Microsoft

Building machines that emulate humans

Lesson plan and more resources are available at: aka.ms/hackingstem

Hacking STEM

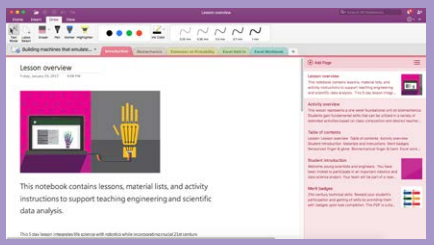
A monthly resource for teachers, delivering inquiry and project-based lessons that complement current STEM curriculum. In this lesson we explore the phenomenon of human body mechanics and discover how it's influencing robot design.

Contents

Activity notebooks

Contains materials lists, lesson plans and activities to support teaching this project, mapped to the NGSS and ISTE standards.

Go to aka.ms/hackingstem for these and other activity notebooks.



Activity overview

The activity integrates life science with robotics, while incorporating crucial 21st century technical skills. Computer and data sciences, along with mechanical and electrical engineering, are integrated to provide an authentic learning experience. Emphasis is placed on the importance of combining science and technology to reflect the mechanics of the human body.

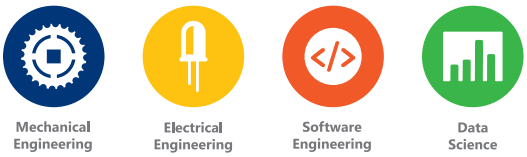
Sensorized glove

Students build a sensor that measures the flexion and extension of a finger to learn about tracking the movement of a human hand. Next, they assemble a cardboard glove and attach multiple sensors to enable visualizing how bones work within the skeletal system.

Robotic hand

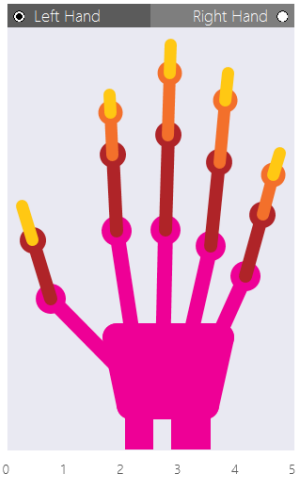
Students will engineer a robotic hand from materials like cardboard, straws, string and servo motors, that can be controlled by their sensorized glove to complete a set of tasks.

21st century technical skills explored in this activity include:



Data visualization:

Students can then run trials with the robotic hand and generate ideas to improve the range of tasks it can accomplish. The data will be visualized for analysis using a customized Excel workbook.



Phalanx Flexion						
		Thumb	Index	Middle	Ring	Pinky
100% = Full Flexion *0% = Full Extension*		0%	9%	0%	0%	0%
x,y coordinates (top of bone)						
Finger digit		*Thumb*	*Index*	*Middle*	*Ring*	*Pinky*
Distal Phalanges	x	0.25	1.77	2.85	3.85	4.75
	y	43.43	63.43	72.20	67.29	52.98
Middle Phalanges	x		1.79	2.83	3.80	4.64
	y		60.23	67.20	62.29	48.98
Proximal Phalanges	x	0.43	1.83	2.80	3.70	4.45
	y	37.43	52.65	56.20	51.29	41.98
Metacarpals	x	0.75	1.90	2.75	3.55	4.15
	y	26.94	39.00	39.20	36.29	30.98

Hack our projects

We love innovation and encourage you to hack our projects and make them your own.

Steps for success

For those who tend to use instructions as loose guidelines, we've indicated integral steps with the A-Ok hand symbol. Read and follow these steps precisely to increase your likelihood of success.

Substituting everyday objects

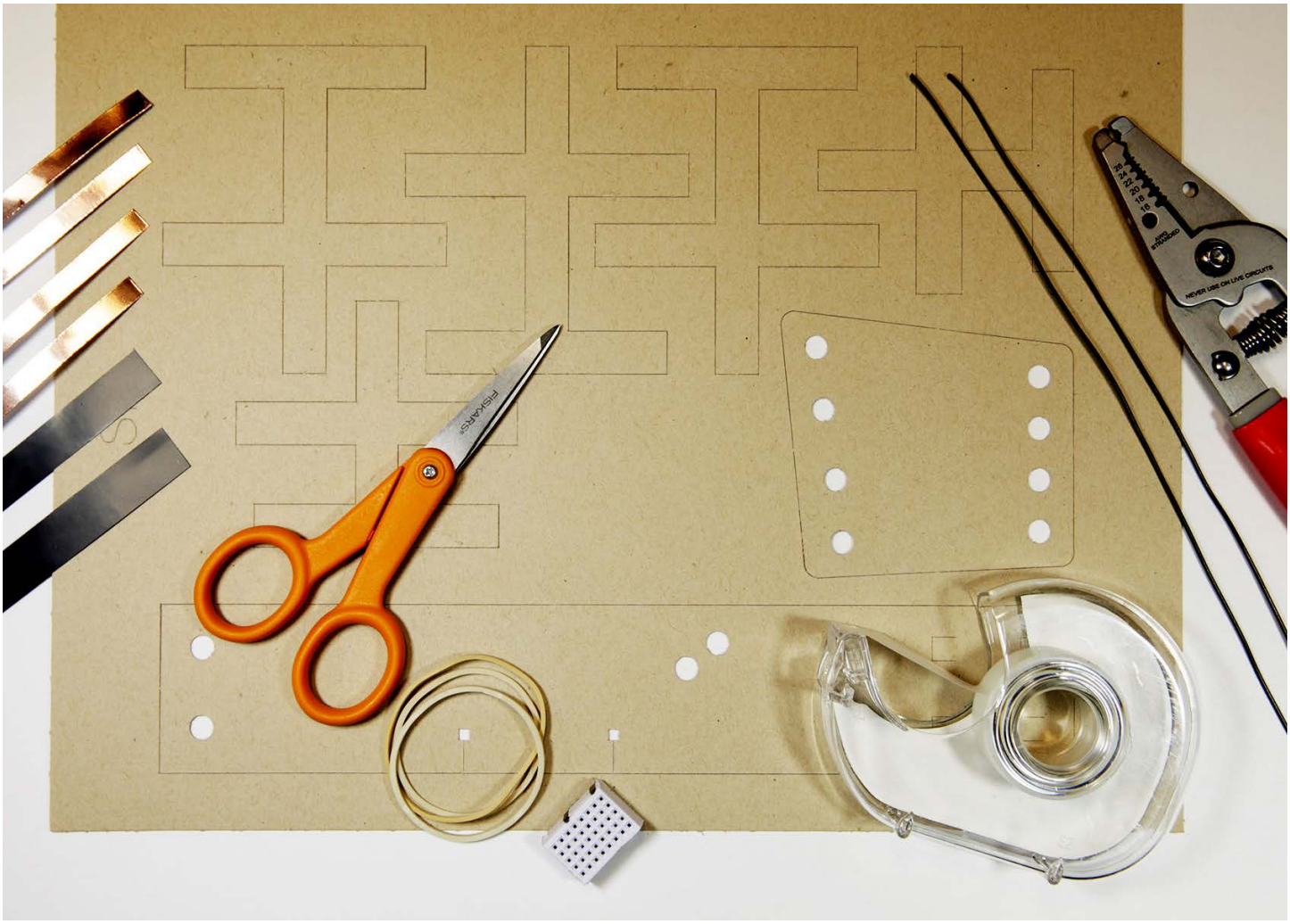
Similar items can be substituted/hacked for most materials according to availability and the student design process.

Sourcing specialized materials

Many of these items can be easily found online or at your local hardware store. You can find an online shopping list for this entire lesson at: aka.ms/robotichandshoppinglist

Part One

Sensorized Glove



Things you'll need

Materials

- 1 printed template (pg 17 & 18)
- U-shaped guide template (build instructions on following page)
- 1 piece of kraft heavy card stock or a cereal box, flattened and turned inside out
- 1 mini bread board (55 holes)
- 3 medium rubber bands
- 10 strips of Velostat plastic, 1 cm x 8 cm
- 20 pieces of copper tape, 7 cm long
- 10 pieces of 30 cm solid core wire

Tools

- scissors
- Scotch tape
- wire stripper
- single hole punch
- X-acto blade

Download an Excel spreadsheet that includes a complete shopping list for this lesson:

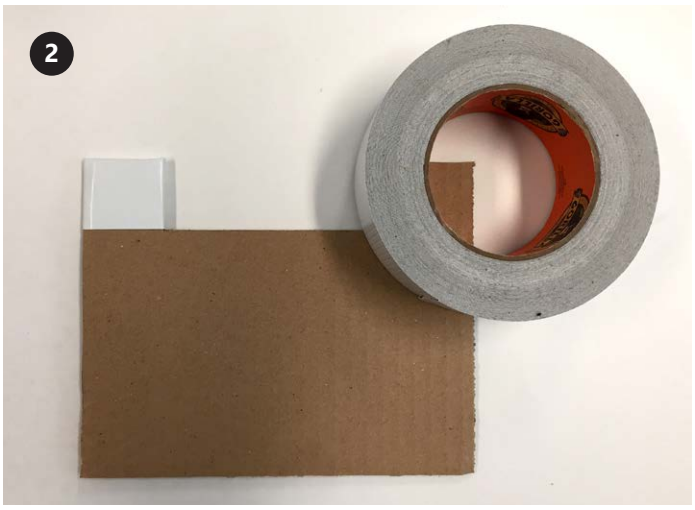
aka.ms/robotichandshoppinglist

Tips for success:

We've indicated integral steps with the A-Ok hand symbol. Read and follow these steps precisely to increase your likelihood of success.

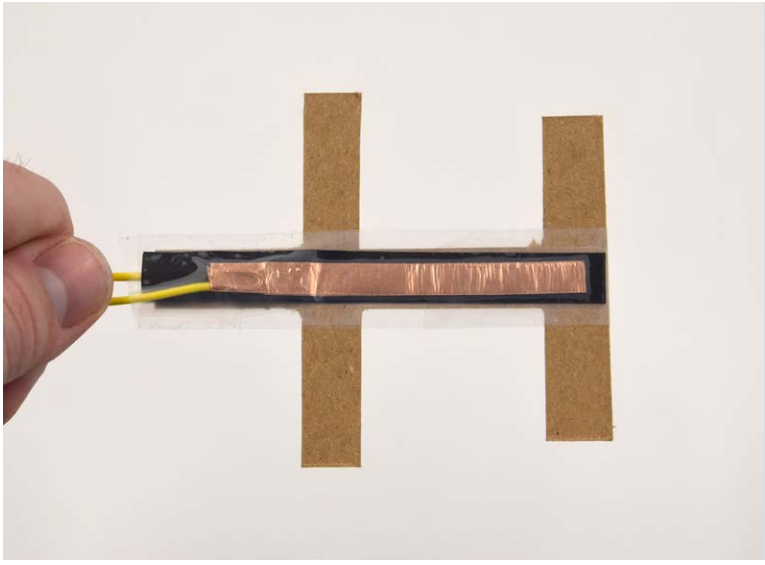
Make a guide for sensor building

A simple U-shaped Guide makes sensor building easy. Cut or gather a piece of cardboard, roughly 20 cm x 16 cm. Next, cut out a notch about 3.5 cm deep and 11 cm long.



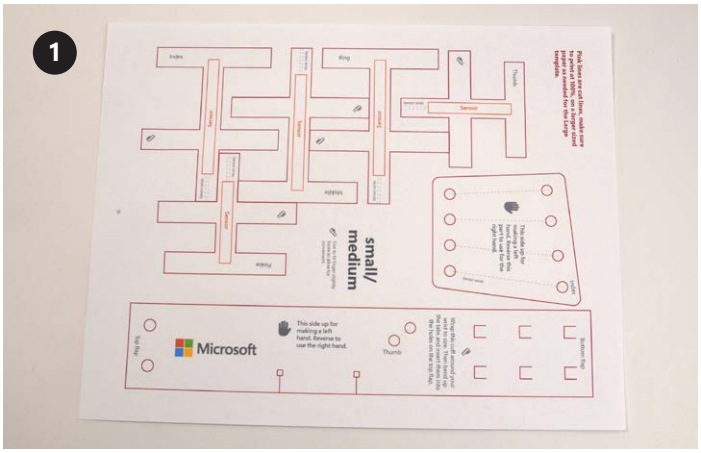
Wrap the two ends you just created with tape, this will simply provide you with a base to build sensor halves that can easily be removed from the non-stick tabs.

Make a "sensor sandwich"



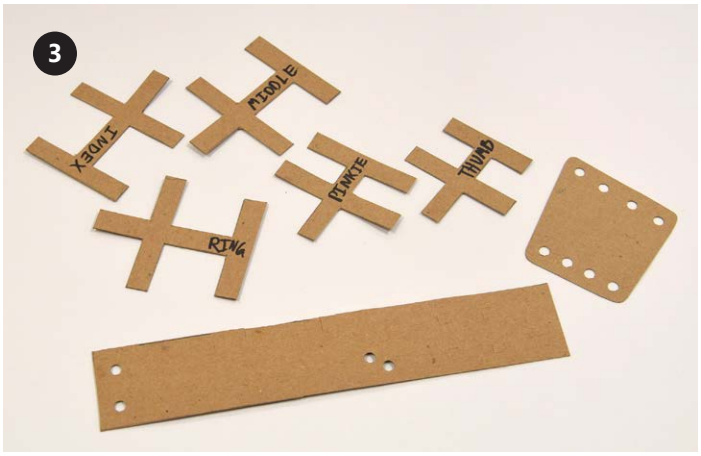
Sensor Layer Overview

- 11. clear tape
- 10. copper tape
- 9. wire
- 8. copper tape
- 7. Velostat strip
- 6. Velostat strip
- 5. copper tape
- 4. wire
- 3. copper tape
- 2. clear tape
- 1. finger splint



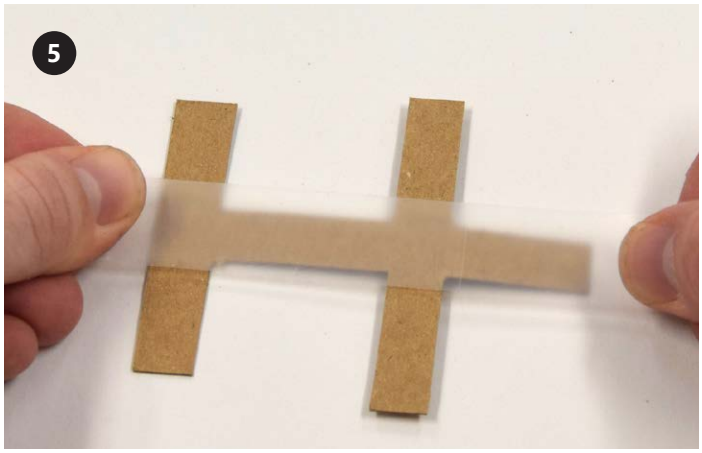
Select and print a template based on your hand size (pg. 17 & 18).

Cut out the template and trace your pattern onto cardboard.

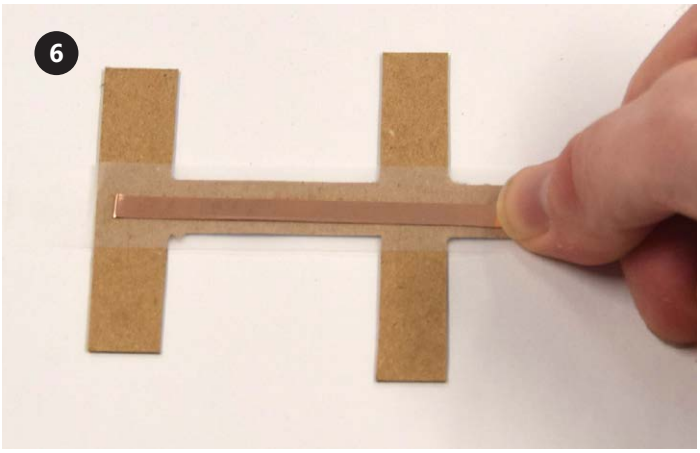


Cut out the traced cardboard templates and use a hole punch to cut out the holes for your wires.

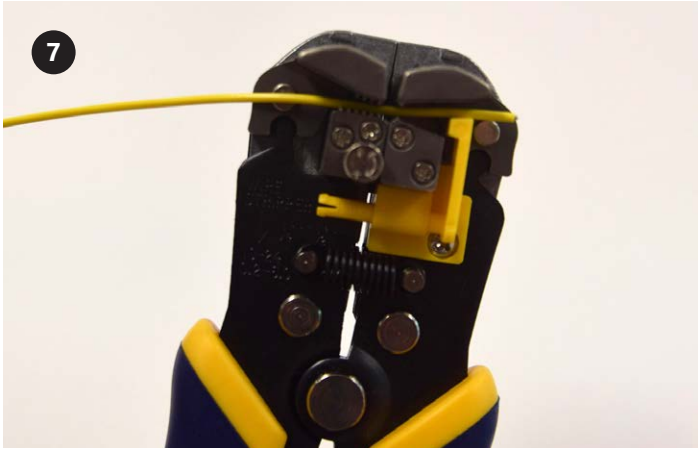
Make sure to label your cut out finger splints so that you do not get the finger sizes mixed up.



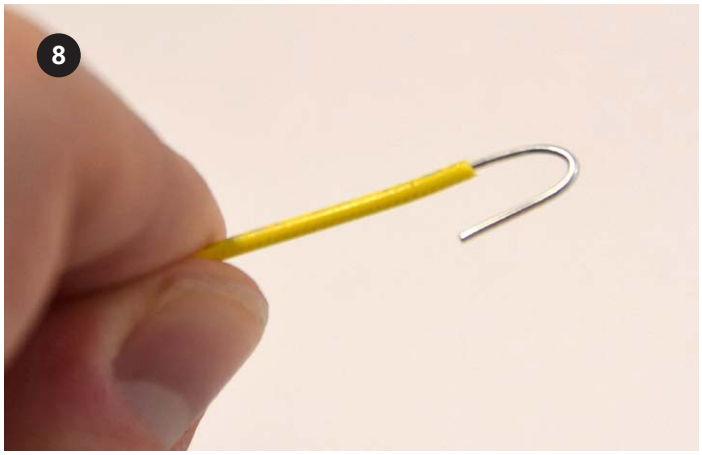
Place a piece of clear tape, **sticky side down**, over the entire length of the Index finger splint to act as a base layer.



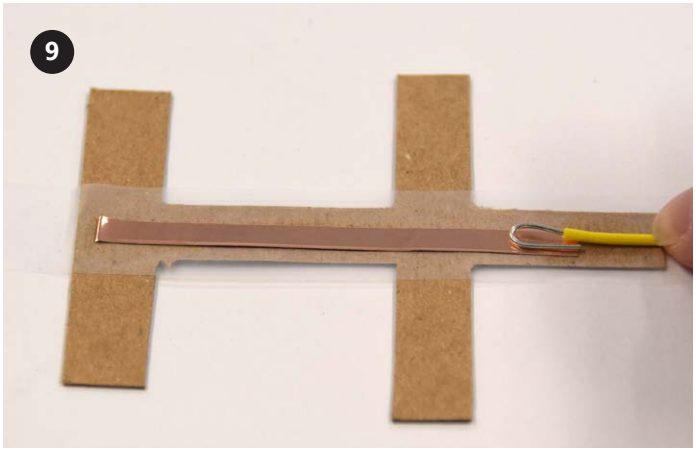
Remove the backing from one strip of copper tape, and adhere it to the splint.



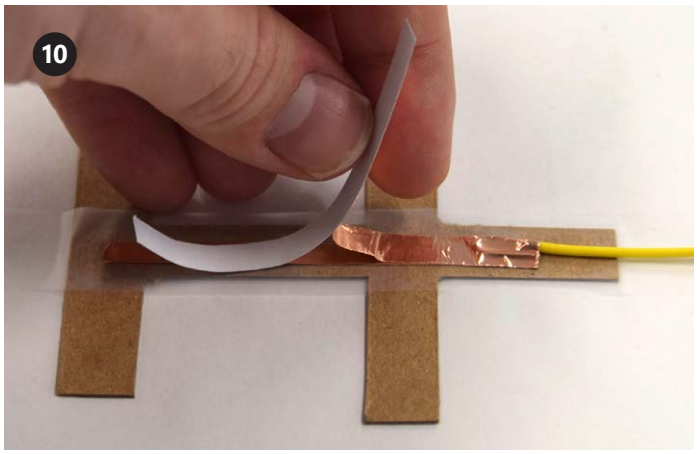
Use wire strippers to remove roughly 2 cm of the plastic coating from the end of a 30 cm wire, exposing the solid core inside.



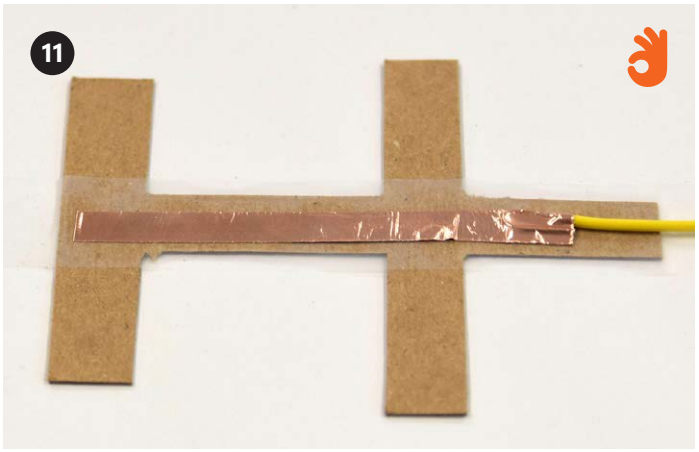
Bend the exposed end of the wire.



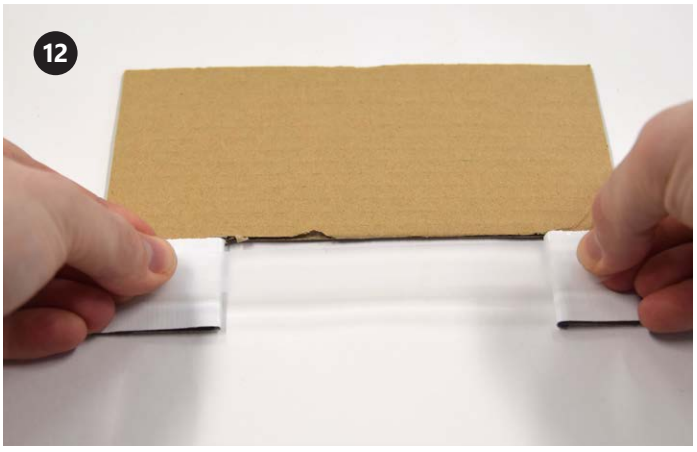
Place the wire loop at the end of the end of the copper tape.



Peel backing from a second copper tape strip and attach directly over the first strip and the wire loop.

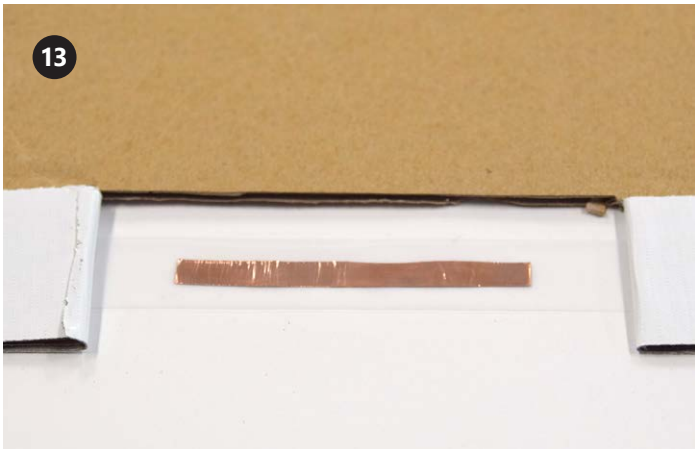


Press firmly, making sure your loop of exposed wire is secured.

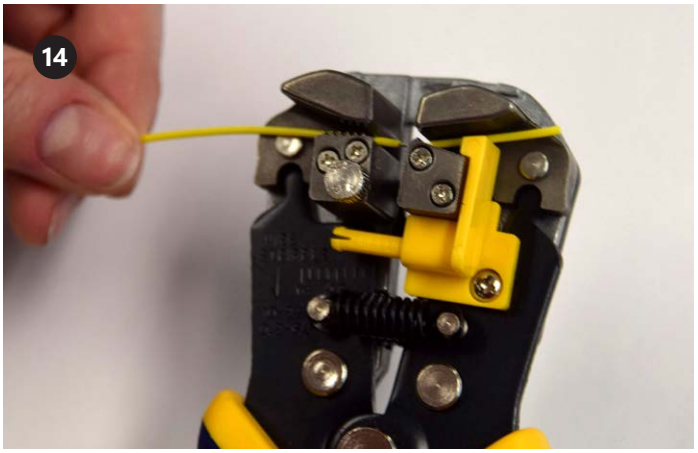


Use the U-shaped guide to build the second half of the sensor. Place a piece of tape between the two tabs.

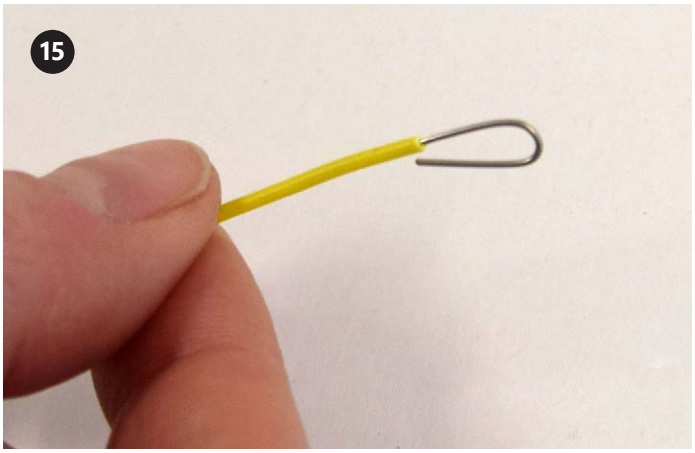
If you end up with any bends or folds in your copper tape you might want to start over with a fresh piece of tape, as the sensor may not work.



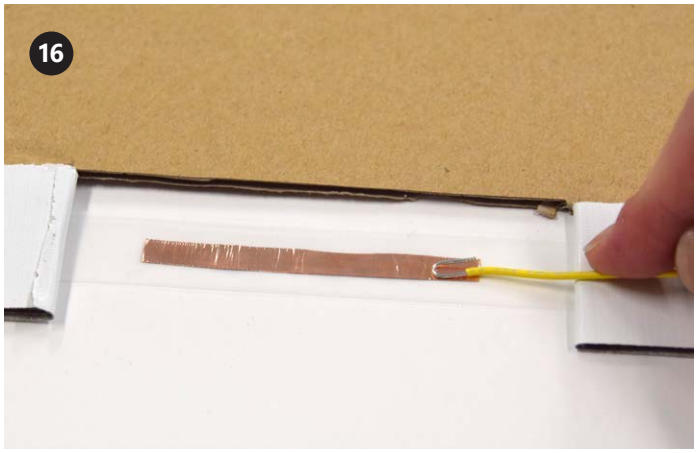
Flip the guide over so that the **sticky side is up**, then place copper tape **sticky side up** and remove the backing on the copper tape.



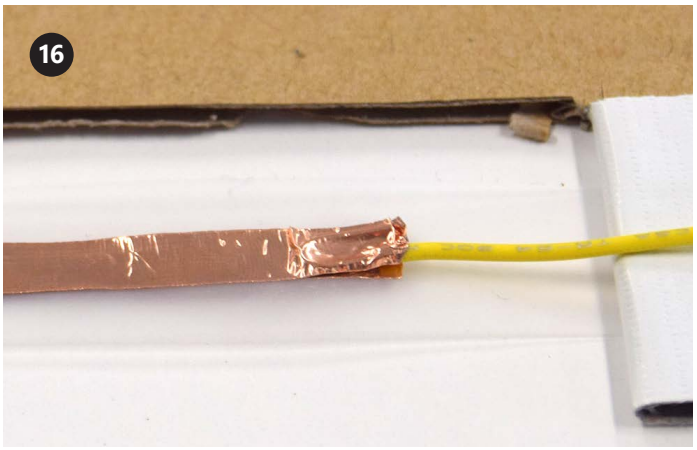
Take a second wire, and remove approximately 2 cm of the plastic coating with wire strippers.



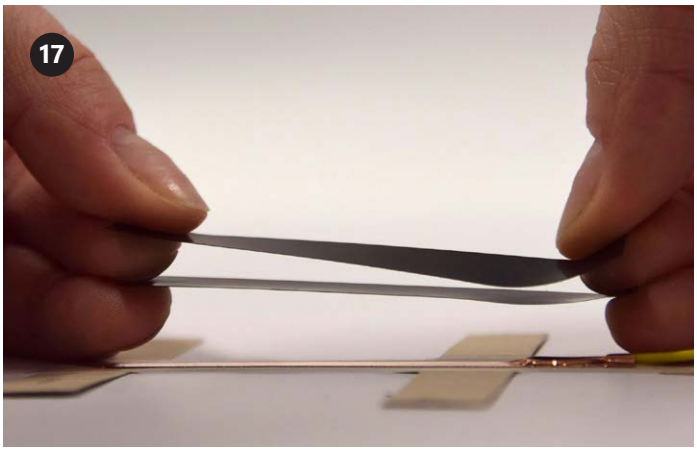
Bend the exposed end of the wire.



Place the wire on top of the copper tape.

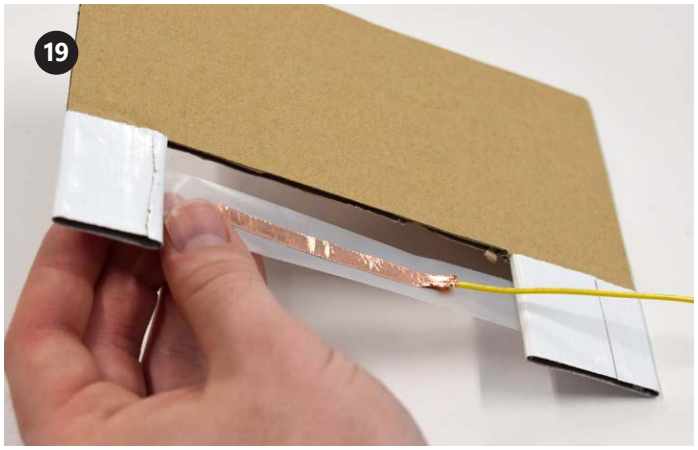


Place another piece of copper tape, **sticky side down** pressing firmly to secure a good electric connection.

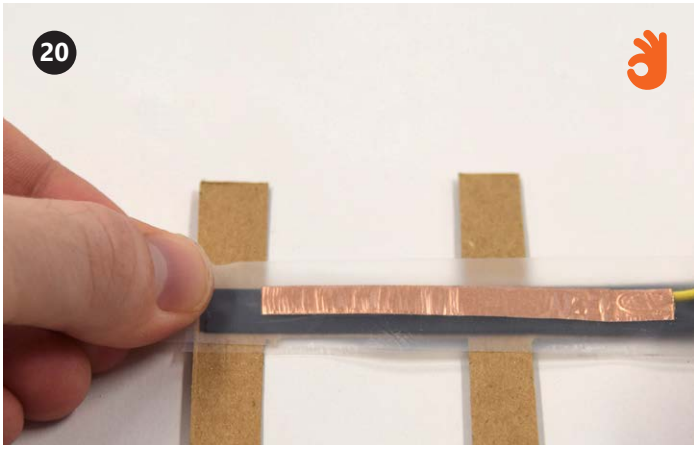


Take two strips of velostat to lay over your finger brace.

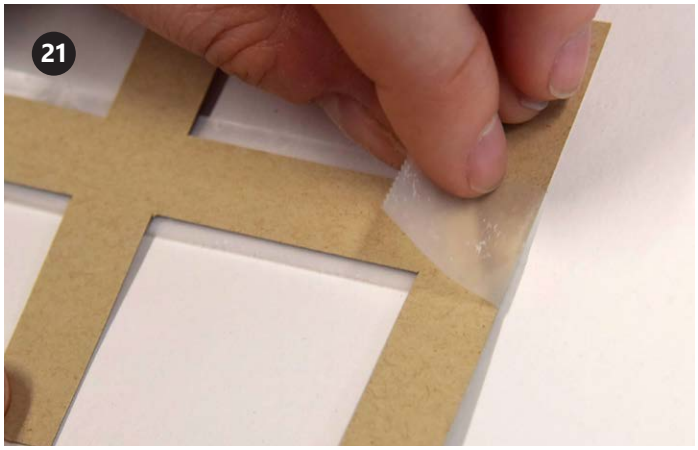
Place both Velostat strips directly over the base layer of your sensor.



Carefully remove the sensor half from the U-shaped guide.

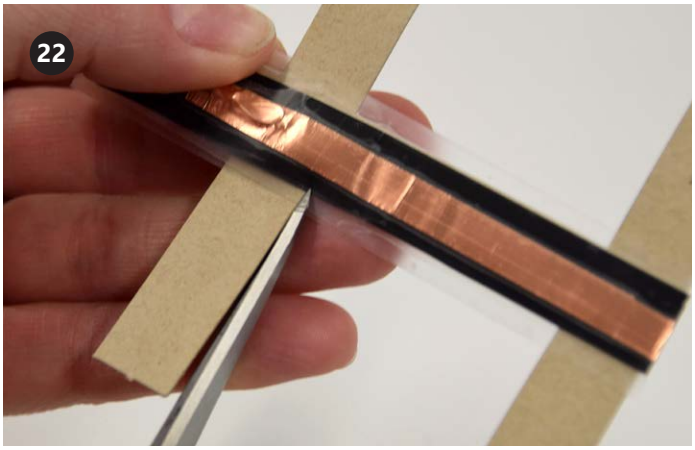


Flip the sensor half from the guide over and attach it to the layer on the finger splint, encasing the Velostat strips and completing the sensor sandwich.

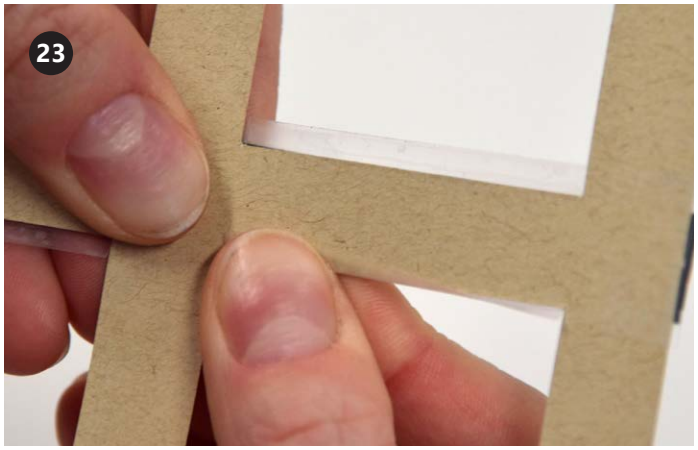


Now tape the sensor in place on the finger splint, making sure to not wrinkle or bend the copper tape.

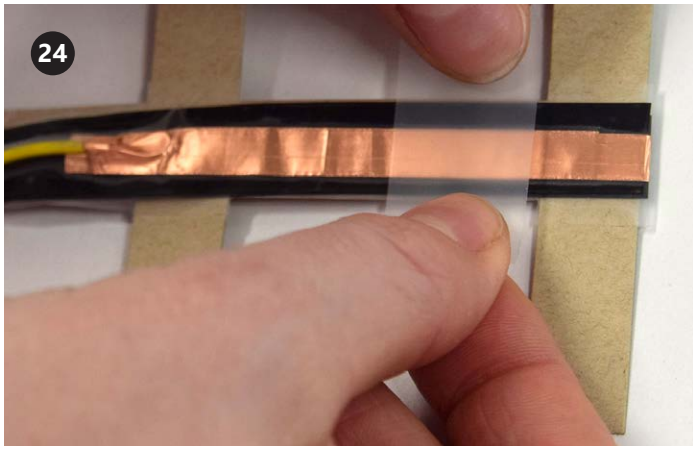
Tip: It is very important that the Velostat layers separate the two sections of copper tape so they are not touching.



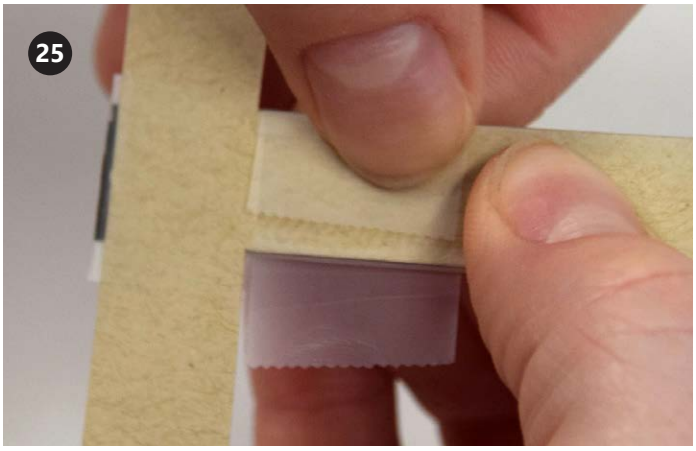
To secure the sandwich layers, snip the tape at the corners.



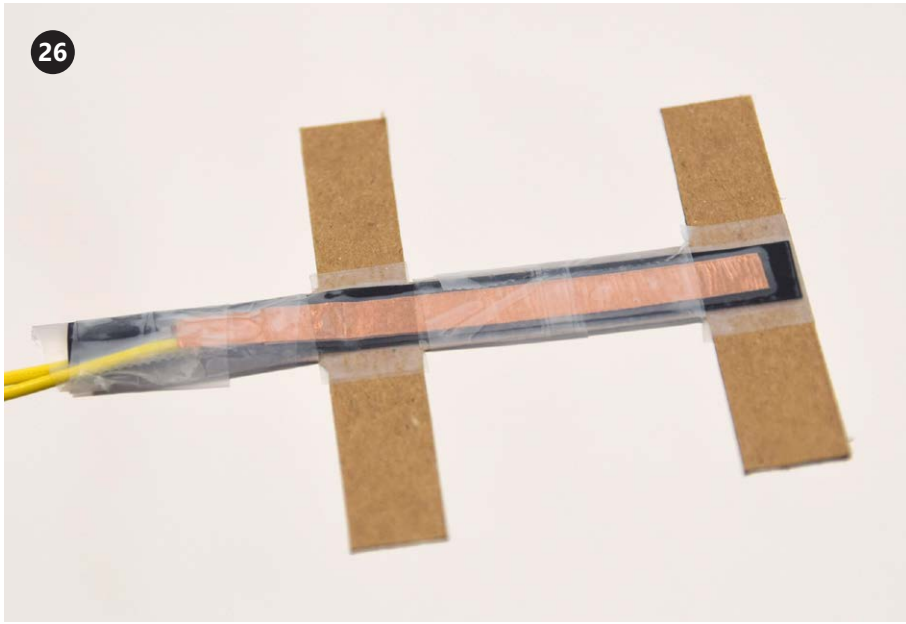
Then fold the excess tape over the back side of the brace.



To further secure the layers and prevent separation, tape cross-wise across the brace in a couple spots on the splint.



Wrap the tape around the back side and close.

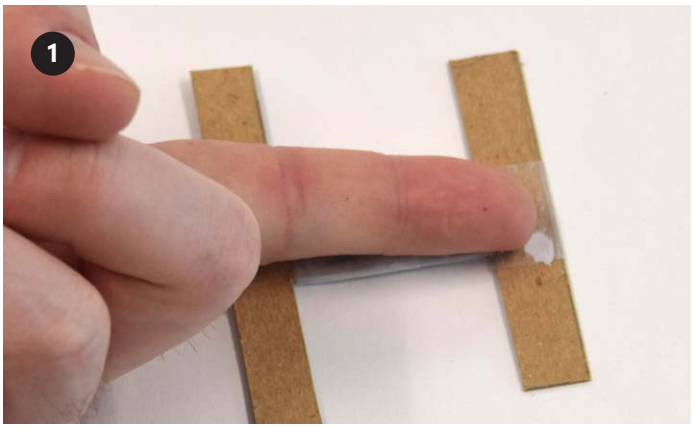


Your sensor sandwich is now complete.

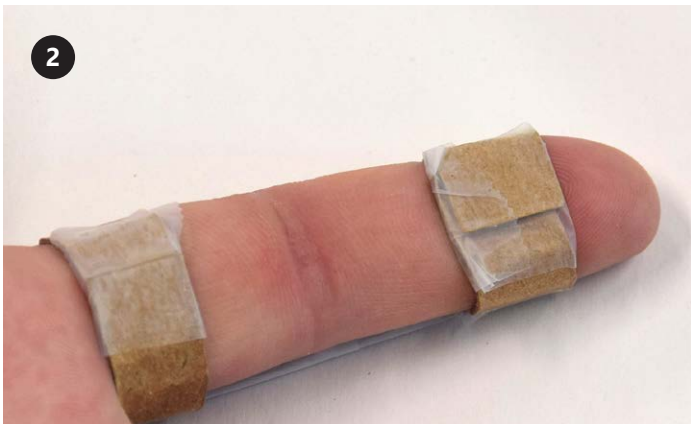
- 11. clear tape
- 10. copper tape
- 9. wire
- 8. copper tape
- 7. Velostat strip
- 6. Velostat strip
- 5. copper tape
- 4. wire
- 3. copper tape
- 2. clear tape
- 1. finger splint

Check your sensor layers using the guide above.

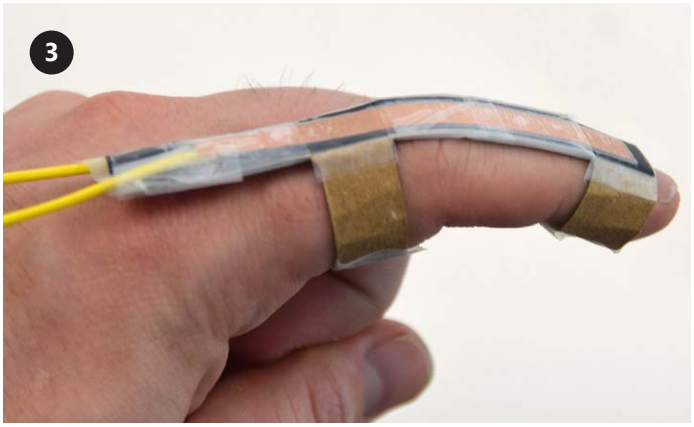
Assemble fingers and glove



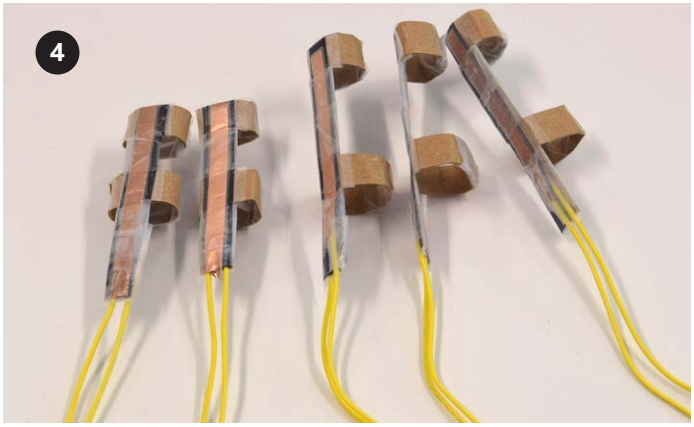
Place your finger on top of the splint, with the sensor side out.



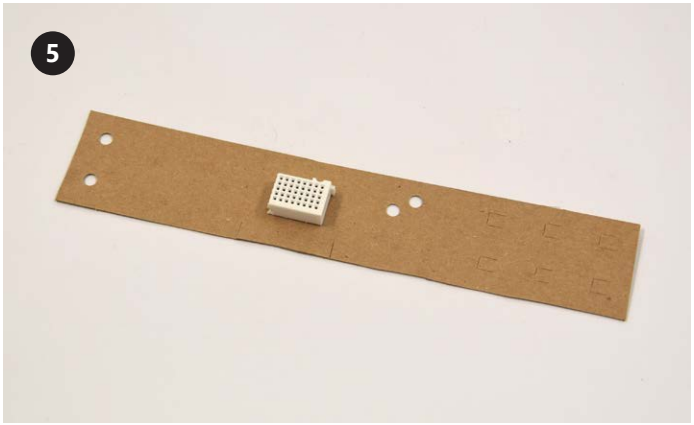
Fold the tabs around your finger, keeping the loose so that your finger can move freely inside the cuff.



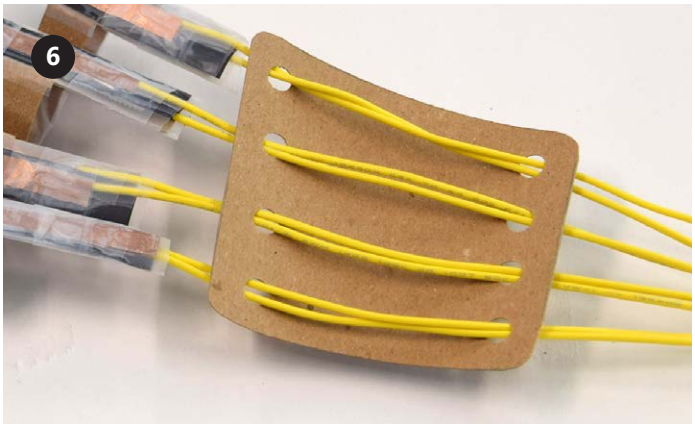
Tape the cuffs closed.



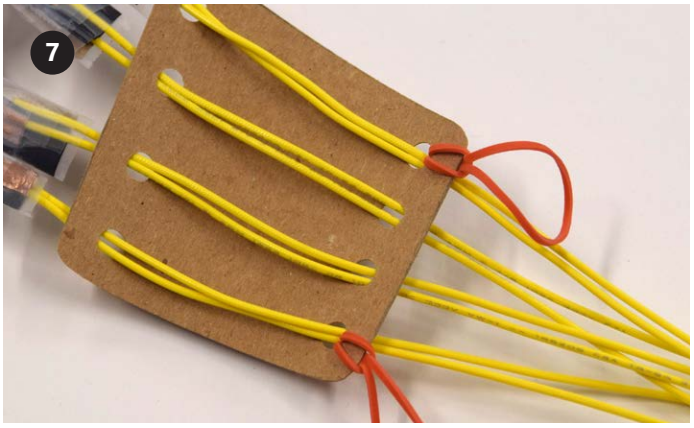
Repeat the sensor and finger splint making process for each of the fingers and the thumb.



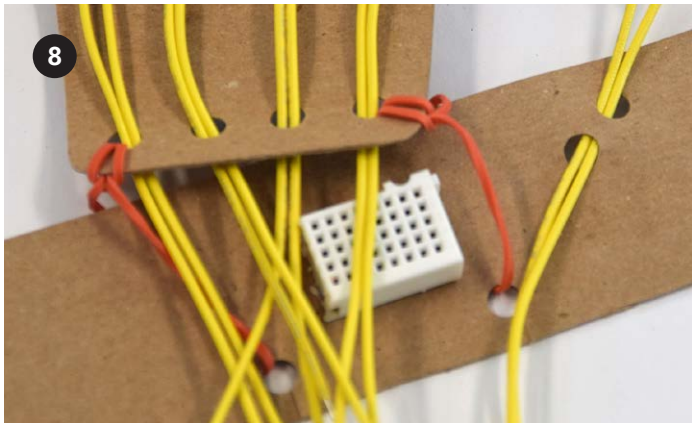
Now attach the mini breadboard to the cuff, placed as shown.



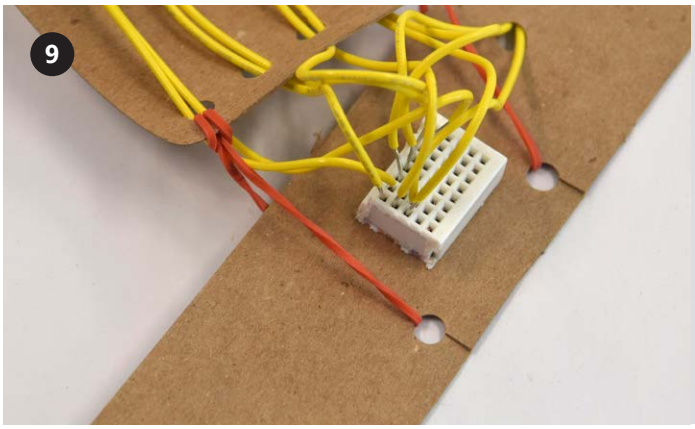
Thread each of the fingers through the metacarpal plate.

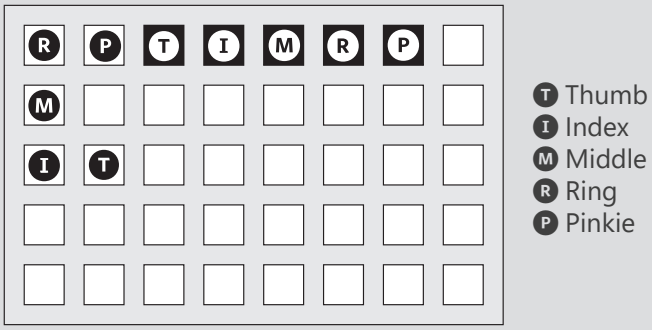


Take two rubberbands and pull a loop through the left and right bottom metacarple plate holes to create two large loops.

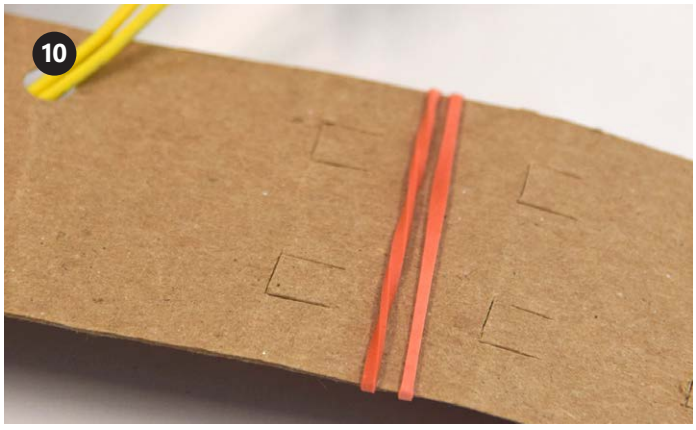


Slip the cuff through the rubber band loops and thread the thumb through the cuff diagonal thumb holes.

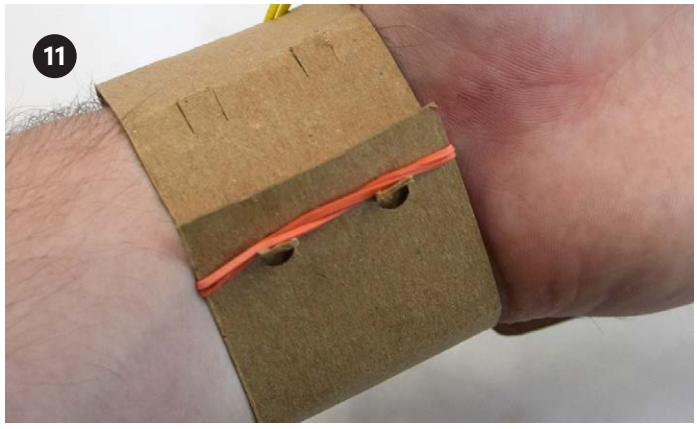




Use your wire strippers to remove 1 cm of insulation at the end of the finger wires, and plug into the breadboard according to the schematic on the right.



Use the box tabs you cut earlier to help secure the wrist cuff. Double a rubber band and slide it over the cuff.



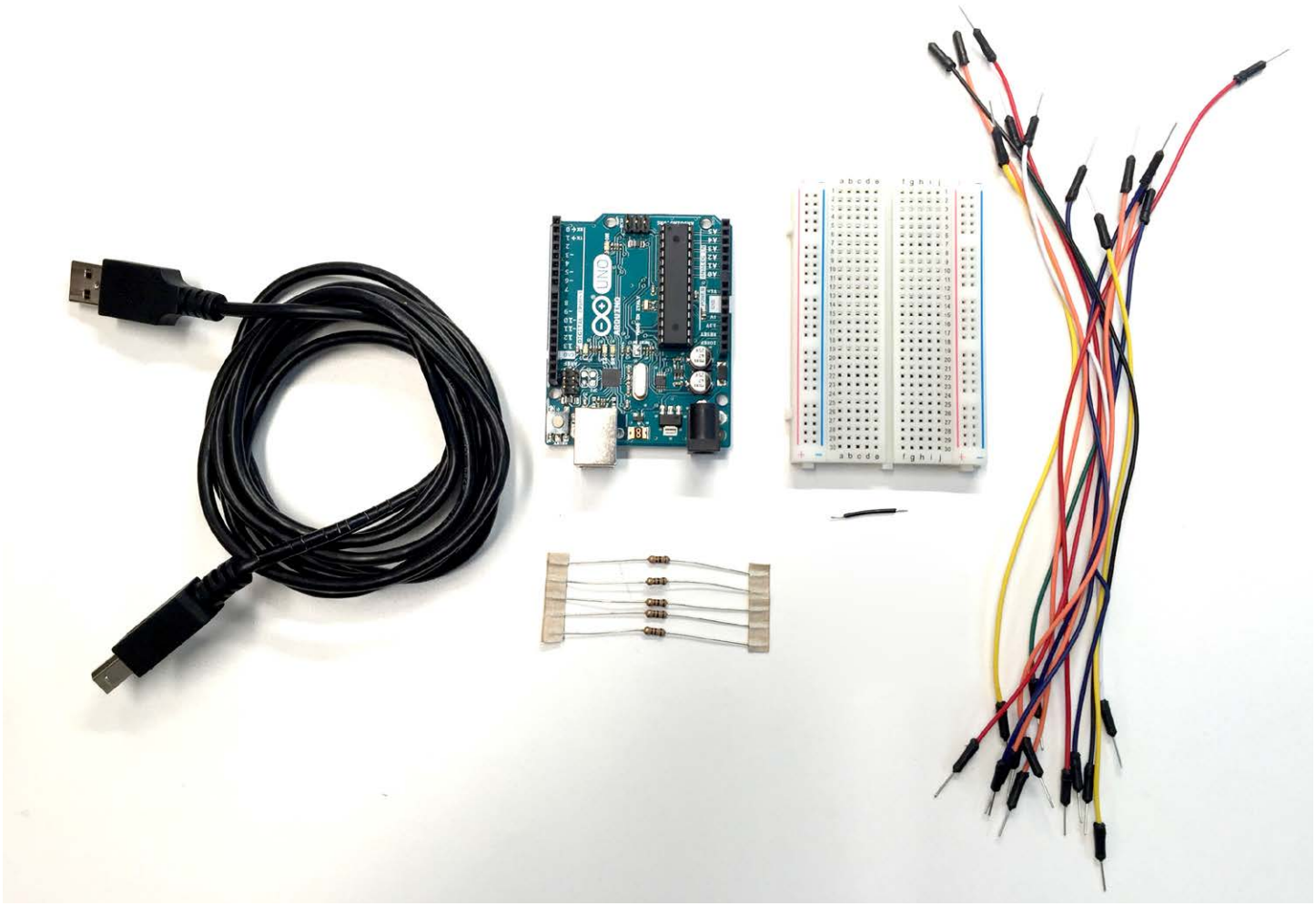
Put the set of tabs that fits most comfortably around your wrist through the two hole punches, then slide the rubber band over the end of the cuff and under the tabs to secure the cuff.

Sensorized Glove
Arduino Activity Part 1

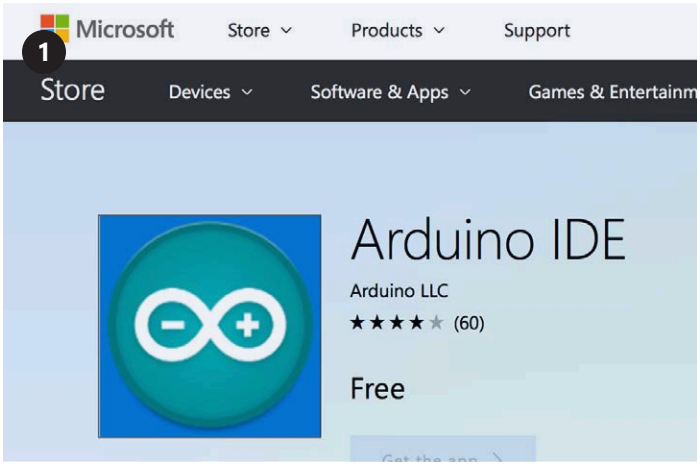
You can now use your sensorized glove to visualize how bones work within the skeletal system. You will use a microcontroller and several specialized components to connect to an Excel workbook.

Things you'll need

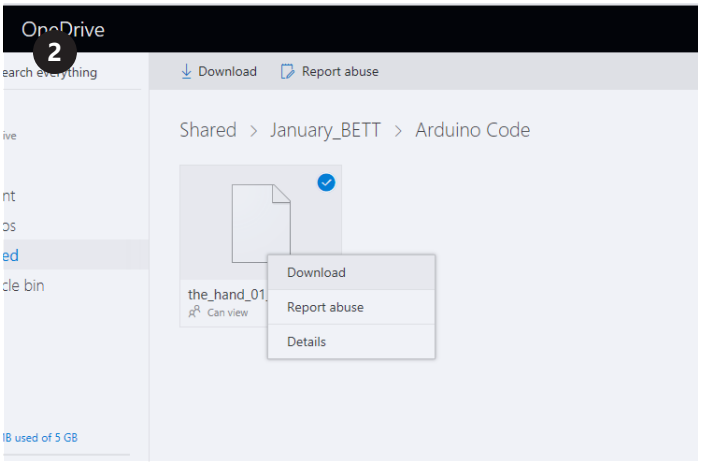
1 Arduino UNO
13 solderless breadboard jumper wires
5 100 Ohm Resistors
1 large breadboard (5 cm x 3 cm)
1 micro USB Cable
1 length of solid core wire, roughly 2 cm long



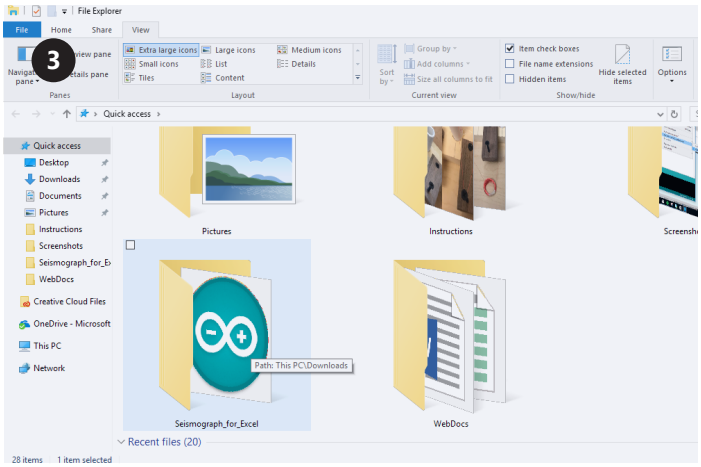
Connect the microcontroller



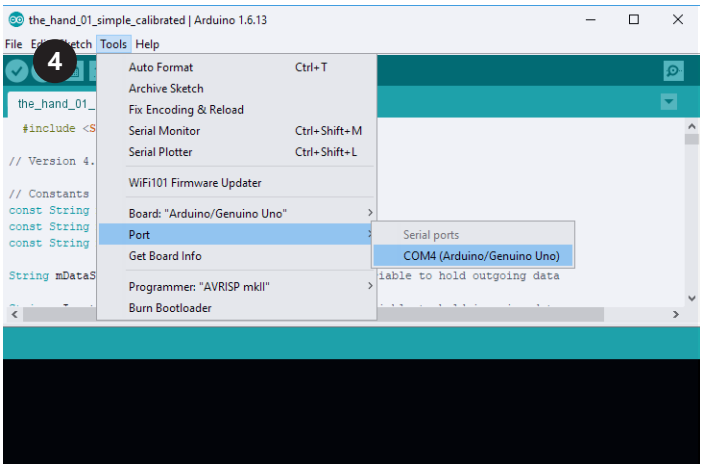
Start by connecting your Arduino UNO to your computer with the USB cord, then download and install the Arduino IDE, by following the prompts.



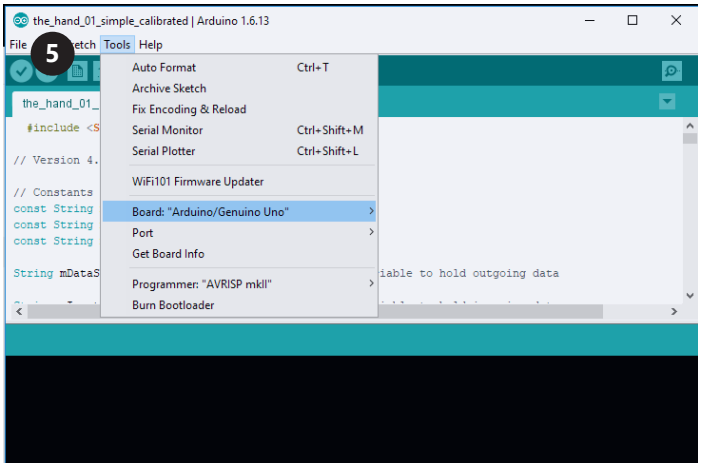
Go to https://aka.ms/biomechanicsarduinocode and download the flash code.



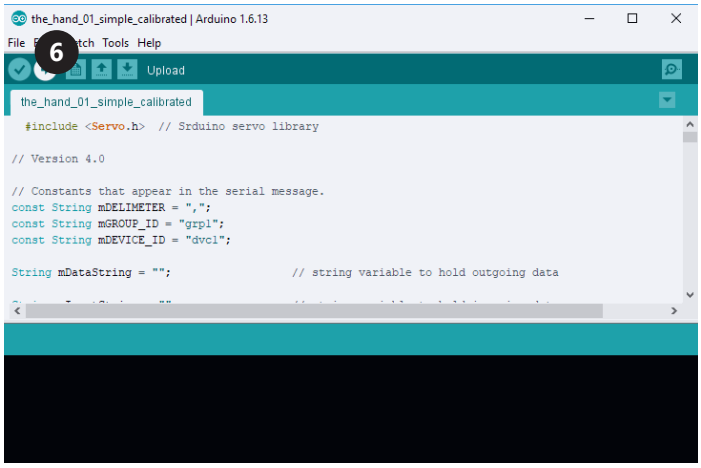
Open your downloaded file to launch the Arduino App.



Next, select: Tools > Port > COM4 (Arduino UNO) Your com port may be different than COM4.



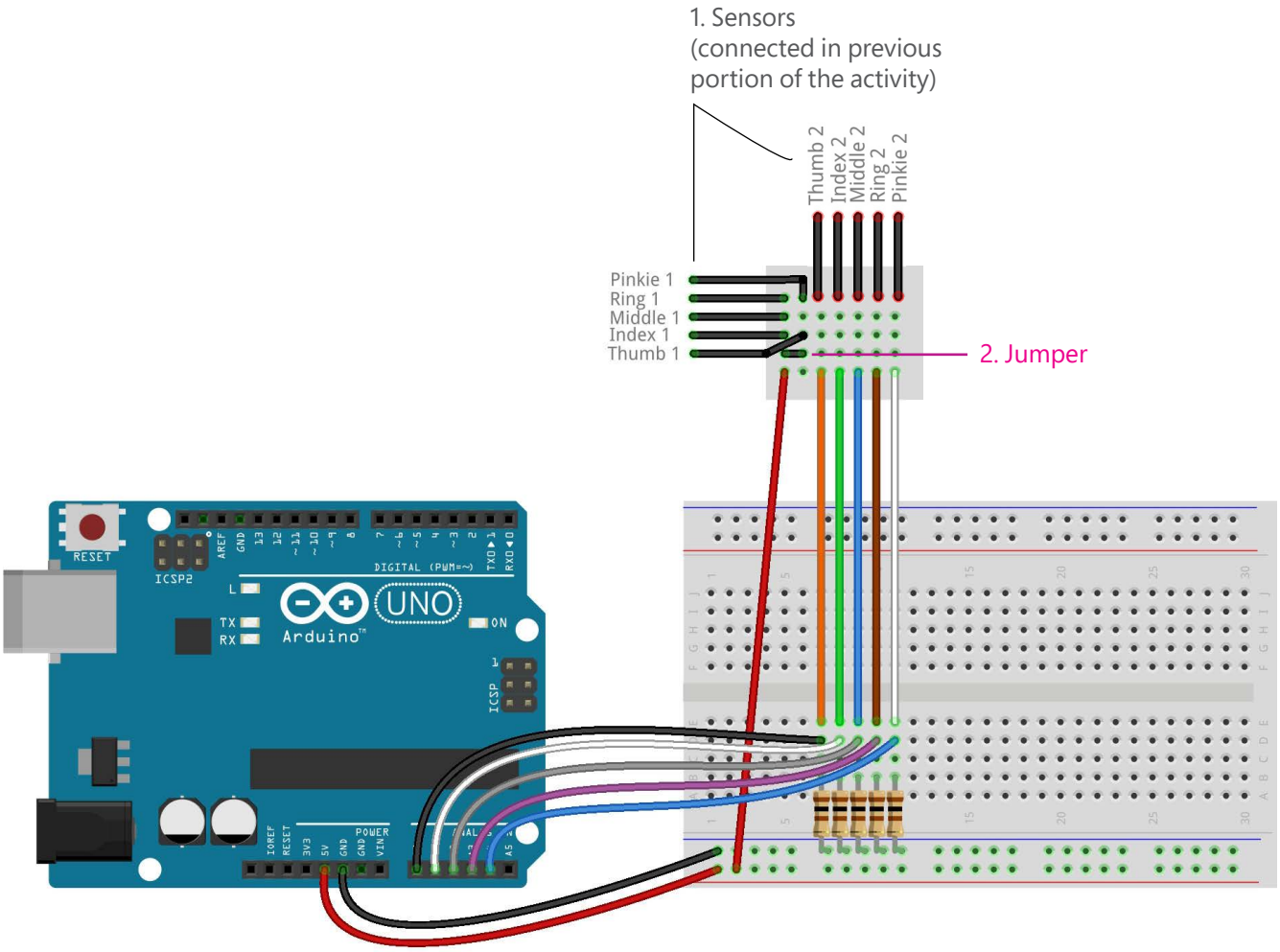
Then select Tools > Board: "Arduino/Genuino Uno" > Arduino UNO.



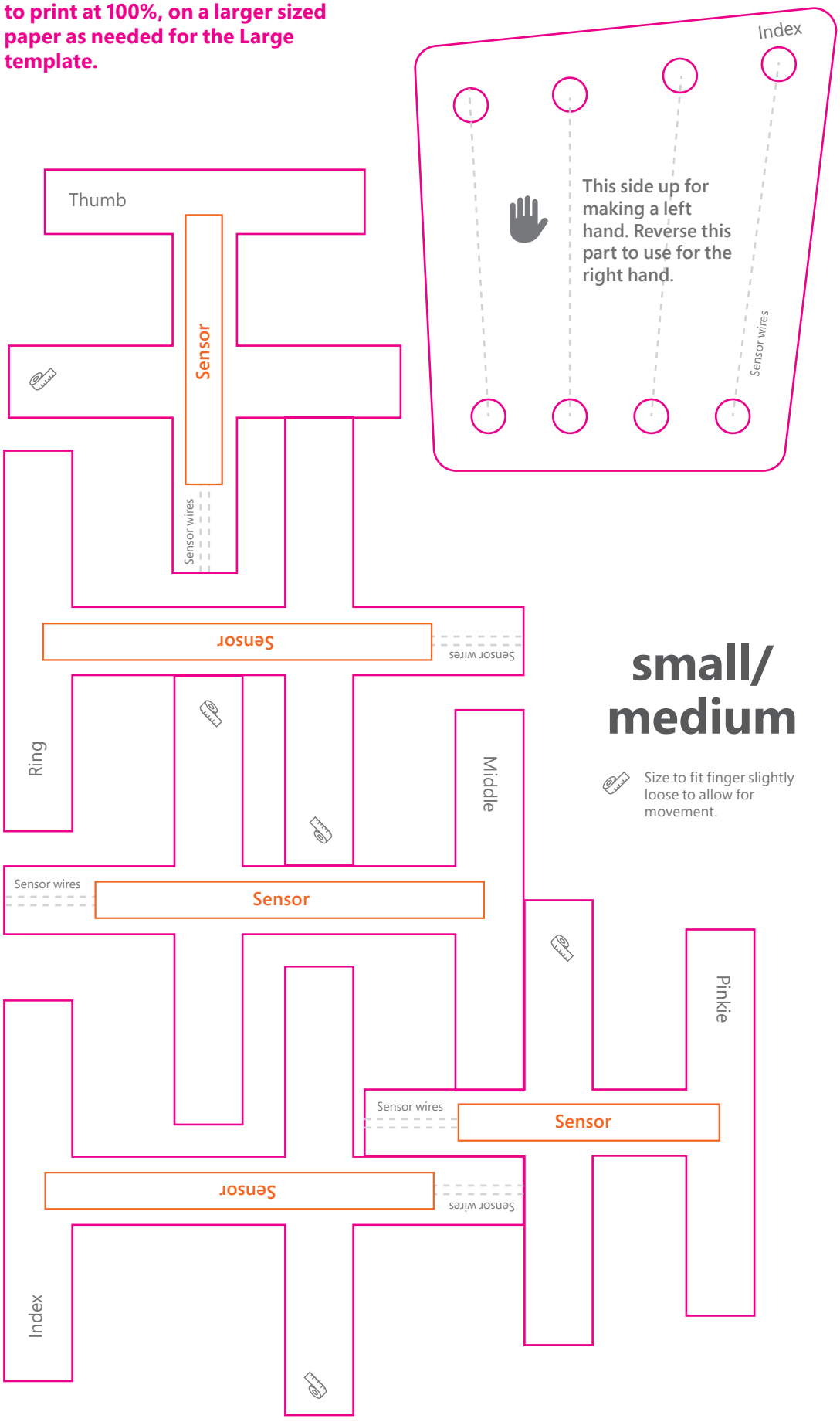
Click on the circular right arrow button to upload.

Connect to the Arduino module

1. Much of your mini breadboard is already completed when you attached your finger sensors, those components are included in the diagram.
2. Take a very small length of wire, between 1 and 2 cm and strip the ends to create the Jumper which should be placed in the mini-breadboard as shown.
3. Use the remaining components and complete the assembly of the module.

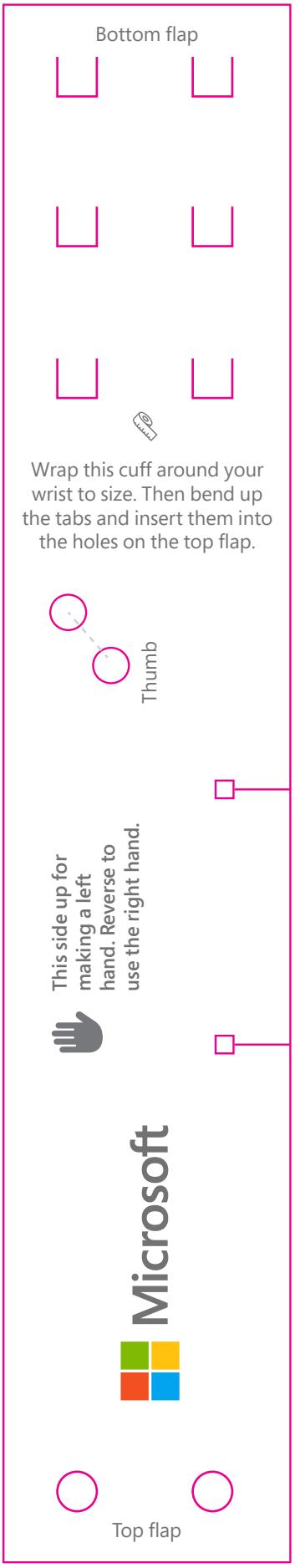


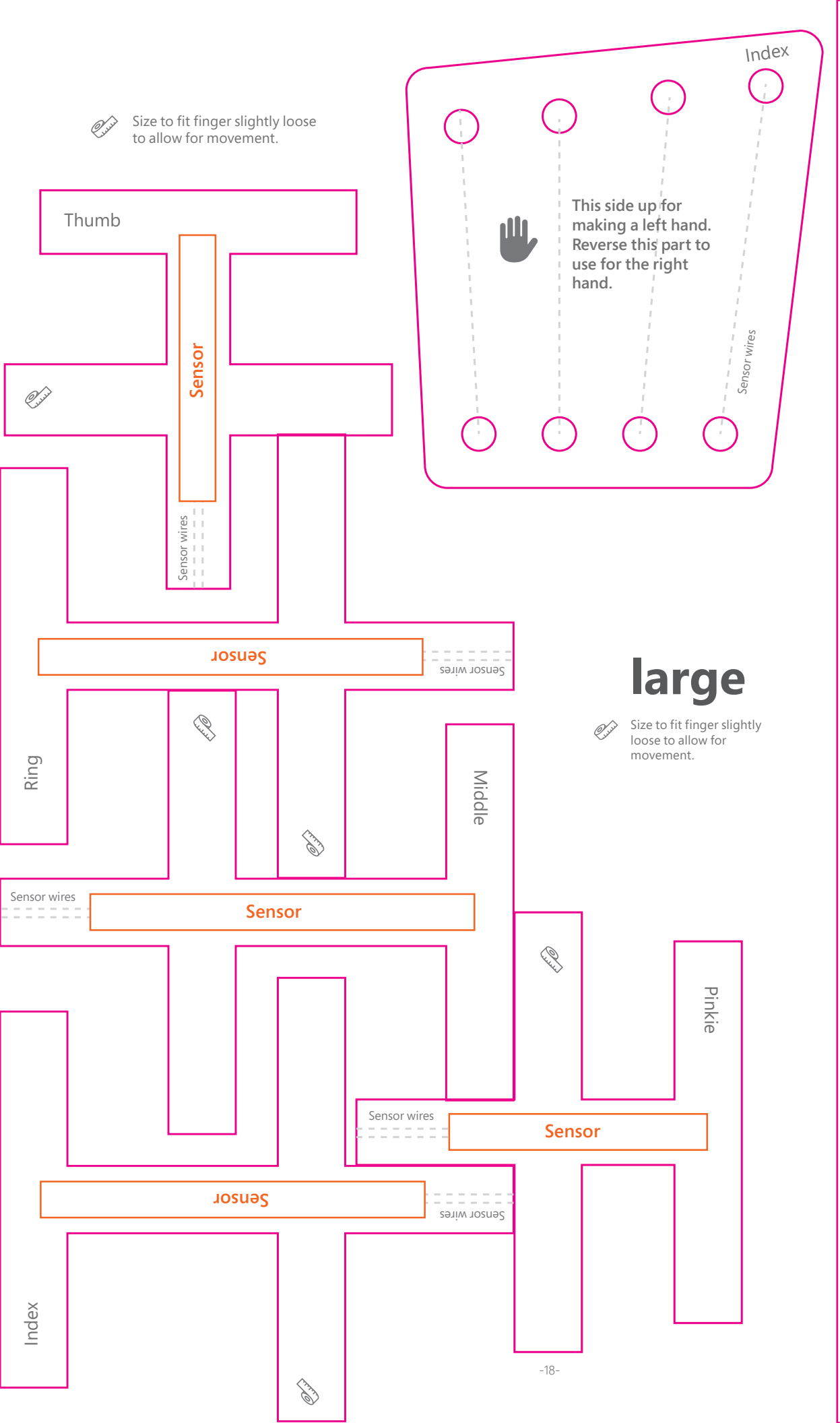
Pink lines are cut lines, make sure to print at 100%, on a larger sized paper as needed for the Large template.

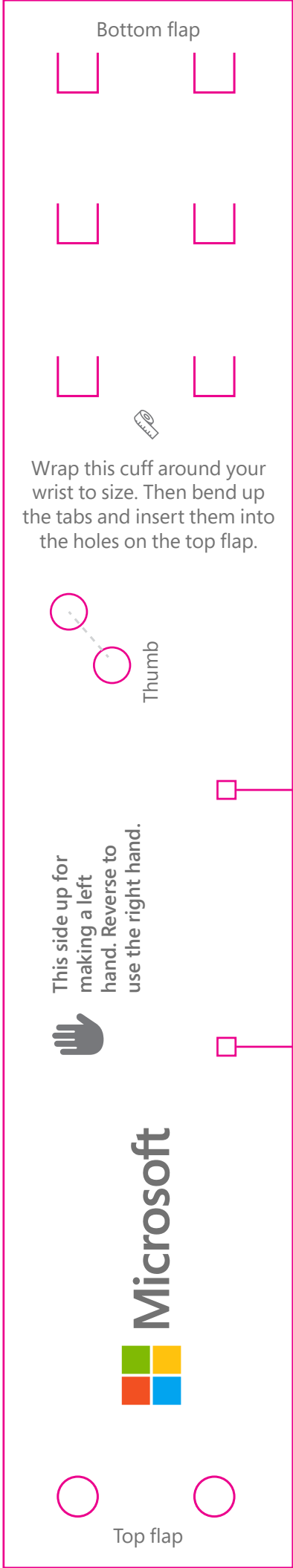


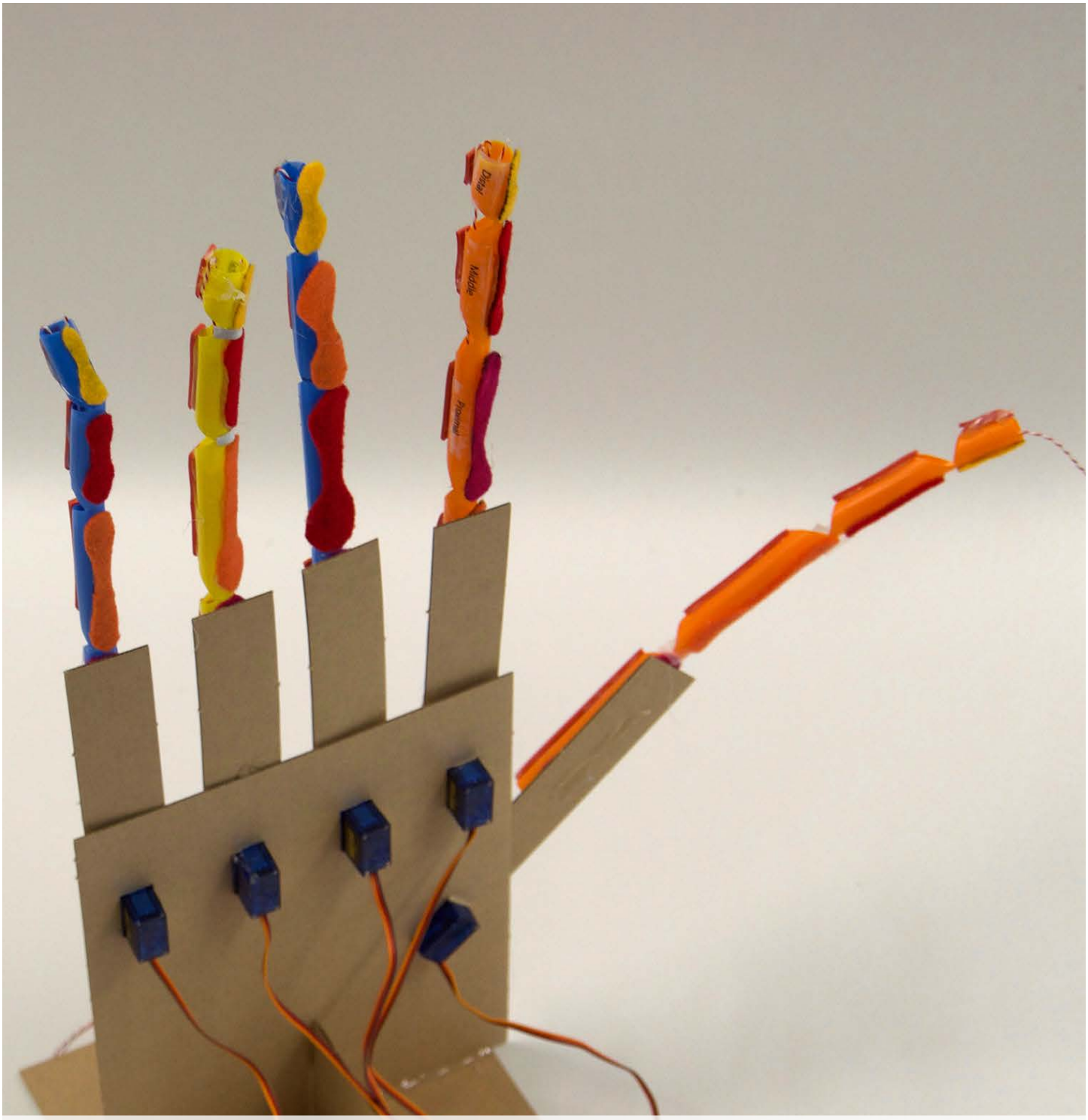
small/ medium

Size to fit finger slightly loose to allow for movement.



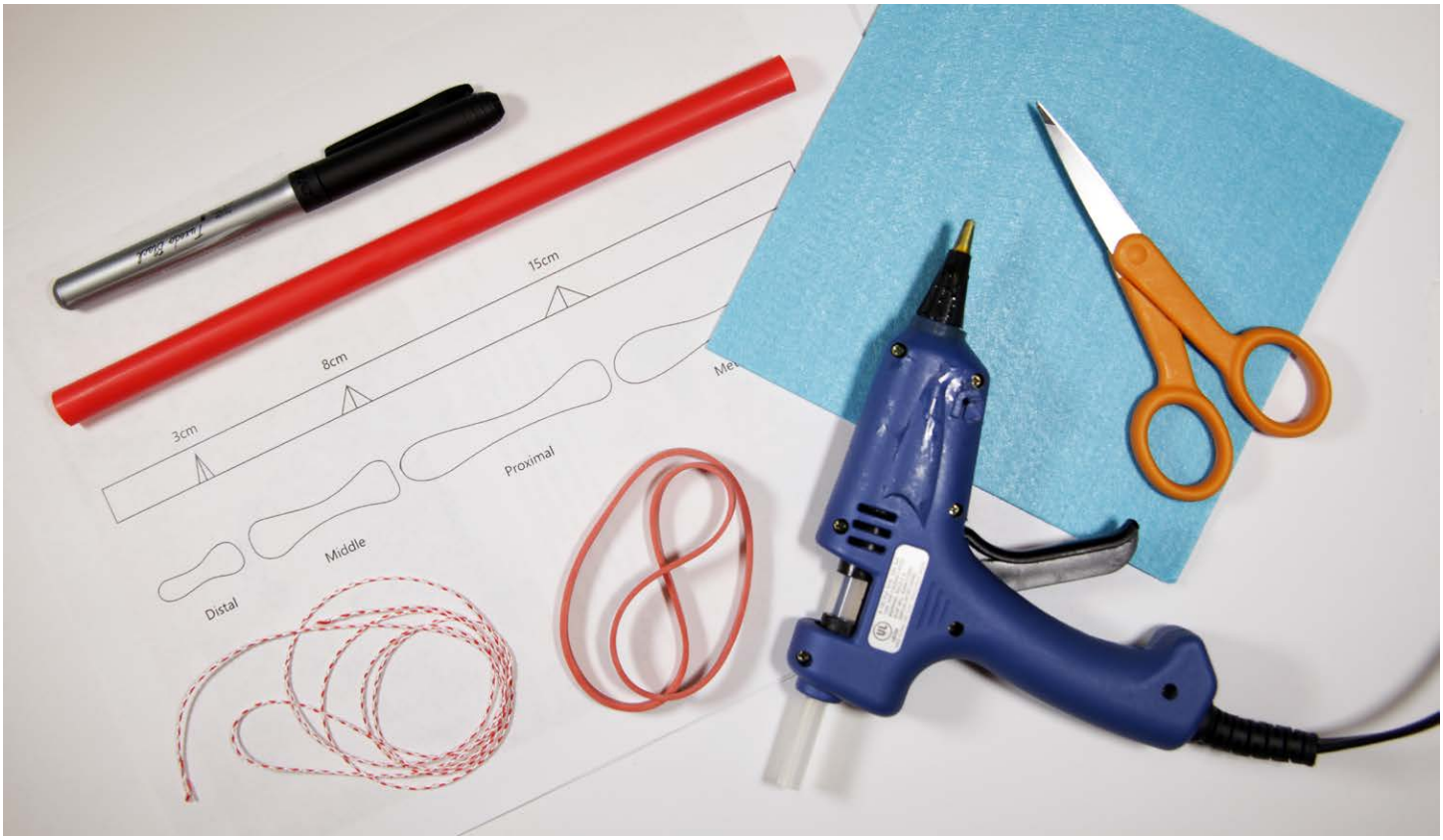

Size to fit finger slightly loose to allow for movement.
Thumb
Sensor
Sensor wires
Sensor
Sensor wires
Ring
Middle
Sensor wires
Sensor
Pinkie
Sensor wires
Sensor
Sensor wires
Index
Index
This side up for making a left hand. Reverse this part to use for the right hand.
Sensor wires
large
Size to fit finger slightly loose to allow for movement.


Bottom flap
Wrap this cuff around your wrist to size. Then bend up the tabs and insert them into the holes on the top flap.
Thumb
This side up for making a left hand. Reverse to use the right hand.
Microsoft
Top flap



Part Two

Robotic hand



Things you'll need

Materials

- 10 milkshake straws (double what you may need, in case of breakage)
- braided dacron kite line, or fishing line
- wide rubber band (size #16)
- felt
- 5 Servo motors
- roughly 40 cm by 60 cm worth of cardboard
- straw and felt patterns (pg. 25)

Tools

- scissors
- Scotch tape
- hot glue gun + glue sticks
- Sharpie marker

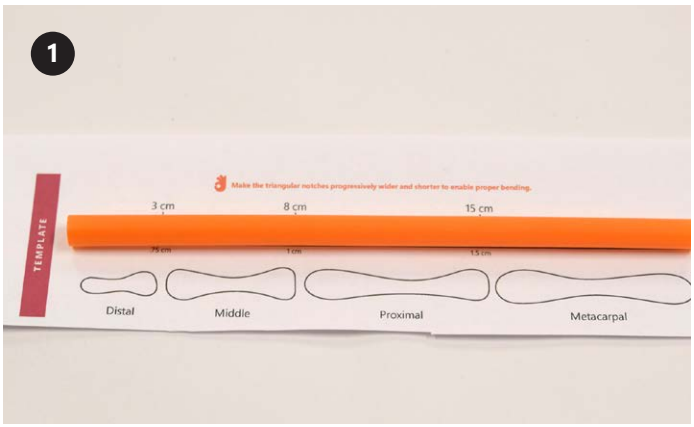
Tips for success:

We've indicated integral steps with the A-Ok hand symbol. Read and follow these steps precisely to increase your likelihood of success.

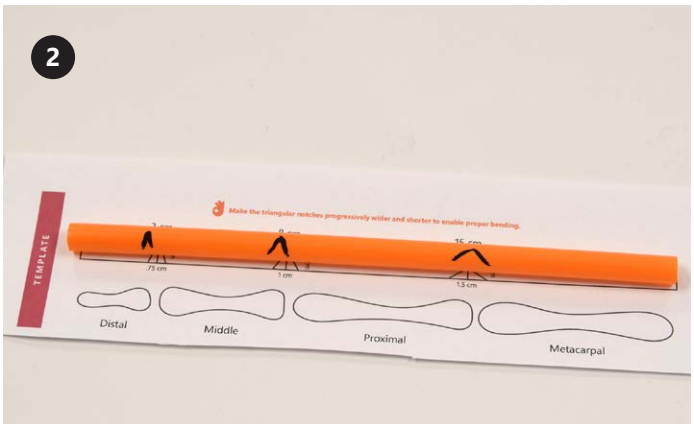
Download an Excel spreadsheet that includes a complete shopping list for this lesson:

aka.ms/robotichandshoppinglist

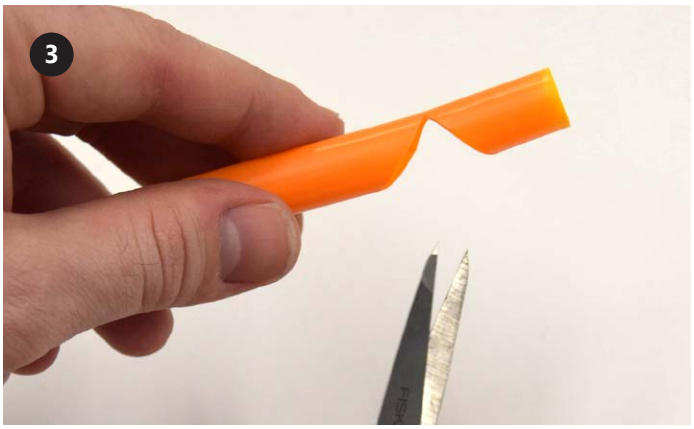
Construct fingers



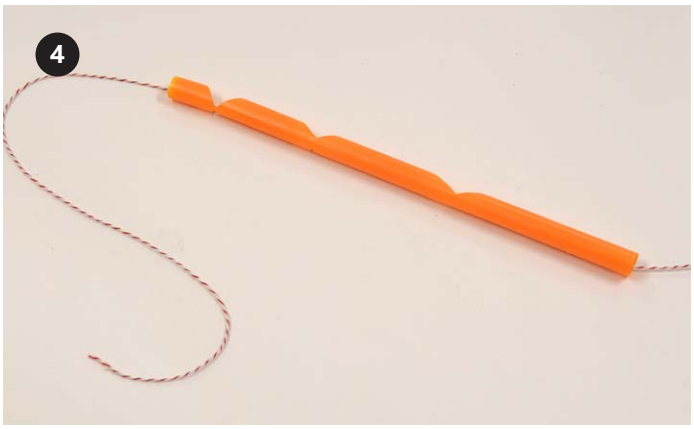
Align straw to the template on page 25.



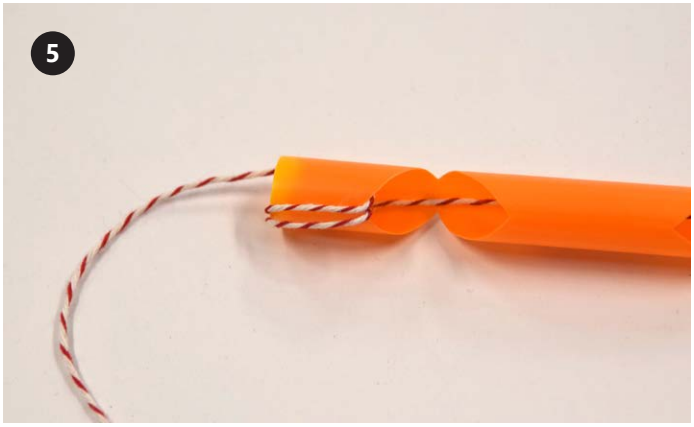
Using the spacing guide, replicate the three triangles on your straw with a marker on both side.



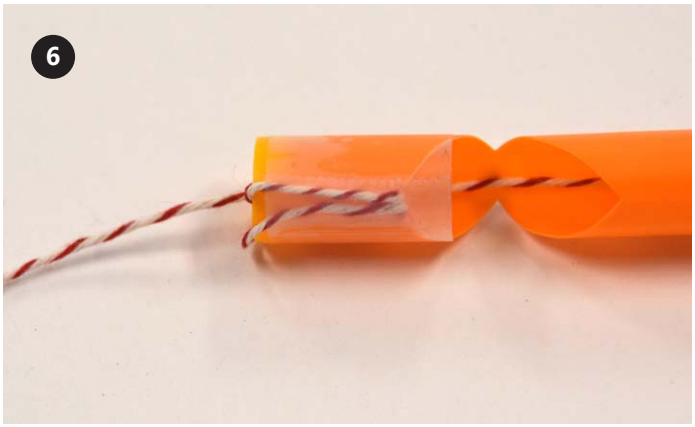
Using scissors, carefully cut at the marks so that you have a diamond shaped cutout notch. Avoid cutting with the tips of the scissors, and instead go with the middle of the blades, as this avoids snapping the straw.



Cut a piece of braided dacron about 90 cm in length. Drop the thread through the straw from the end closest to the distal notch, leaving about 7 cm at the top of the straw.

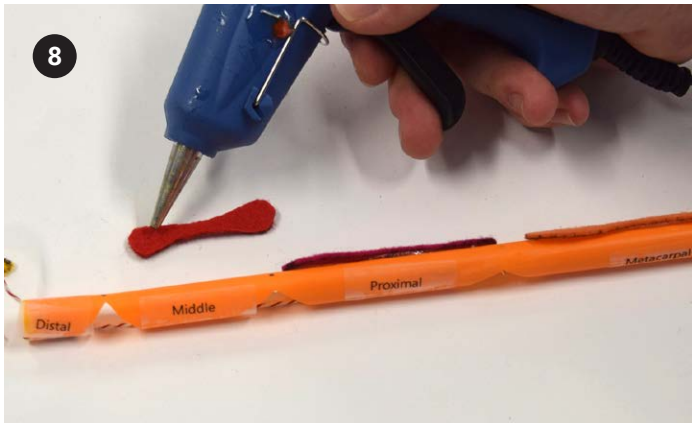


Wind the string around the top section twice.

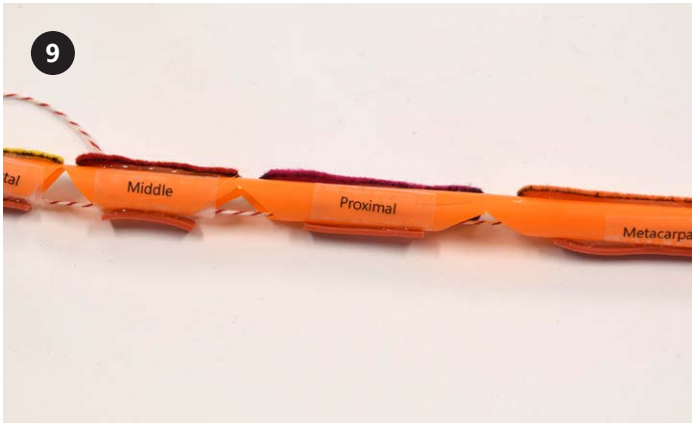


Tape the thread to the top end of the straw.

Label the finger bones using a label maker or pieces of paper.

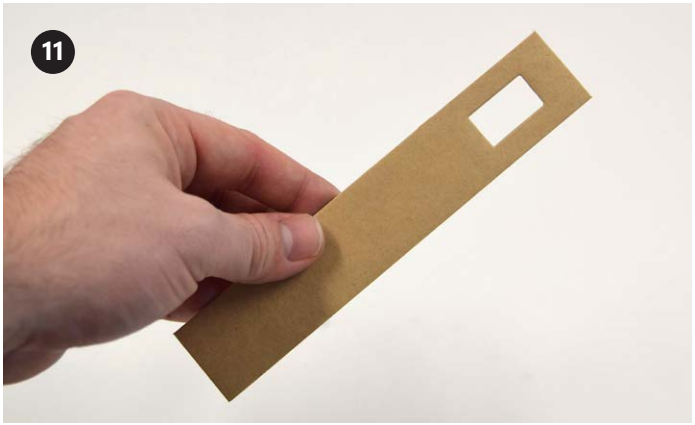


Follow with shapes cutout of felt to further represent the bones.

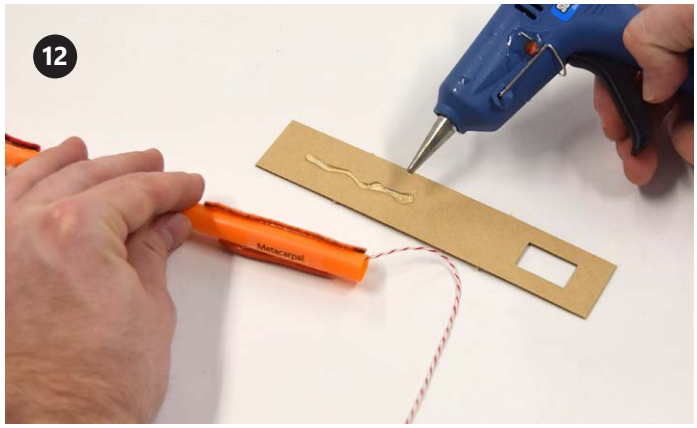


Next, cut a large rubber band into smaller pieces and glue to the inside of the finger straw to provide grip.

You should now be able to hold the bottom of the straw and pull the thread to make the finger flex along the joints. The joints should progressively bend from top to bottom. Try flexing the finger by holding the straw in one hand and pulling the string using the other. If the flex is not right try again using a new straw.

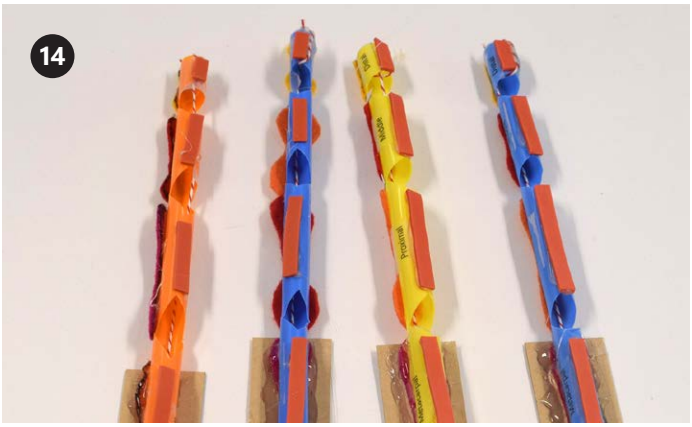


Using the finger template on page 32, cut five cardboard fingers and a servo motor mount for each finger. Pay close attention to making the hole that you will insert the servo motor into. You will want it to have a tight fit.

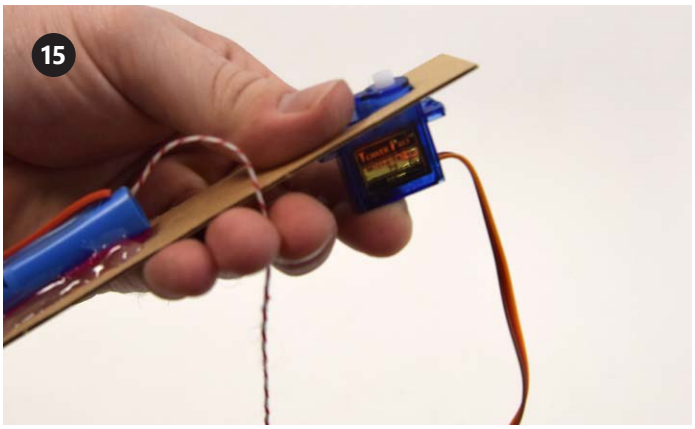


Attach the metacarpal part of the straw (the bottom ¼) to the center of the cardboard as pictured with a hot glue gun.

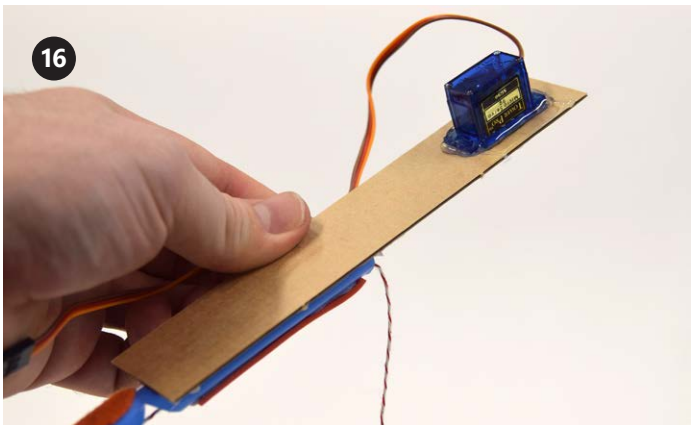
Your finger straw will resemble the above photo when completed.



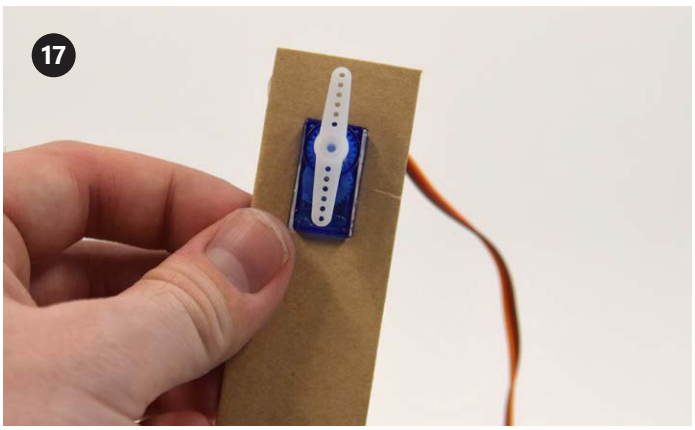
Make four additional fingers.



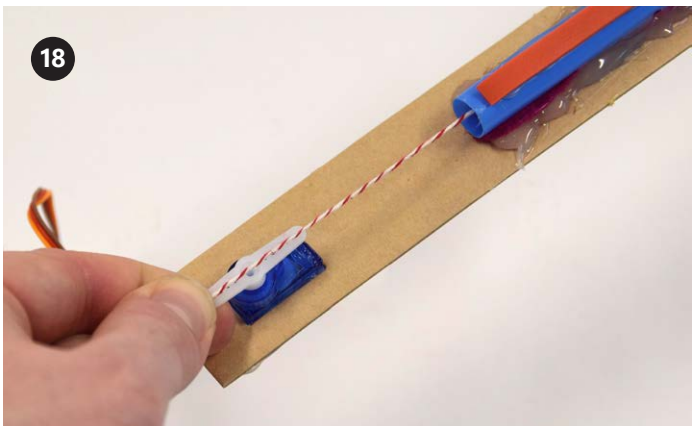
Insert a servo motor without the arm.



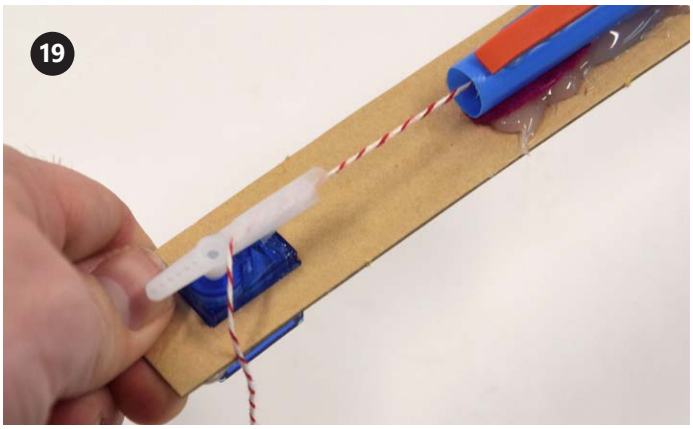
Hot glue it in place with control wires protruding out the back. Make sure that you don't glue down any of the wires.



Attach the plastic servo arm to the servo motor and slowly rotate clockwise until it stops. Remove the servo arm and reposition it so that the longest arm is pointing straight up or just past the 12 o'clock position.



Attach the string from the finger with tape so that it is tight. Pull the excess string back across the plastic arm and tape again to secure the string.

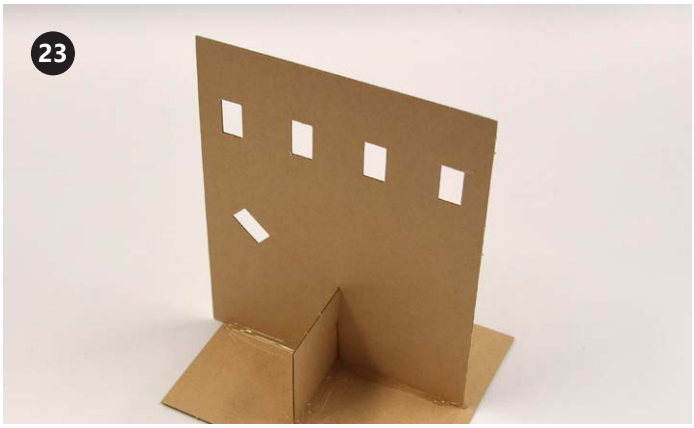


You can tape it a third time if it is helpful to keep it tight and secure.

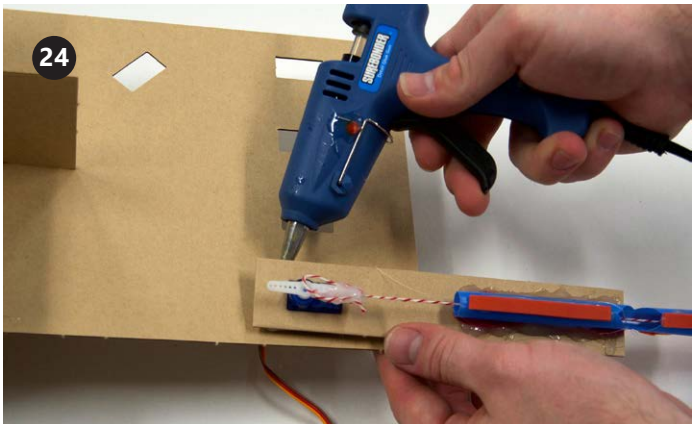
Cut out the rest of the shapes using the template on page 31 and prepare to create the base and palm.

Hot glue the palm to the center of the palm base.

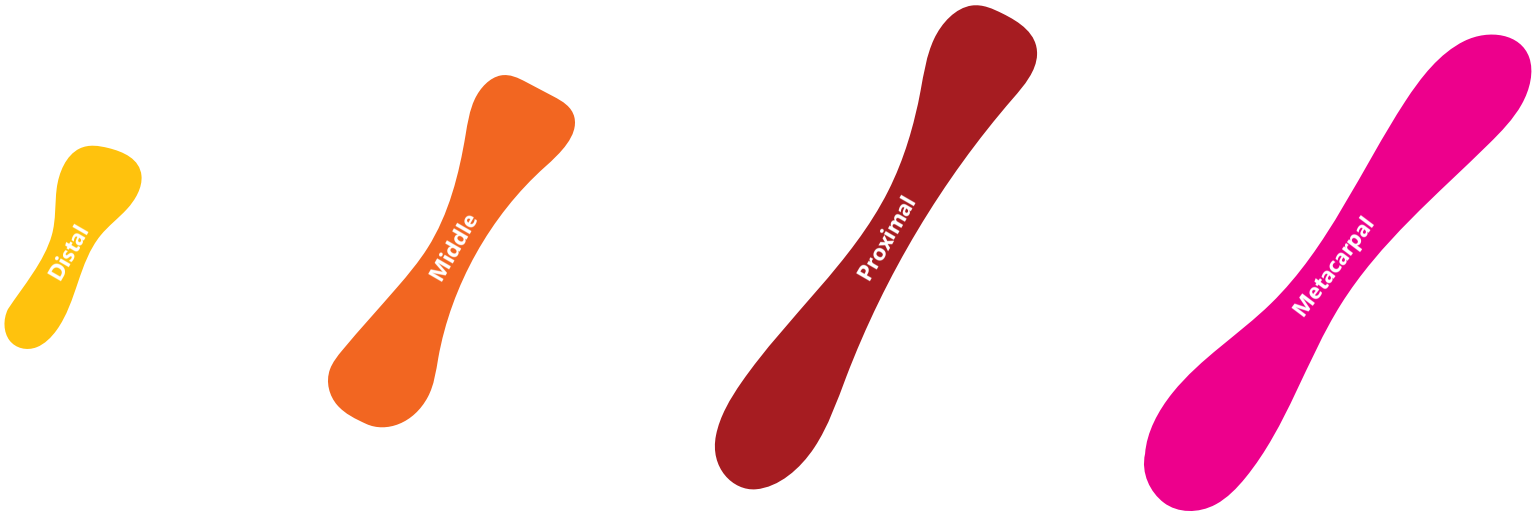
This will serve as the support for the next piece.



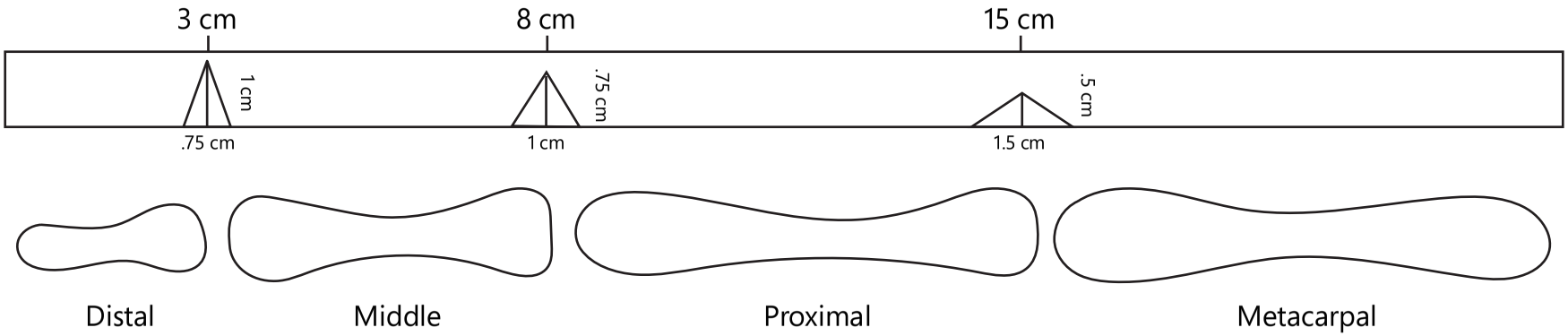
Use the palm support pieces to keep the palm stable and glue all peices together so they will stay put.



Attach each of the fingers, securing them around the servo notches with hot glue. Continue until you have all your fingers attached. You are now ready to connect to your microcontroller and operate your robotic hand!



Make the triangular notches progressively wider and shorter to enable proper bending.



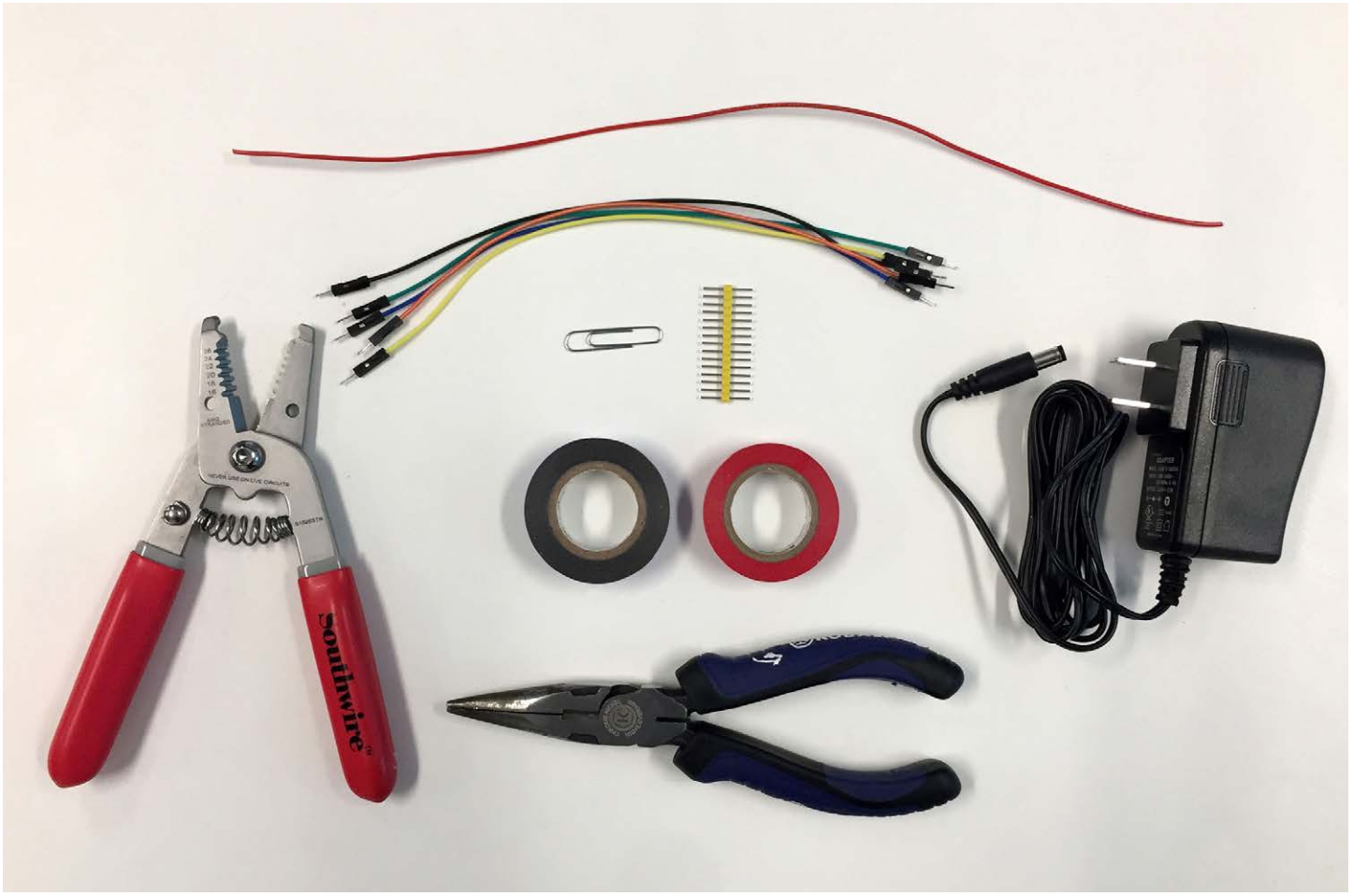
Robotic Hand
Arduino Activity Part 2

You can now use your robotic hand to visualize how bones work within the skeletal system. You will use a microcontroller and several specialized components to connect to an Excel workbook.

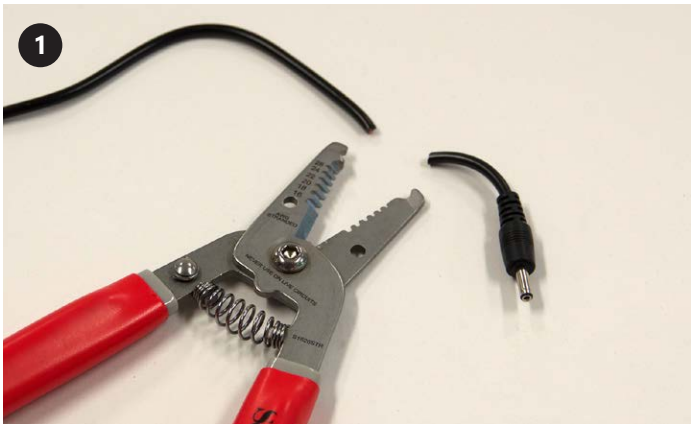
Things you'll need

Materials
- 16 solderless breadboard jumper wires
- 1 length of solid core wire, roughly 20 cm long
- 1 fifteen pin header strip
- 1 modified 5V power supply (See following page for mod instructions)
- 1 paperclip

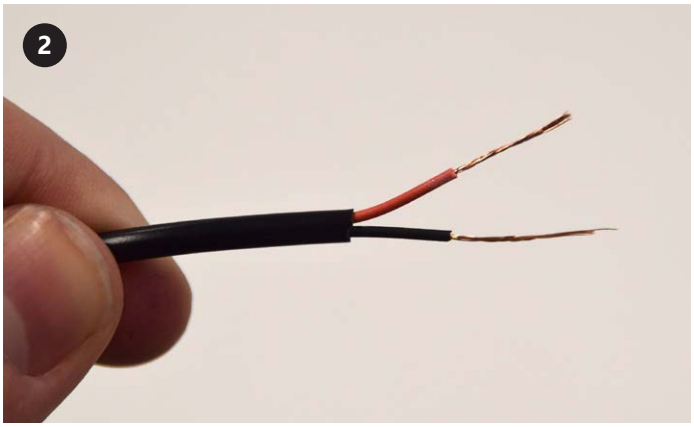
Tools
- wire cutters
- pliers
- red and black electrical tape



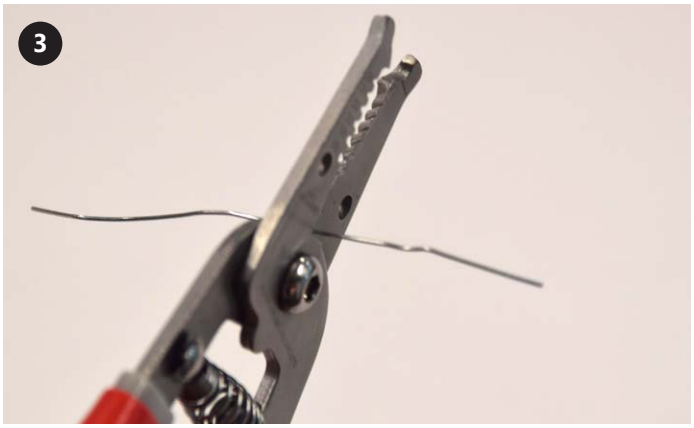
Modify the power supply



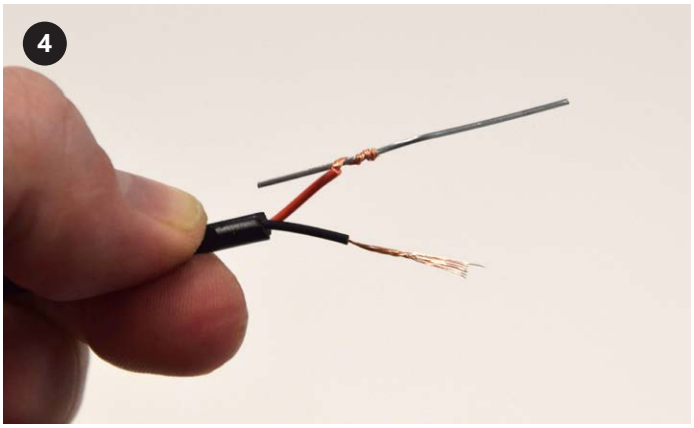
Take the power supply, and using wire cutters, cut the end off the connector.



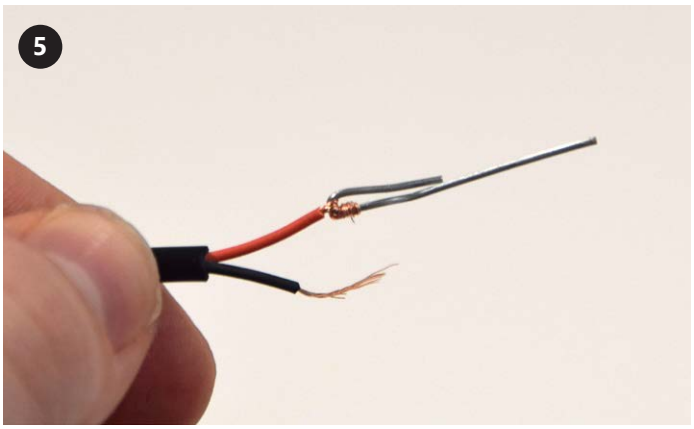
The cable is made of two wires, side-by-side. Peel the two wires apart at the end. Using wire strippers, remove about 2 cm of insulation from the ends of the wires.



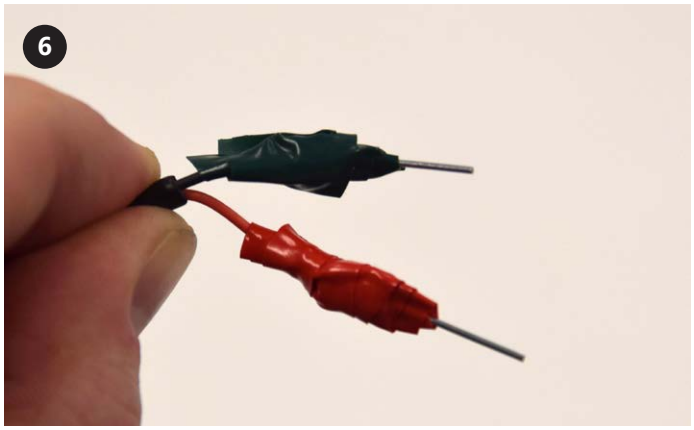
Straighten the paper clip and cut it into 2 pieces 5 cm long.



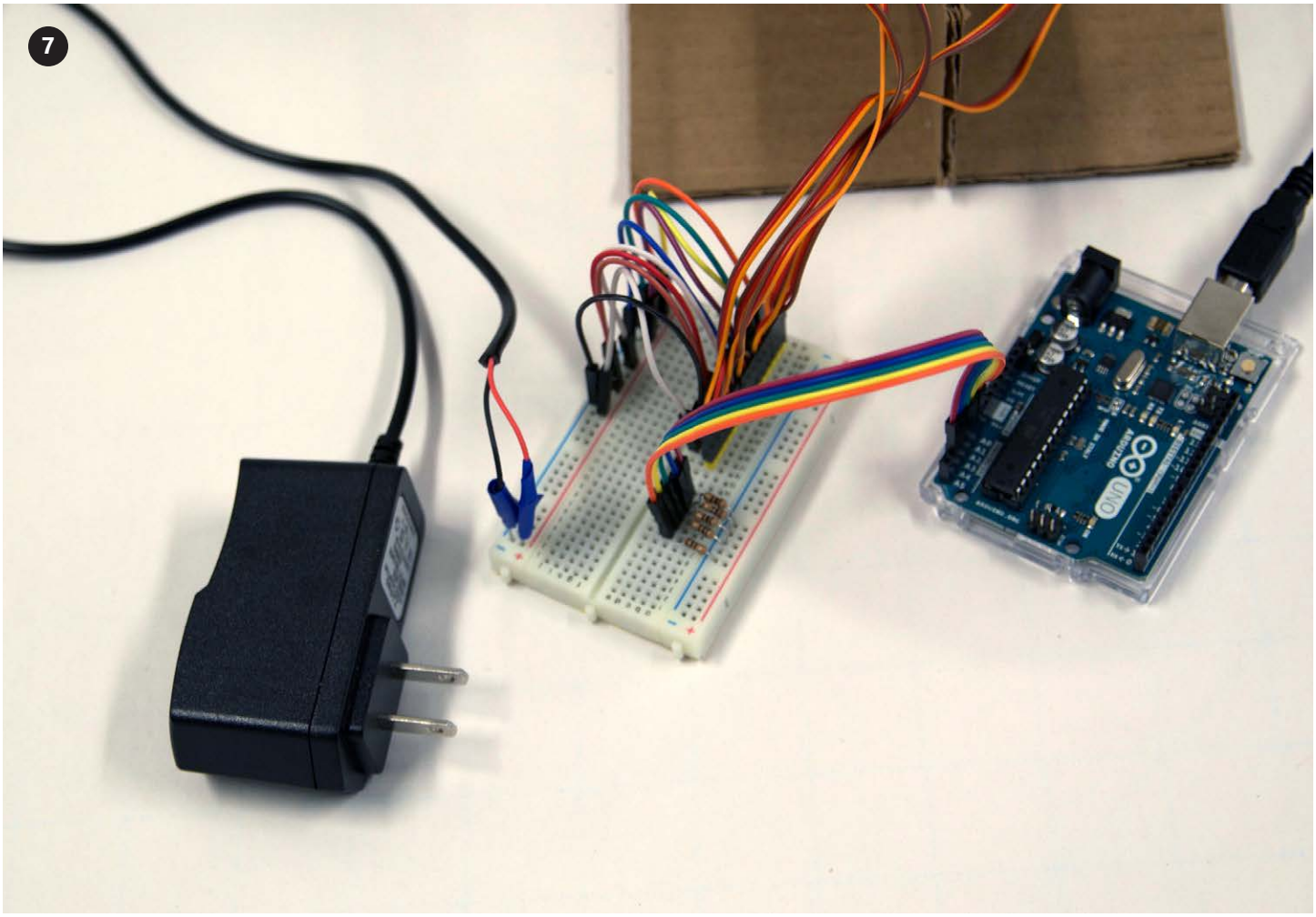
Line up one piece of paper clip with one of the wire ends and wrap the wire around the end of the paper clip, as shown in the photo above.



Using pliers, bend the paper clip over the wrapped wire, as shown in the photo. This prevents the wire from slipping on the paper clip when removing it from the breadboard.



Wrap black electrical tape around the end of the unmarked black negative wire (as opposed to the red or white-dashed positive wire) ensuring that the end of the paperclip can be inserted into the breadboard. Wrap red electrical tape around the other paper clip and wire in the same fashion as you did previously with the black wire.



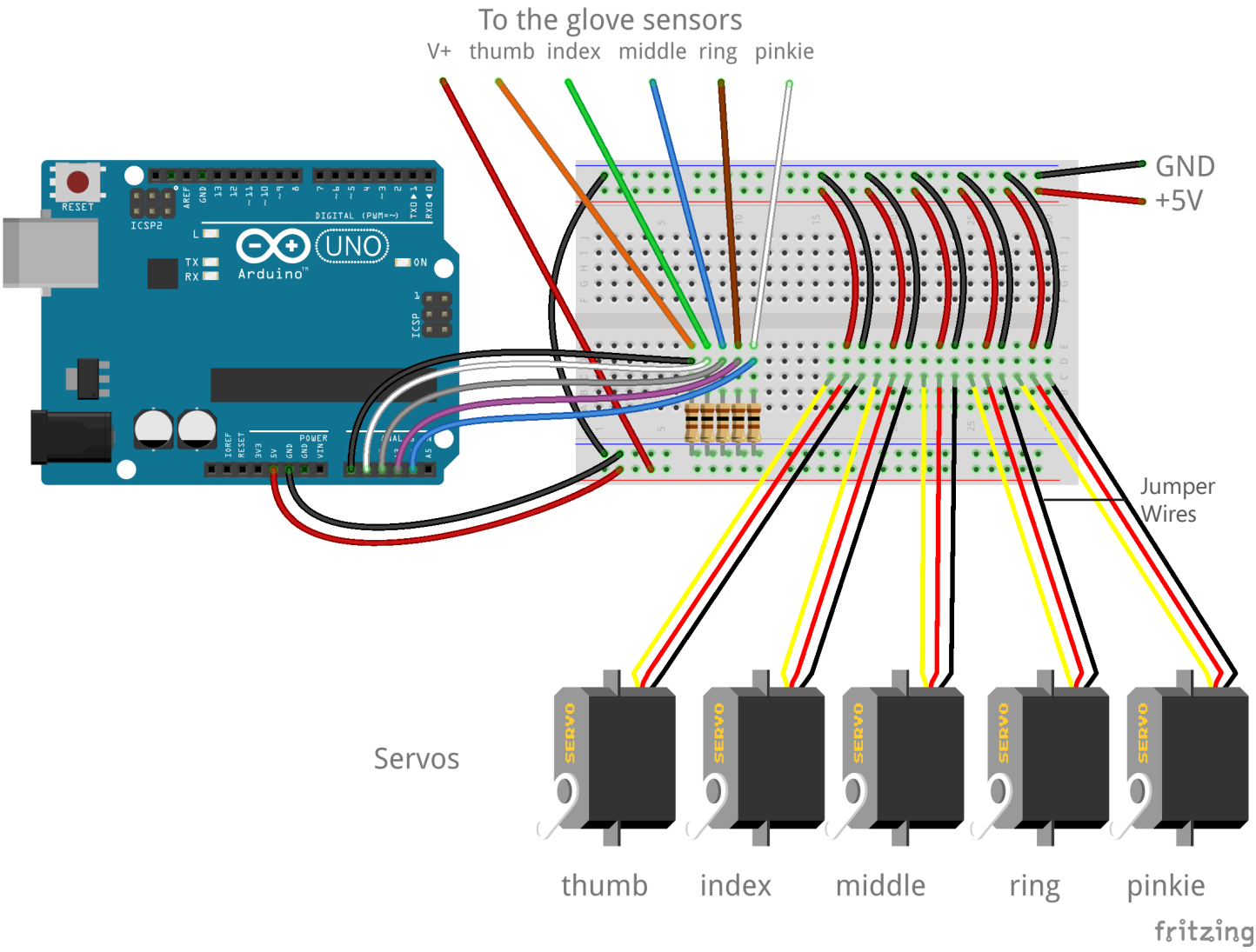
Place the ends of the power wires into the end of the breadboard like so. We will go more in depth on the breadboarding schemes on the next page.

Connect to the Arduino module

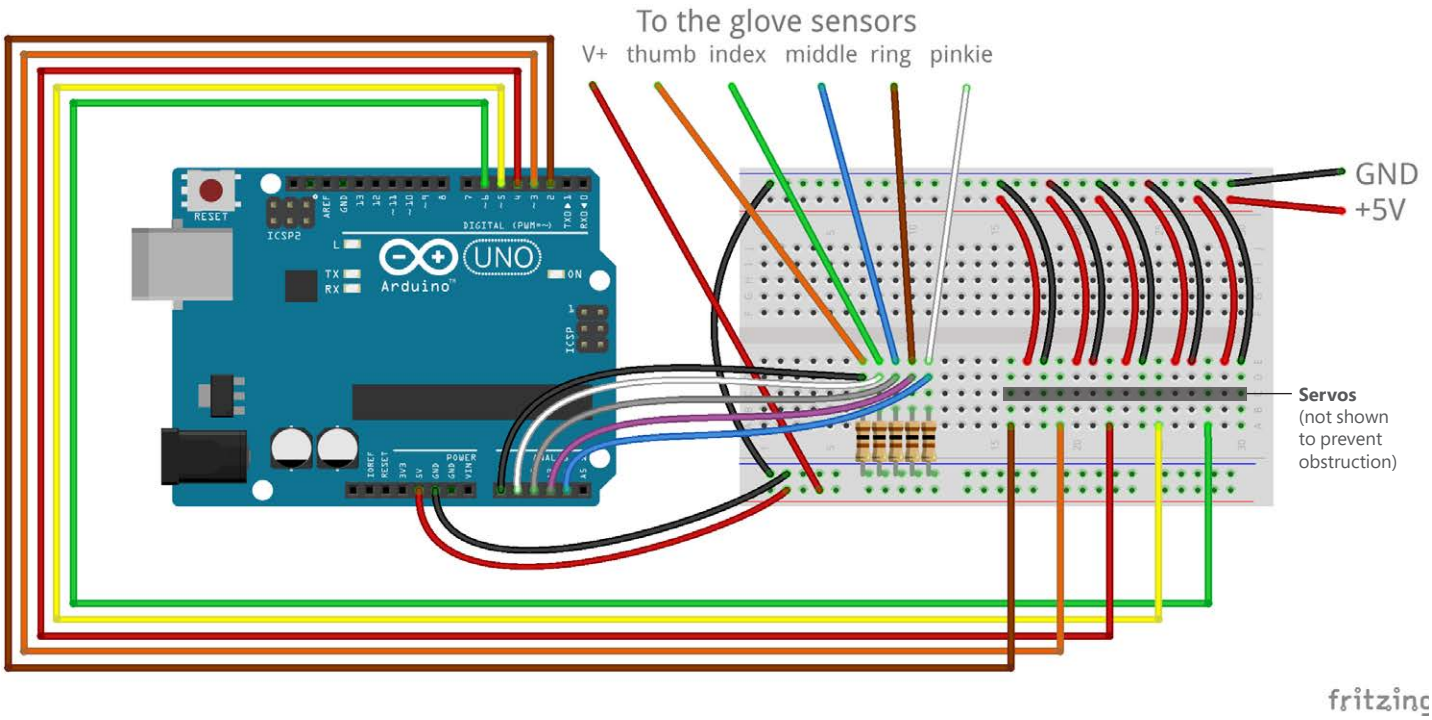
1. Gather your modified 5V power supply along with the other materials listed on page 26.
2. Next, cut your Pin header strip to include just 15 pins if you have not done so already. This is enough to accomodate the servo connections.
3. Insert the 10 jumper wires into the breadboard as shown in the diagram below.
4. Using your remaining components, complete the breadboarding as shown in the diagram. Note: the diagram does not show the items placed in Part 1.

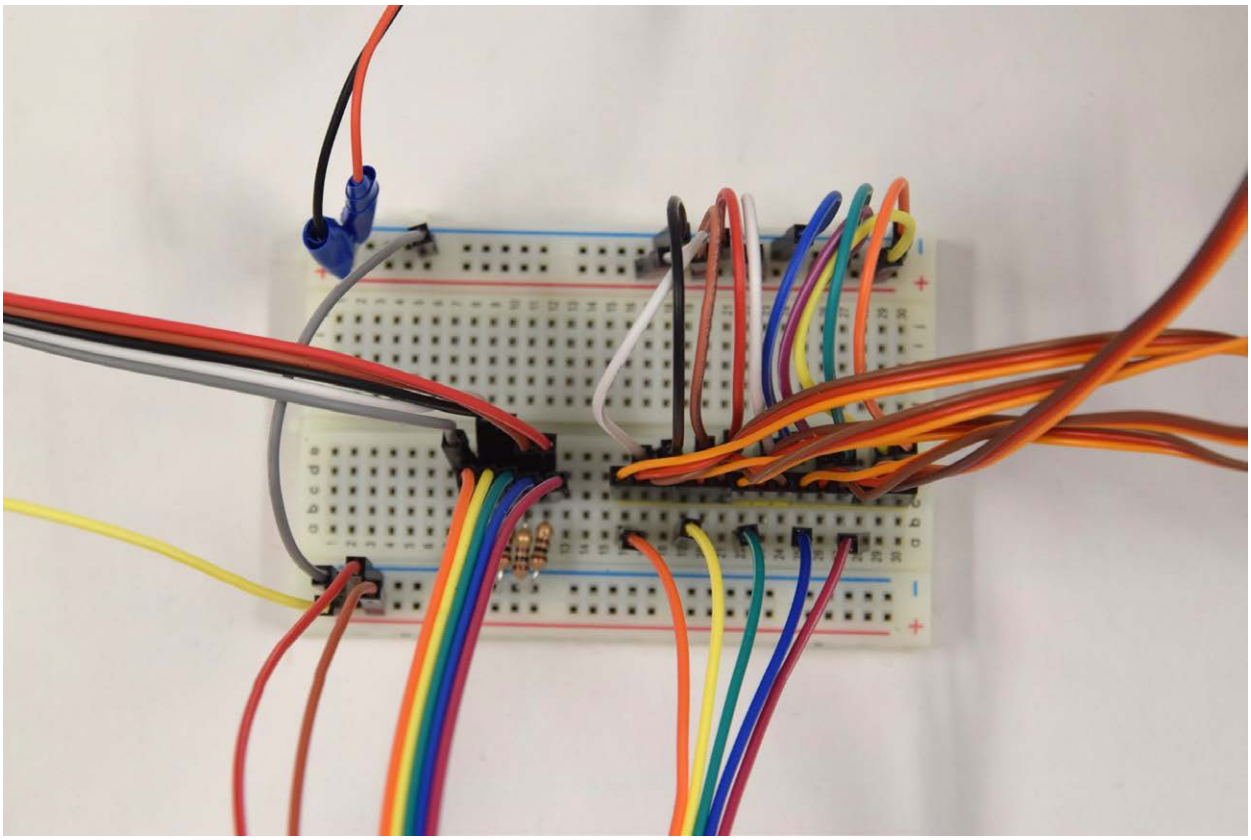
Note: For simplicity, this diagram does not show the breadboarding done in Part 1. The full diagram is shown on the next page.

PART 2 BREADBOARDING

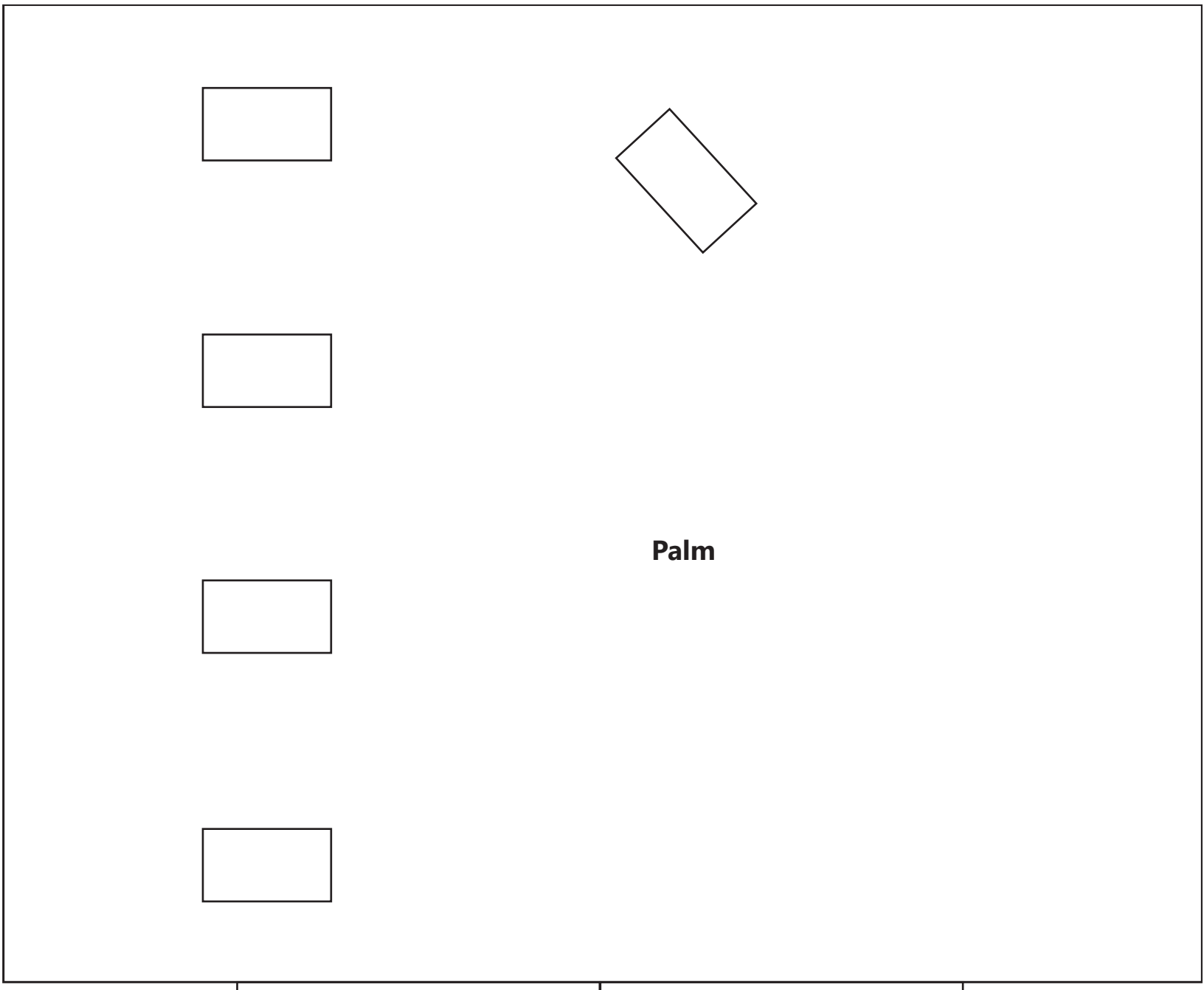


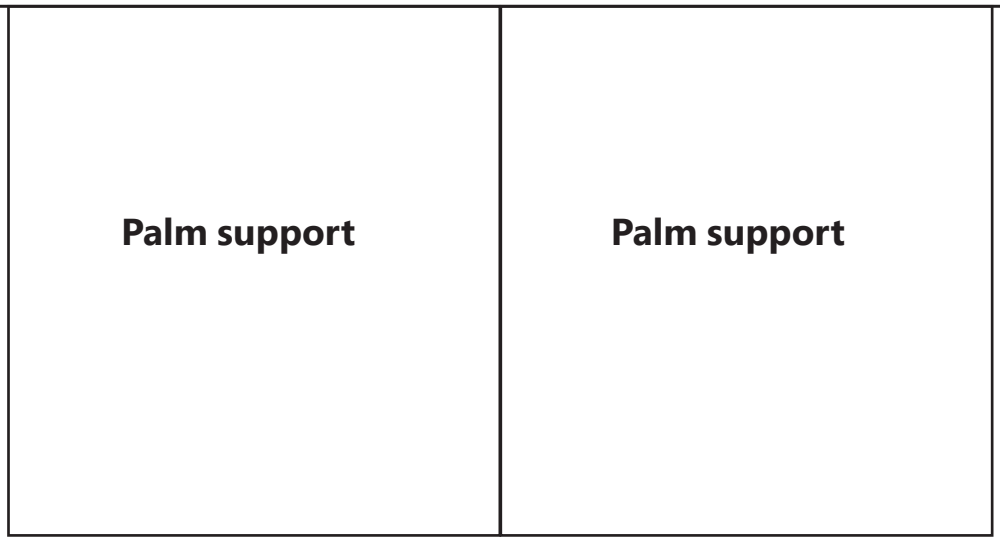
PART 3 BREADBOARDING



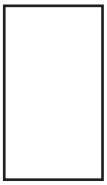


Congratulations! You are now ready to connect to Excel and operate your robotic hand. See page 33 to make sure your ready to go with required Excel add in, then you can move through to the Excel Workbook section and view your data in Excel.


Palm


Palm support
Palm support

Finger Template



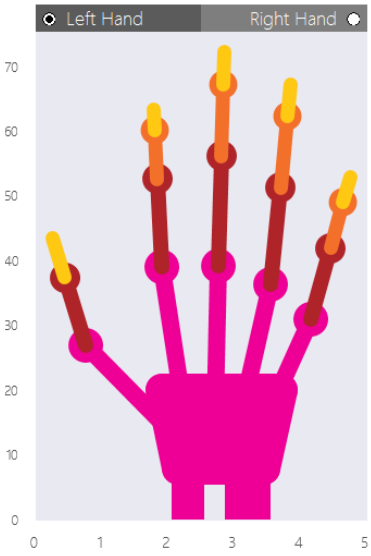
Hand Base

Get ready to visualize data

To complete the full project, make sure you meet these technical requirements:

- PC running Windows 10, and Excel 2016 (Desktop)
- Project Cordoba Add-In: Modernize your existing copy of Microsoft Excel 2016 with a free add-in to support real-time data streaming from your projects available at: aka.ms/getaccess
- Customized Excel Workbook available at: aka.ms/biomechanicsworkbook

Excel workbook basics



Hand Visualization

Get started by selecting Left or Right for your gloved hand. As you move your fingers, you should see the movement approximated on the plot.

Phalanyx Flexion

Details on incoming data are provided in a corresponding table, beginning with the Phalanx Flexion. 100% represents a Full Flexion. For example, a closed fist with all fingers fully flexed would be represented by all five fingers having 100% flexion. Alternatively a fully open hand with all fingers fully extended would be represented by all five fingers having 0% flexion .

In real-time, the tops of each phalanx bone in the Hand Visualization are reflected and approximated in the XY coordinates portion of the table.

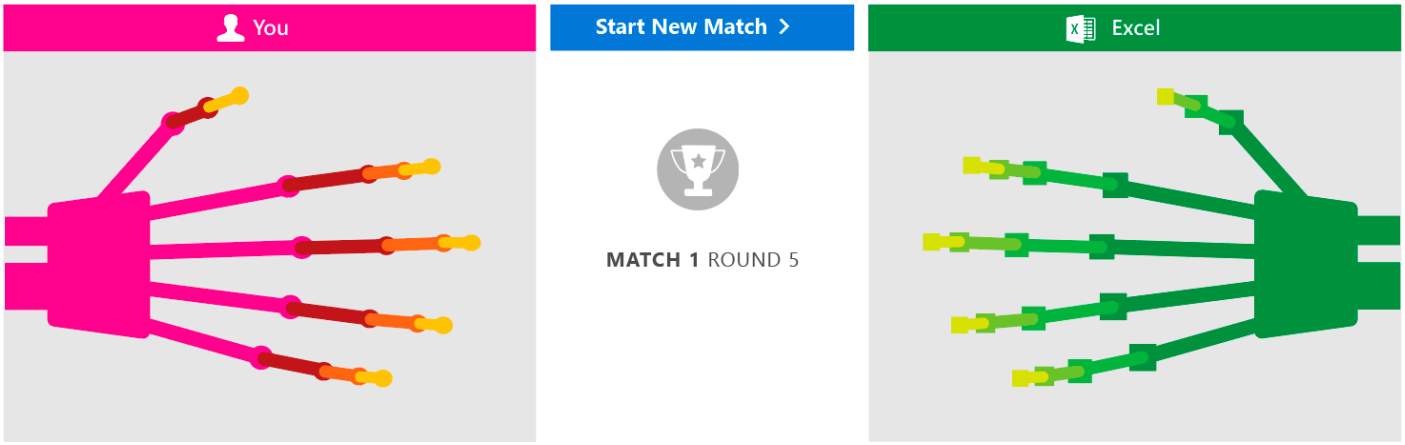
Phalanx Flexion						
100% = Full Flexion *0% = Full Extension*		Thumb	Index	Middle	Ring	Pinky
		0%	9%	0%	0%	0%
x,y coordinates (top of bone)						
Finger digit		*Thumb*	*Index*	*Middle*	*Ring*	*Pinky*
Distal Phalanges	*x*	0.25	1.77	2.85	3.85	4.75
	y	43.43	63.43	72.20	67.29	52.98
Middle Phalanges	*x*		1.79	2.83	3.80	4.64
	y		60.23	67.20	62.29	48.98
Proximal Phalanges	*x*	0.43	1.83	2.80	3.70	4.45
	y	37.43	52.65	56.20	51.29	41.98
Metacarpals	*x*	0.75	1.90	2.75	3.55	4.15
	y	26.94	39.00	39.20	36.29	30.98

Rock, Paper, Scissors Extension

With your glove connected to the Project Cordoba add-in, you can play Rock, Paper, Scissors (RPS) with Excel.

Game basics

The sensorized glove you have created and connected to the excel worksheet can be found on the left side of the worksheet while Excel's hand gestures are represented on the right. An RPS match will consist of 5 rounds. In each round you will see the message sequence "Ready", "Set", "GO!". When "GO!" appears, throw your RPS gesture.



RPS game history

The rounds will be shown below the hand visualization while the match number can be found in the between the two hand visualizations (Note: if your gesture cannot be determined, the round will end as a tie). The history of the gestures thrown in the current match's rounds can been seen below the main hand diagram areas. After 5 rounds, the winner of the match will be the player (you or Excel) with more round wins. Details on prior matches are also available at the bottom of the worksheet.

	R / P / S	Round Wins	Match Wins
Today	33% / 67% / 0%	0	0
All Matches	33% / 67% / 0%	0	0

Round Ties	Match Ties
0	0
0	0

R / P / S	Round Wins	Match Wins
33% / 67% / 0%	0	0
33% / 67% / 0%	0	0