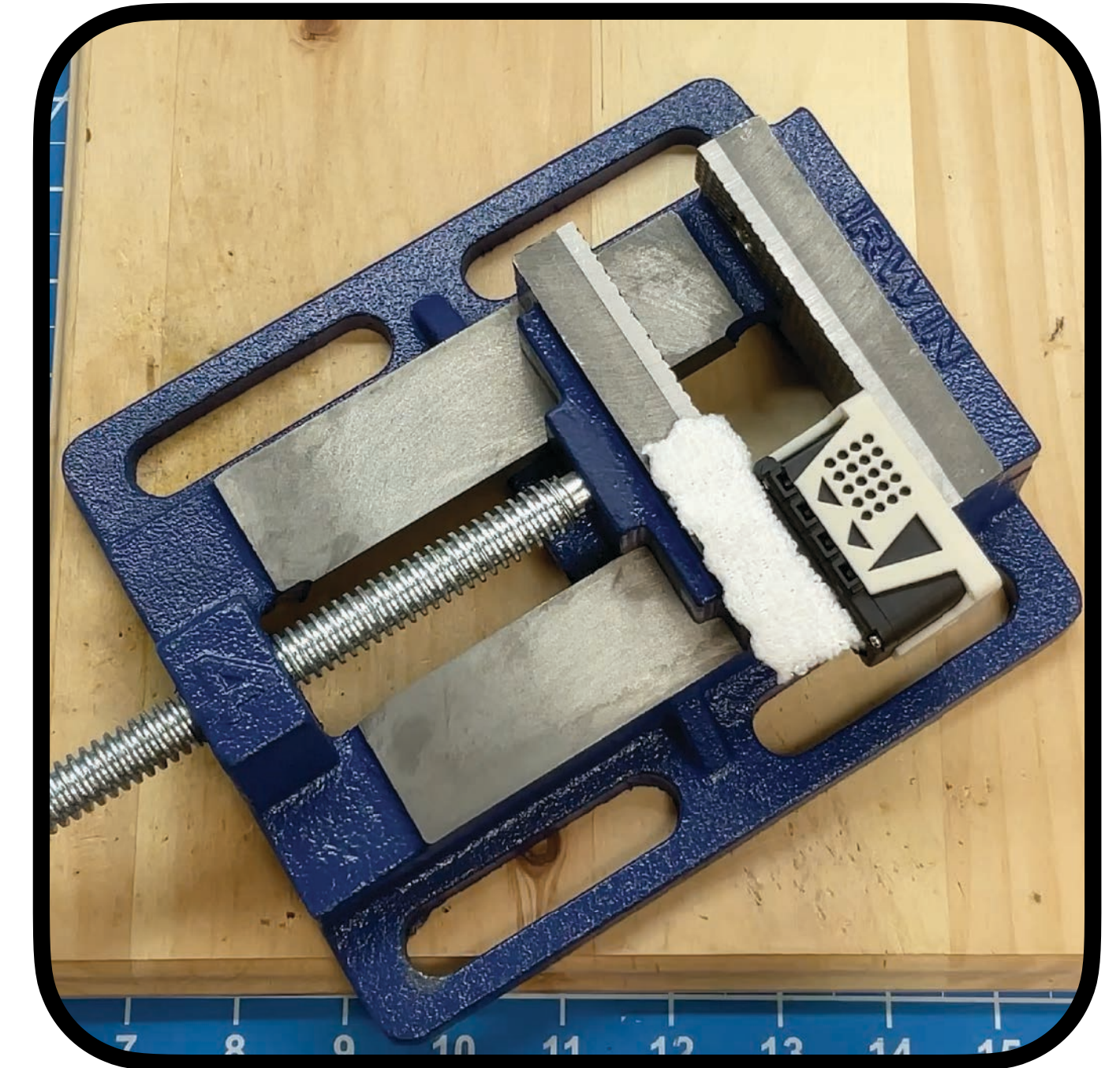


- Before beginning the drilling phase, ensure that everyone in the area is in compliance with all relevant safety regulations.
- Safety glasses must be worn while drilling.
- A respirator with at least an N95 filter can be helpful in protecting against any airborne particles.
- Always follow local safety rules.

Actuator Modification Process

Step #20:

Prepare the drill and position the actuator into a vise or clamp for hole drilling.

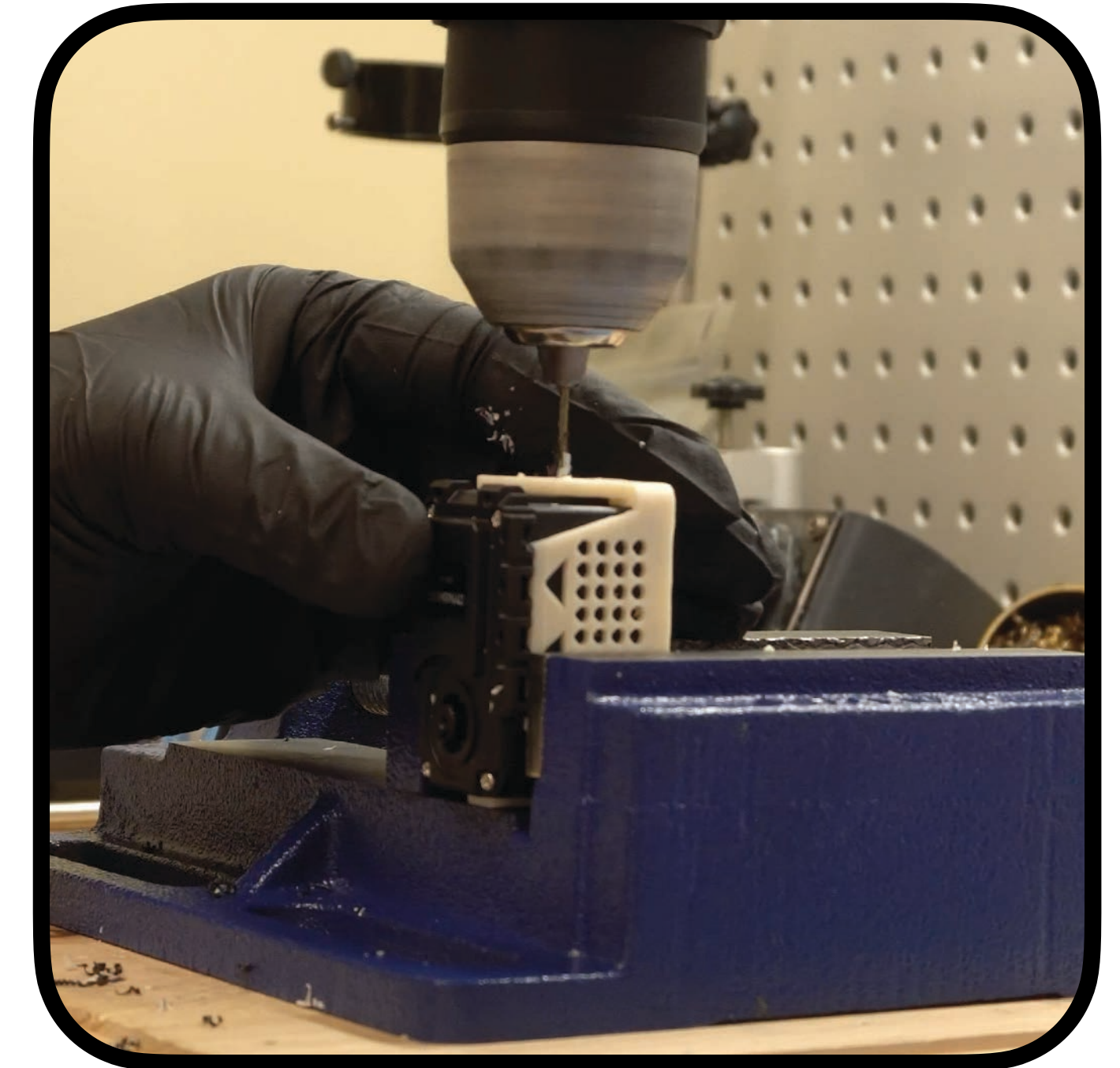
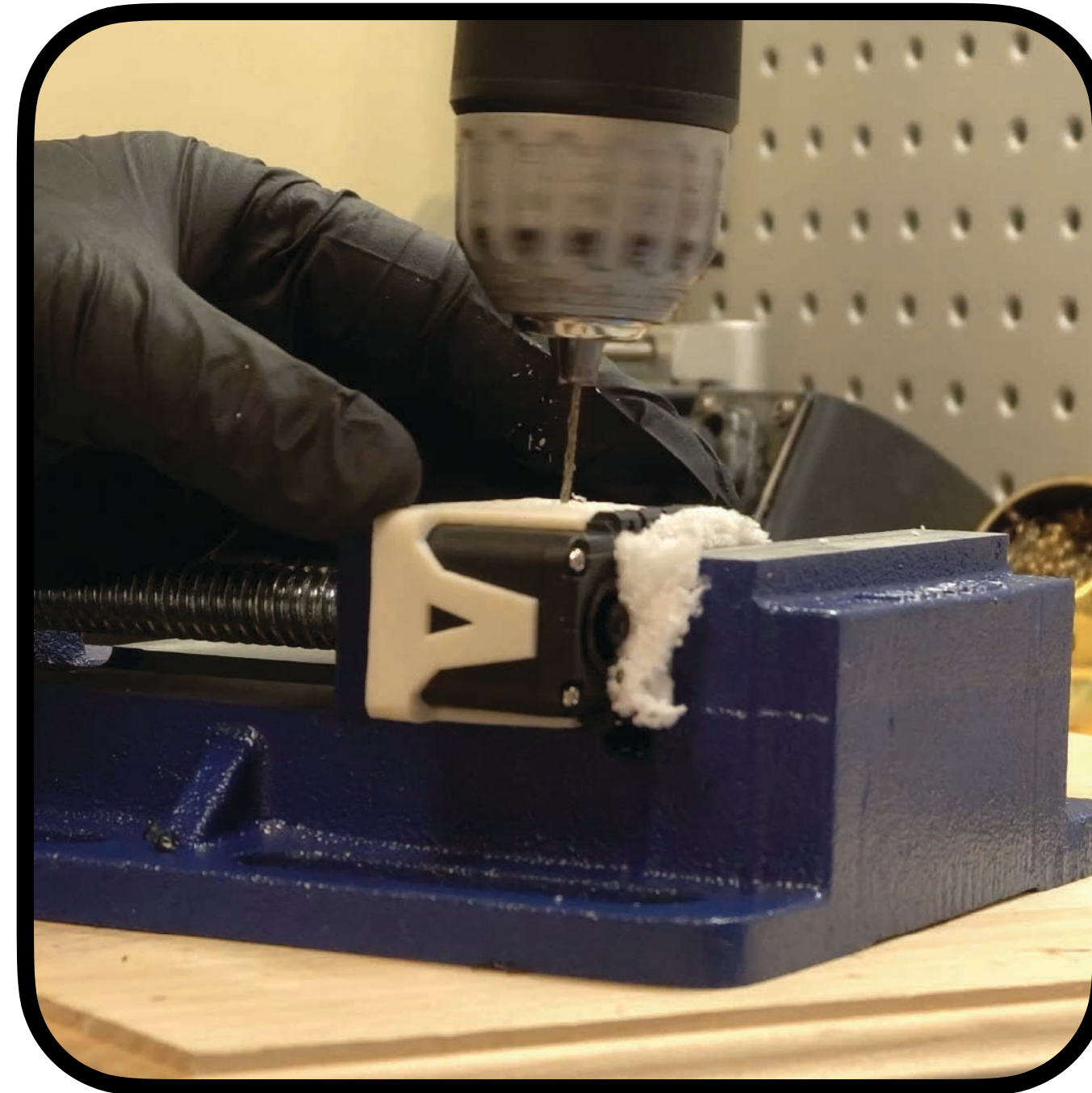
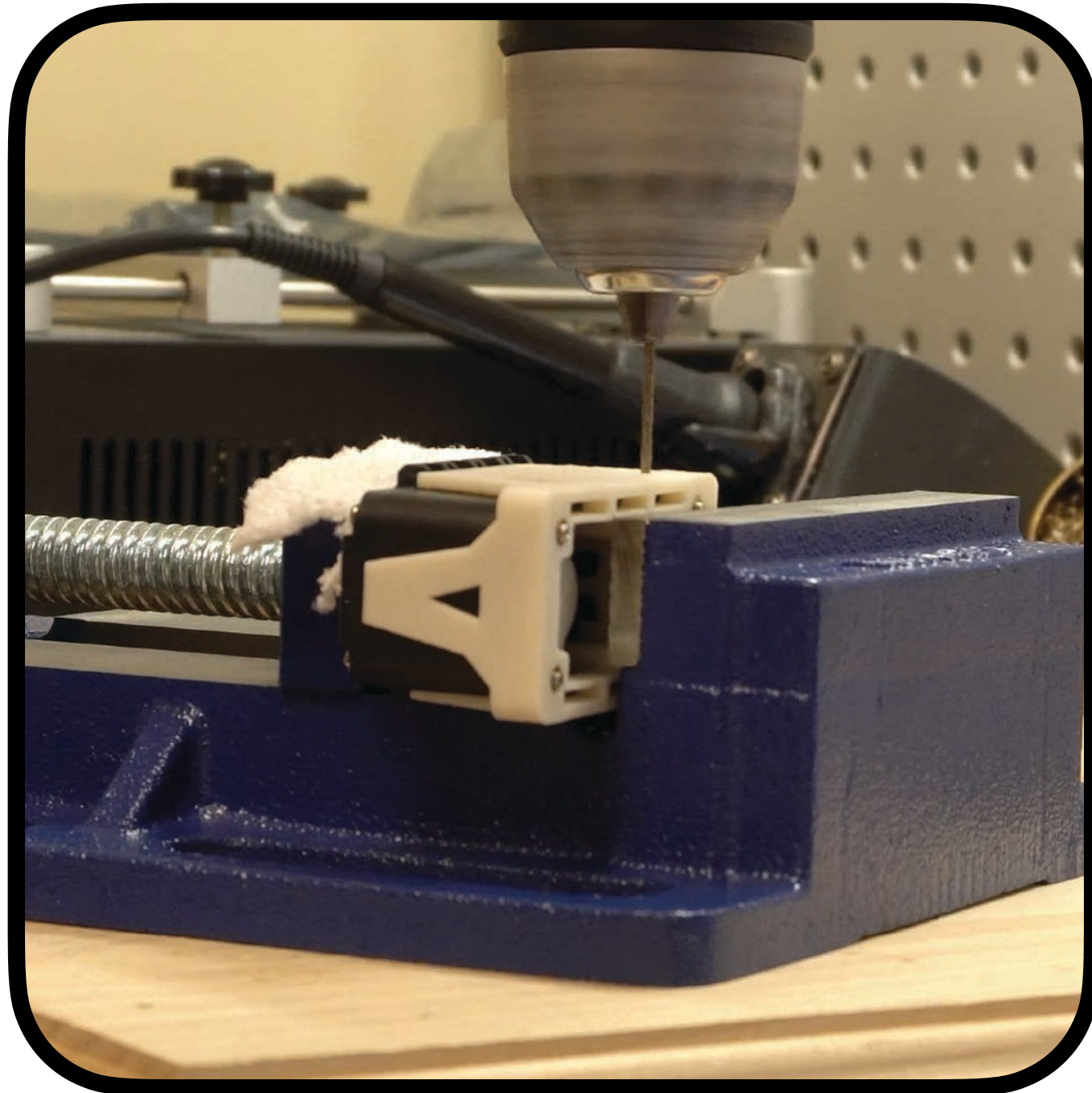


- Begin by inserting a 1.5mm bit into your drill.
 - **NOTE:** If you are using a drill press or CNC you may be able to skip drilling 1.5mm pilot holes and instead move directly to drilling the 2.5mm holes.
- Orient the actuator so that one side of the hole template is facing upward and secure it to your work surface using a vise or clamp.
 - **NOTE:** Use a small piece of microfiber cloth to protect the actuator from scratches while in the vise.
 - **WARNING:** Be sure you have secured your workpiece well as the drill is capable of pulling it with great force.

Actuator Modification Process

Step #21:

Drill pilot holes using the 1.5mm drill bit in each of the hole template holes.

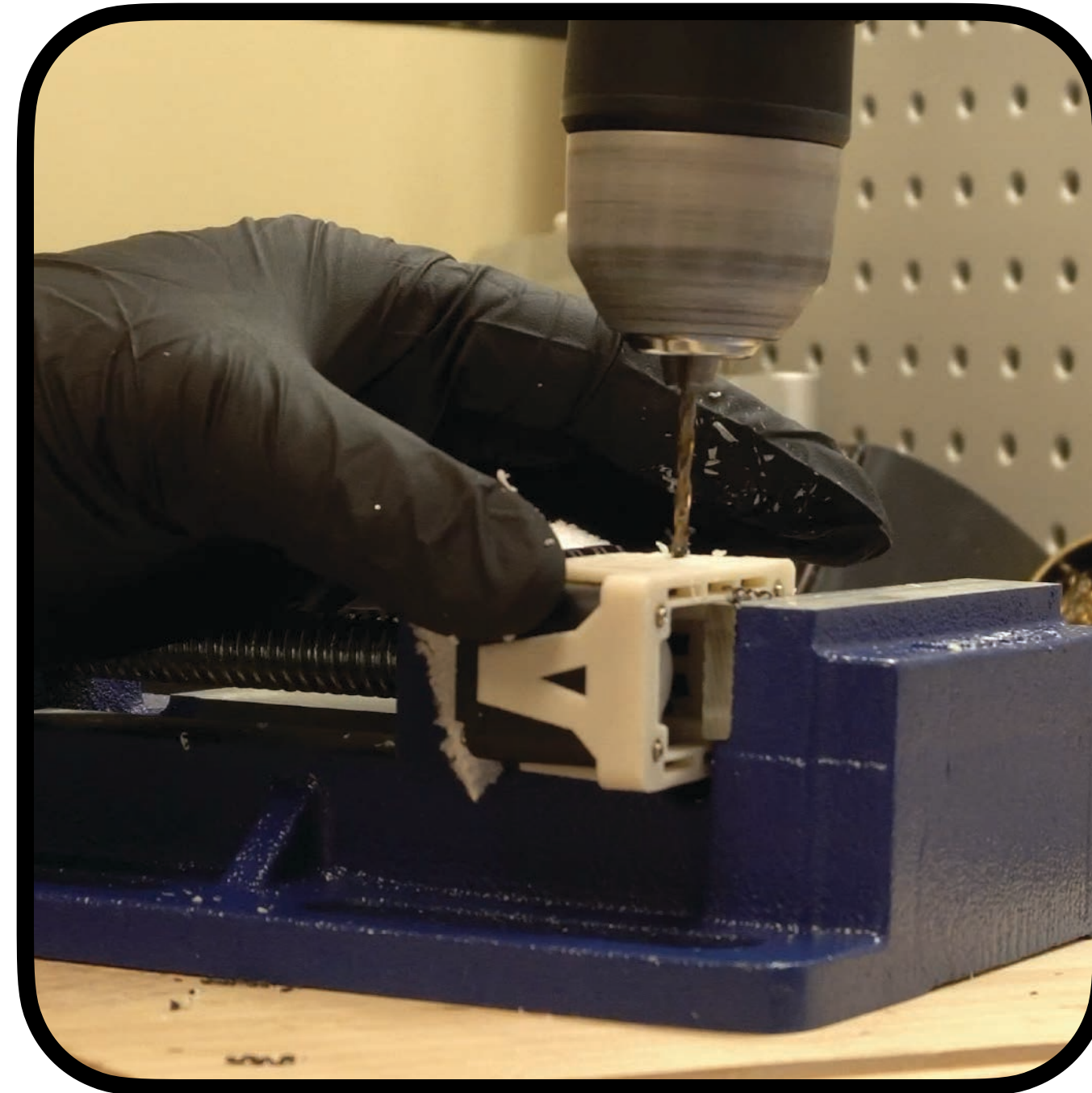


- For each hole on the upward facing side of the template, drill a 1.5mm pilot hole through the black ABS plastic casing.
- The casing is fairly thin (~2mm) and does not take long to drill through.
- Once the drill passes through the black ABS actuator casing it will enter into the support block of the 3D printed part.
 - **NOTE:** You may hear plastic cracking as the bit enters into the support block. This is likely from the 3D-printed part's layers separating and is acceptable.
- Regularly clear ejected plastic from the workpiece using a vacuum or compressed air.
- Use a light to visually verify that each pilot hole has been properly drilled before moving on.

Actuator Modification Process

Step #22:

Continue by drilling 2.5mm holes in each hole in the hole template.

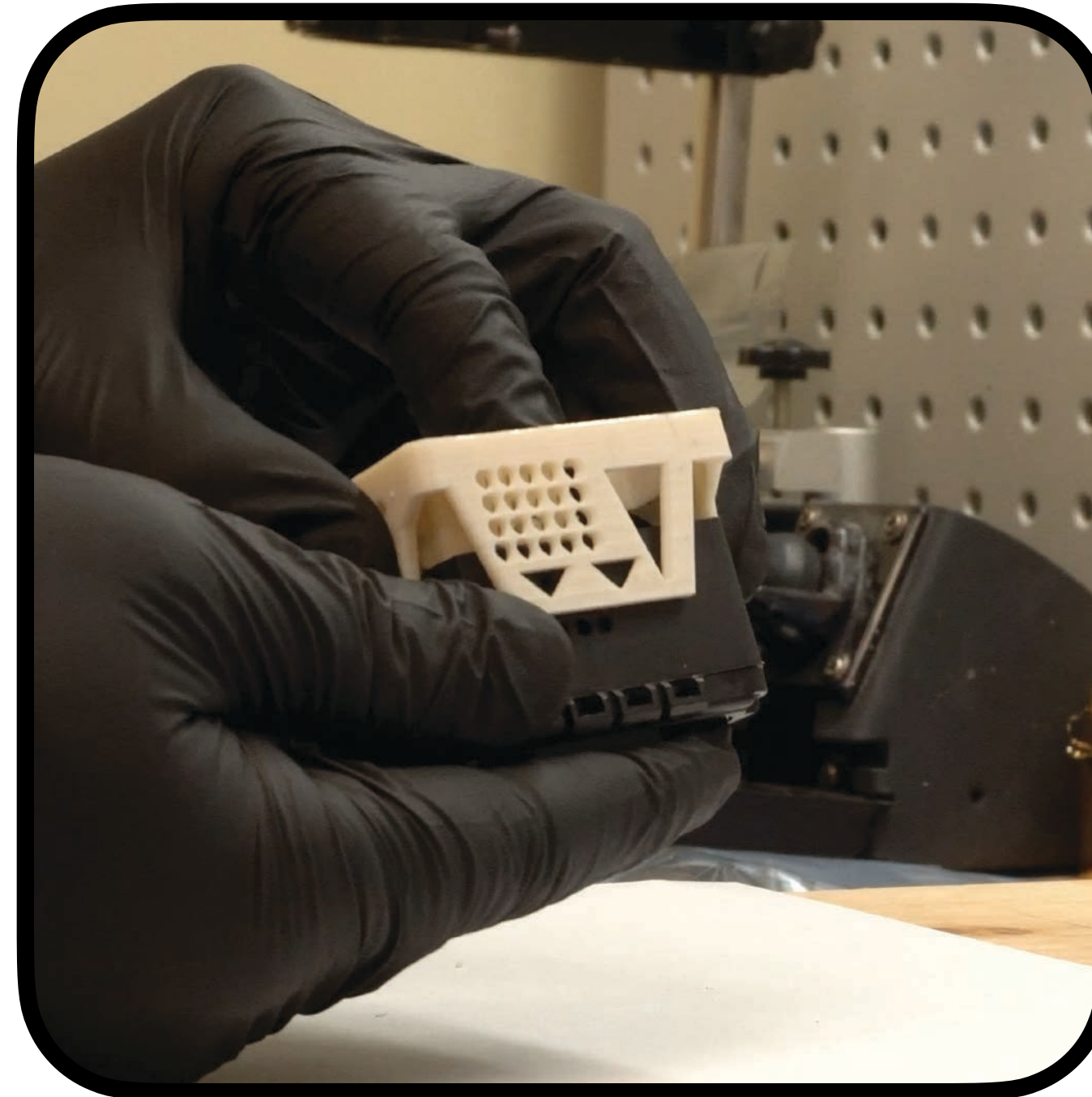


- Once all 1.5mm pilot holes have been drilled, switch to a 2.5mm drill bit.
- Repeat the drilling process for all holes using the 2.5mm drill bit.
- Use a vacuum and/or compressed air to clean all drilled plastic from the workpiece and your work surface.
- Verify that all holes appear complete prior to removing the 3D-printed hole template.

Actuator Modification Process

Step #23:

Remove the screws fastening the hole template to the actuator and remove the hole template.

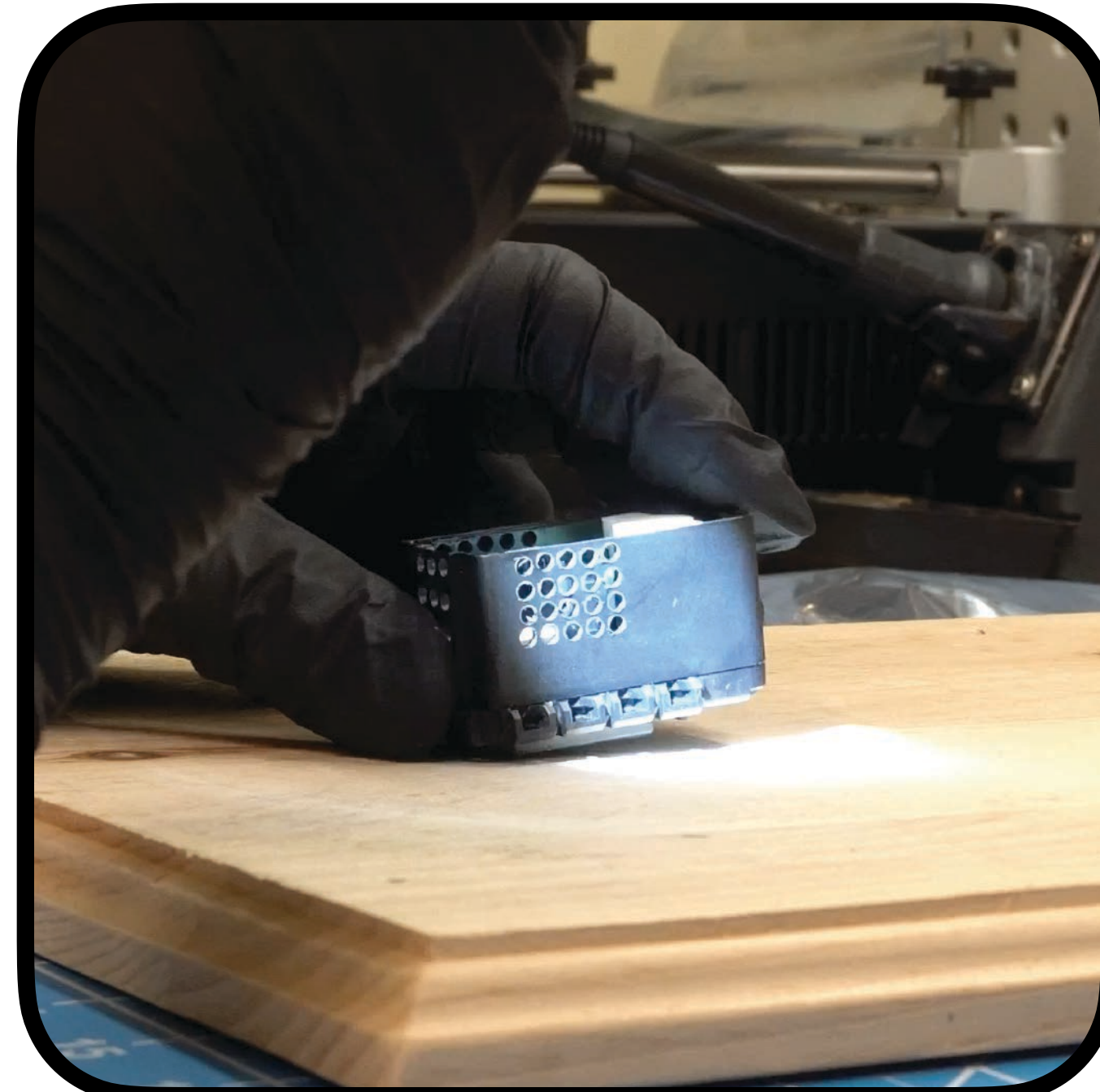


- Remove the four 30mm machine screws from the actuator and set them aside for use with other actuators.
 - Remember to hold the front casing onto the actuator once the screws are removed.
- Remove the 3D-printed hole template part from the actuator, but be sure the 3D-printed spanning cover and the front actuator casing stay attached to actuator.
 - This process may require moderate hand force and should be executed carefully and slowly .
- The 3D-printed hole template part can now be disposed of or reused if in a good condition.

Actuator Modification Process

Step #24:

Inspect and clean the edges of each of the drilled holes.



- Keeping the 3D-printed spanning cap and 3D-printed motor cap in place, use compressed air to clean out any debris from the actuator enclosure and from the drilled holes.
- Use a light visually inspect the drilled holes.
- Remove any remaining plastic fragments from the drilled holes using tweezers or a small file.
- If any hole is not fully drilled it should be corrected before progressing further.

Actuator Modification Process

Step #25:

Remove the spanning cap and motor plug and clean any remaining debris.

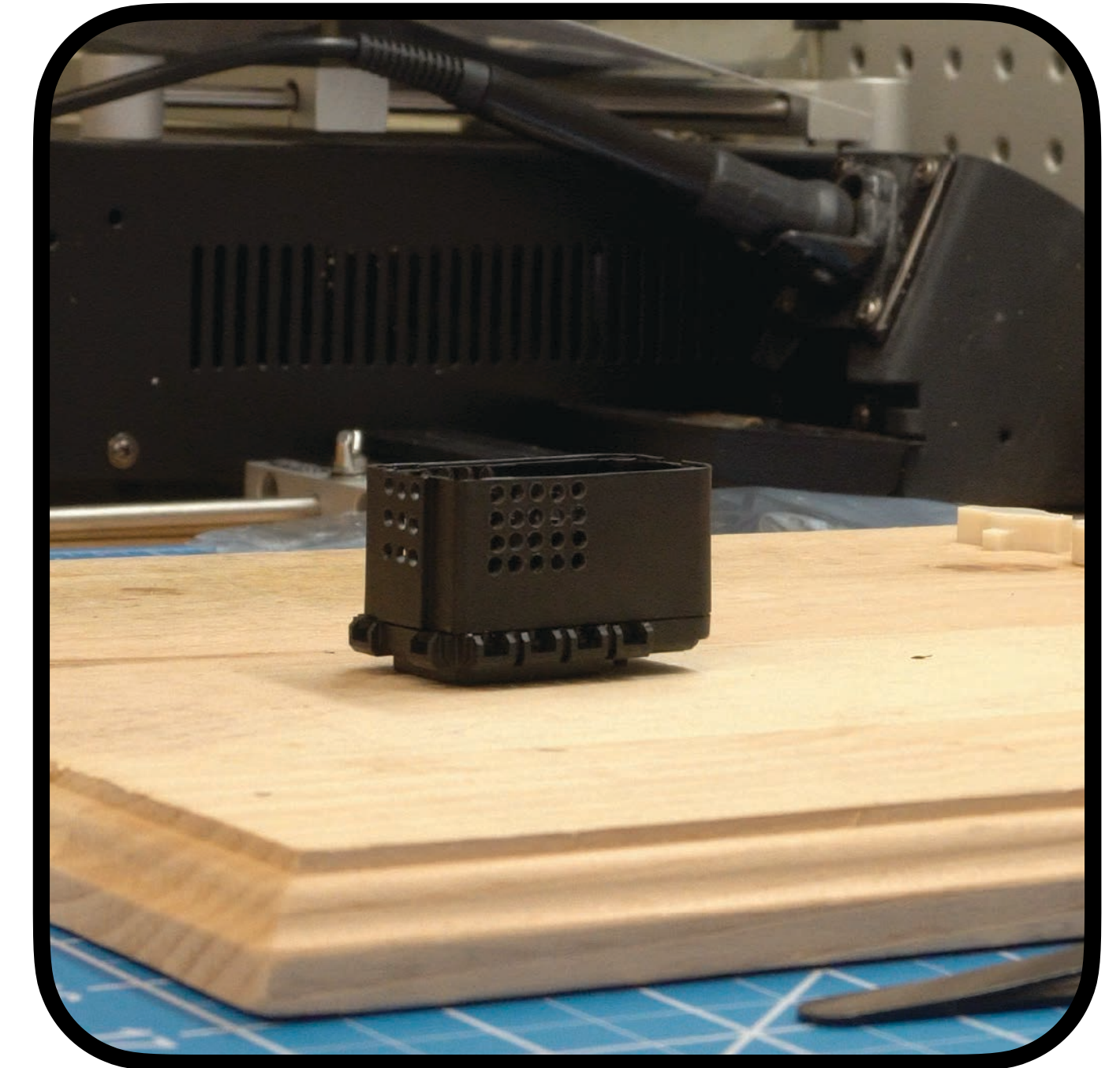


- Remove the 3D-printed spanning cap, but leave the masking tape seal in place.
- Set the 3D-printed spanning cap aside for use with other actuators.
- Remove all visible debris from the actuator.
- Use tweezers to remove the 3D-printed motor plug, but leave the masking tape seal in place.
- Set the 3D-printed motor plug aside for use with other actuators.

Actuator Modification Process

Step #26:

Remove the both pieces of masking tape and remove any remaining debris.



- Remove all visible debris from the actuator.
- Use tweezers to remove both masking tape seals from the inside of the actuator's back section.
- Dispose of both masking tape seals.

Actuator Modification Process

Step #27:

Prepare the work surface and yourself to work with greased parts again.



- Be sure you are wearing nitrile gloves for the reassembly process.
- Use a sheet of paper or a disposable cloth to protect your work surface from transient grease.

Actuator Modification Process

Step #28:

Re-install the electronics and DC motor into the back of the actuator casing.

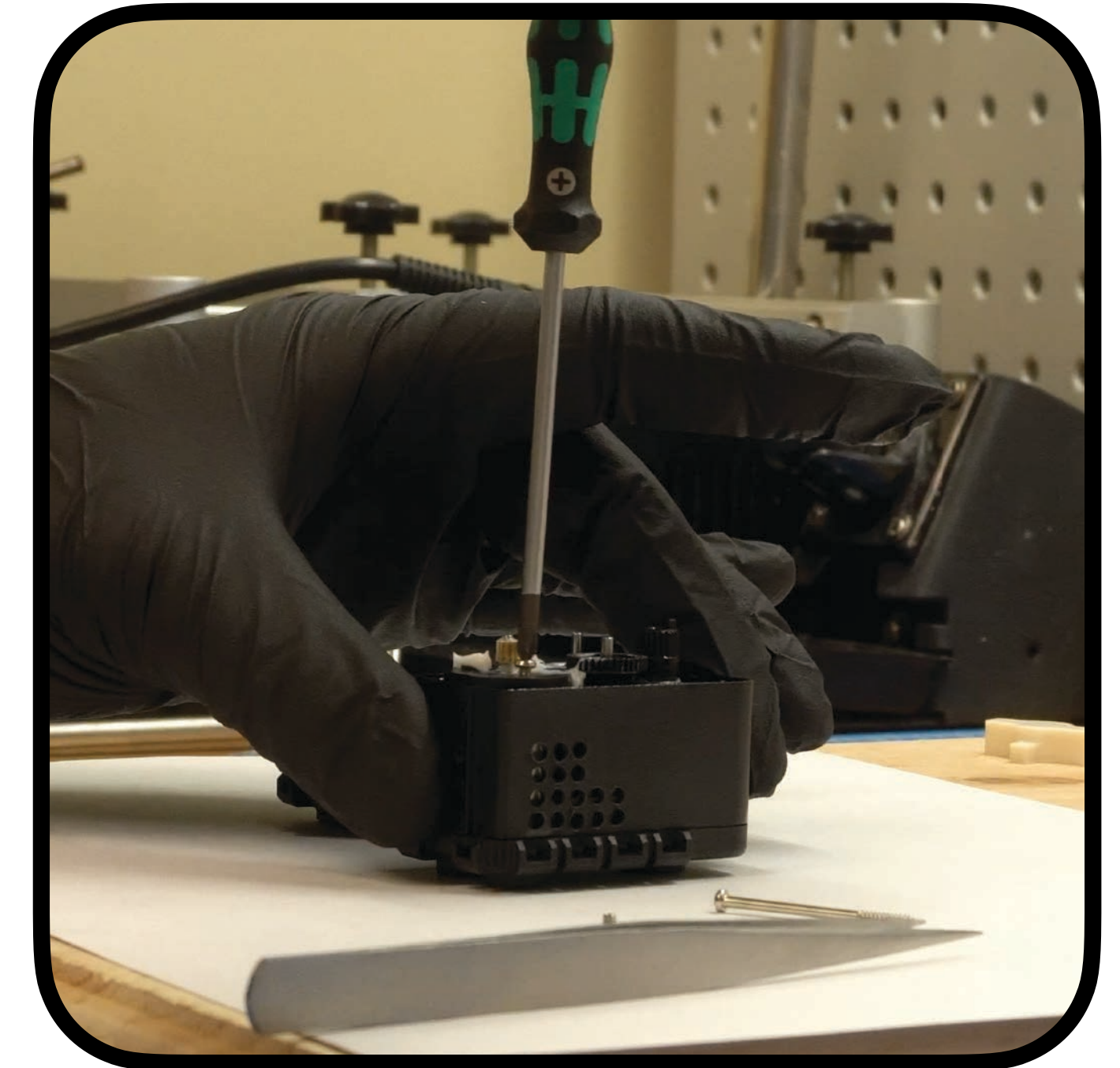
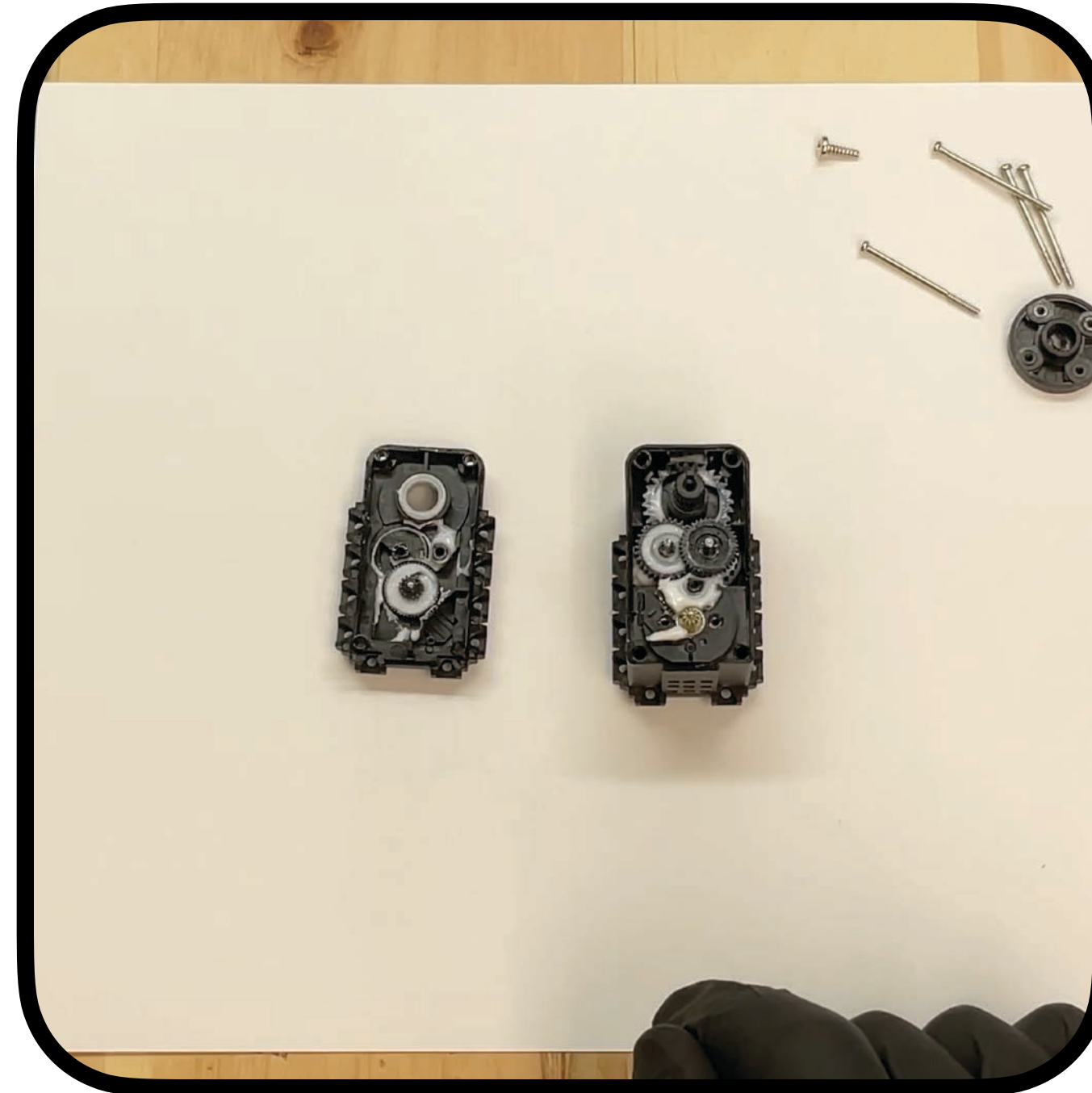


- Retrieve the small PCB screw and the actuator back casing from the grease-free plastic bag.
- Retrieve the actuator's PCB and DC motor assembly from the ESD bag.
- Align the PCB and DC motor assembly and slide it back into its original position in the actuator casing.
- Fasten the small PCB screw back into place.
- Reposition the actuator's back casing and ensure that it fits properly, but do not screw it into place yet.

Actuator Modification Process

Step #29:

Remove the front casing and re-secure the DC motor.



- Orient the actuator so that the front is facing upward.
- Retrieve the two small screws used to secure the DC motor from their plastic bag.
- Using the same methodology as before, remove the front casing of the actuator to expose the gearbox.
- Fasten the two small screws back into place to secure the DC motor.

Actuator Modification Process

Step #30:

Ensure the actuator's gears are properly meshing together.



- If Gear #1 is attached to the front casing, transfer the axle and gear from the front casing to the gearbox.
- Ensure all gears are in their proper locations.
- Verify that the gears are meshing together by using your finger to lightly rotate Gear #1.
 - You should observe that all gears rotate as you rotate Gear #1.

Actuator Modification Process

Step #31:

Re-attach and secure the front plastic casing.

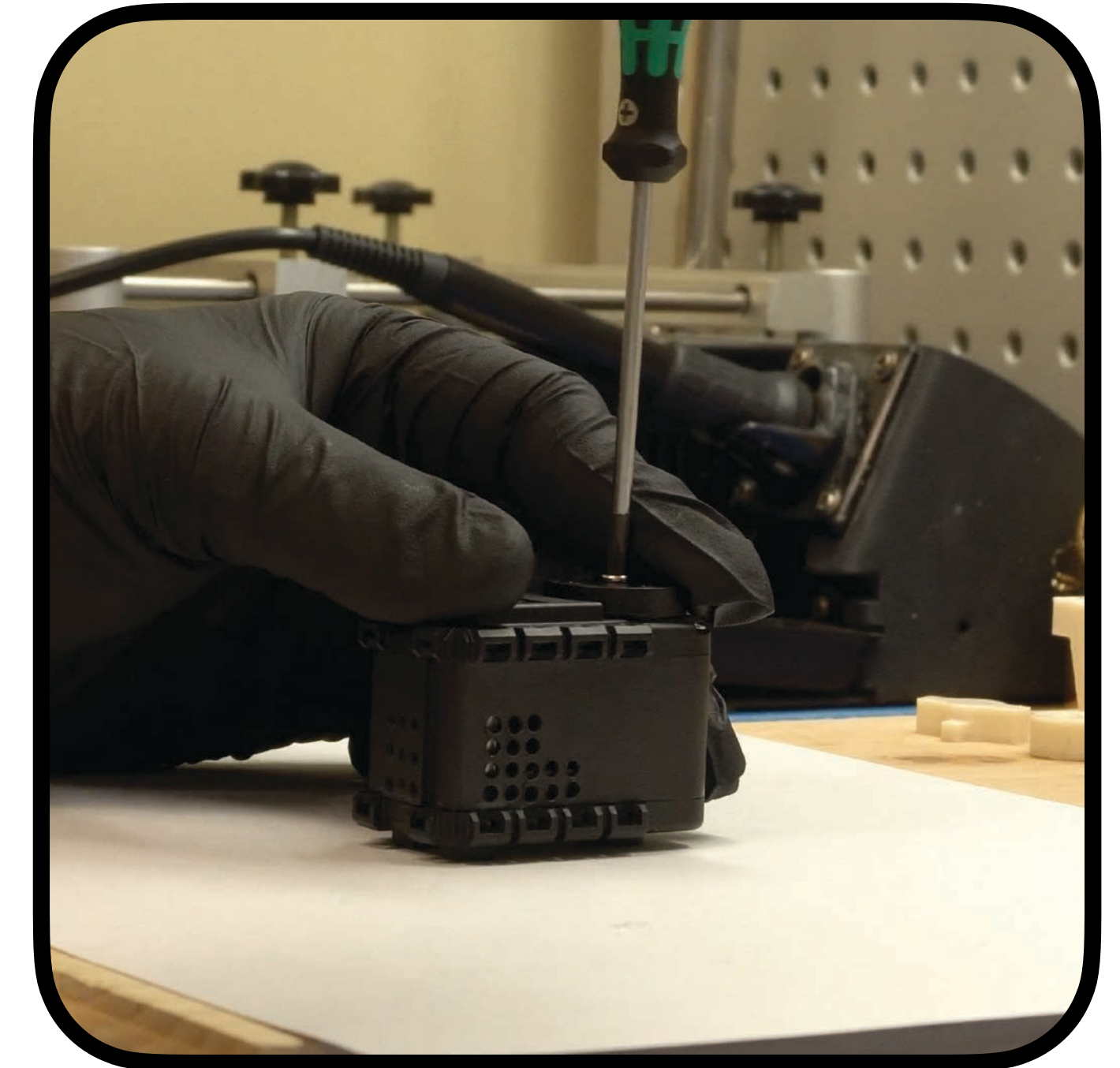


- Place the actuator's front casing back over the gearbox.
- Retrieve the actuator's original four screws from the plastic bag, insert them through the front casing, and fasten them through the actuator into the back casing.

Actuator Modification Process

Step #32:

Re-attach and secure the actuator's horn.

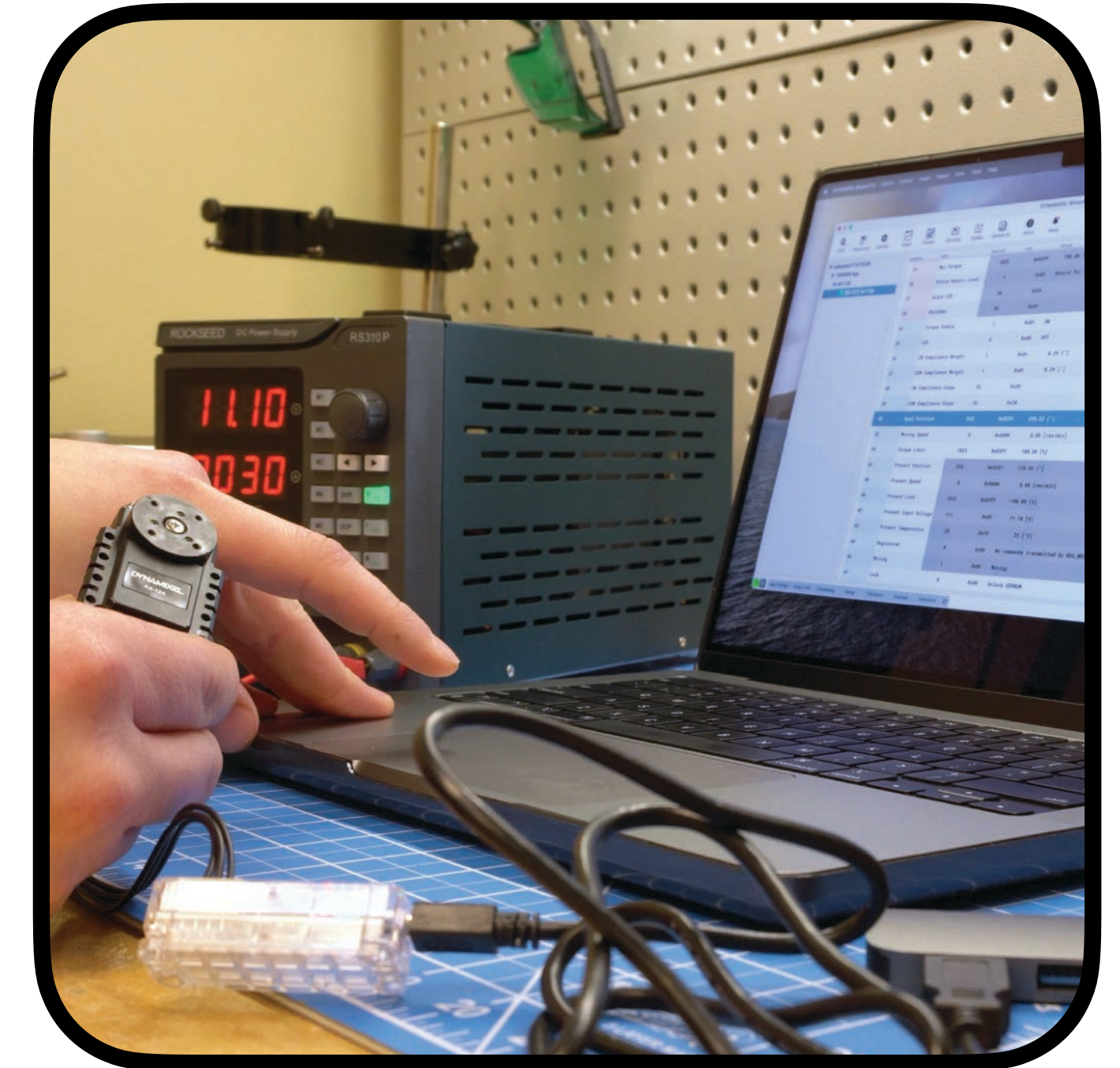
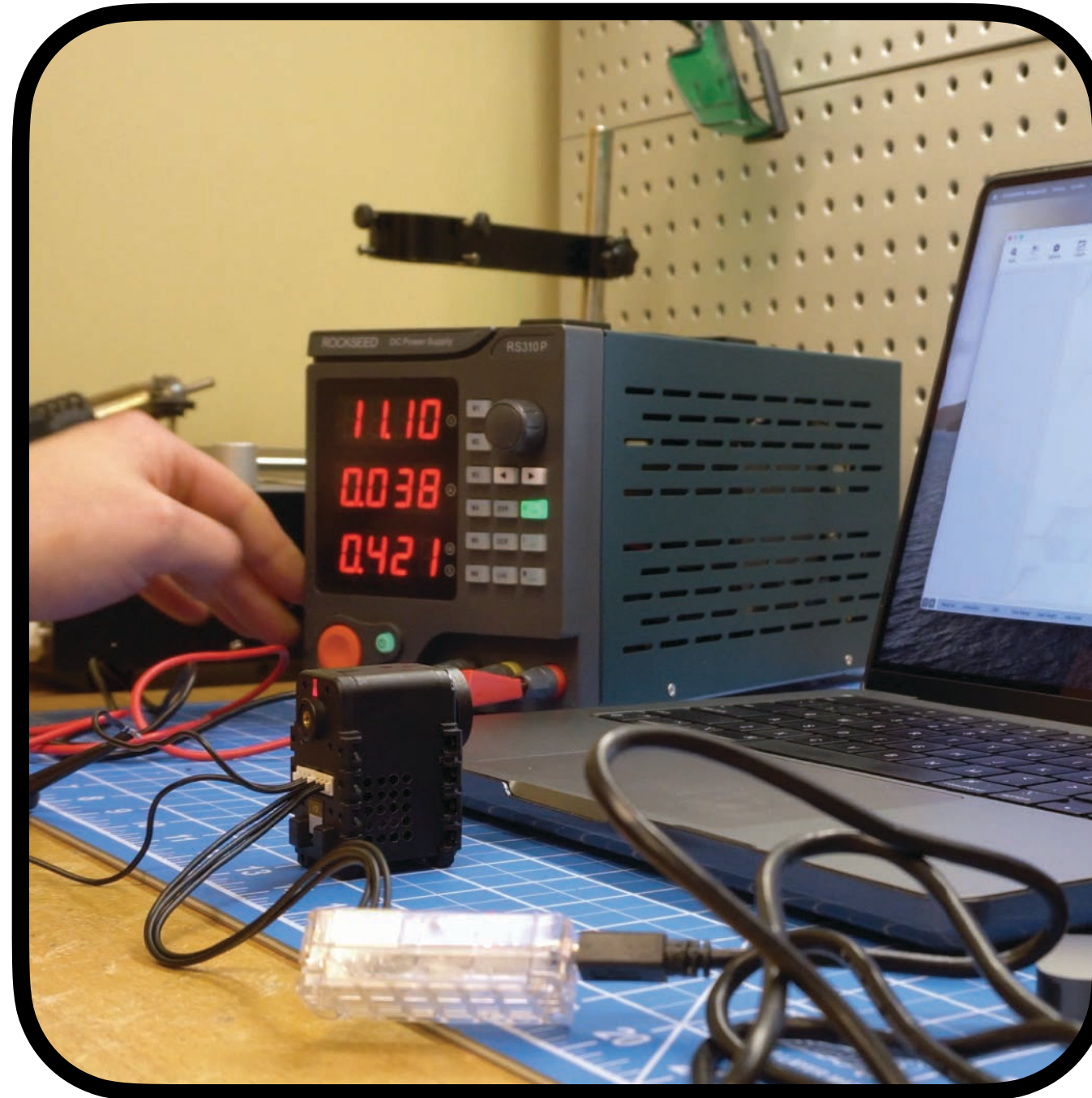


- Retrieve the servo horn and horn center screw from the plastic bag.
- Align the servo horn with the keyed serrated output axle and push it down into place.
- Secure the horn into position by inserting and fastening the center screw.

Actuator Modification Process

Step #33:

Use the test bench to ensure the actuator is in working condition.



- Verify the gears are meshing by rotating the servo horn a small amount in each direction.
- Connect the actuator to your test setup and verify that it operates normally.
- Send the actuator to its center position and disconnect it from the test setup.

Actuator Modification Process

Step #34:

Celebrate successful modification of the actuator!



- **NOTE:** If you were not successful do not celebrate until you are.