Technology Lab: Lab Notebook – Soft Robotics

Lab Notebook

Soft Robotics

Lab Notebook

Soft Robotics

Overview

This module will delve into an exciting and newly developing branch of robotics—soft or flexible robotic structures. When you look at an elephant's trunk or an octopus's arm, you can see natural examples of flexible structures used to grasp and manipulate objects. There are many tasks in our world that a rigid structure just does not perform well. Soft Robotics explores the development of flexible structures to work in these areas. In this module, you and your team will explore the concept of soft robots and learn how flexible structures move and how they can be programmed to perform useful tasks.

This module was developed by the REACH Lab at the University of Tennessee, Knoxville. The group focuses on medical applications of robots and soft robots, and the mathematics behind them. Members design and build new types of flexible structures, mathematically model them, and then develop control systems to transform them into medically oriented robotic systems. They hope to inspire a new generation of young roboticists with this module. You can learn more about their work on their website (https://sites.google.com/site/danielcrucker/). The work on this module was supported in part by the National Science Foundation through CAREER Award No. 1652588.

This module takes six STEM Scout meetings of approximately 90 minutes each.

Meeting 1: Soft Robot Structures

You and your team will dive head-first into the foundations soft robots in this meeting. You will learn why soft robots are needed, how they're different from other robots, and some of the ways they are developed. Using the scientific method, you will experiment with soft structures to determine the factors that influence stiffness and how these factors can make structures more or less flexible. This experience will influence your soft robot designs in future meetings.

Meeting 2: Powering Soft Robots

This meeting delves into the inner workings of a soft robot. You and your team will explore servo motors, transmissions, and powering robot motion. You will build your own flexible mini-robot to see how actuation of a soft robot can be strange, unexpected, and completely different from a traditional robot. This meeting is the second foundational step in building your knowledge so you can eventually design your own robot.

Meeting 3: Build a Soft Robotic Grasper

Not all soft robots are entirely flexible, and in this meeting, you will discover how hybrid rigid-flexible structures can lead to unique solutions by building your own two-fingered soft robotic grasper. You and your team will be guided through a build process and learn about the reasoning behind design decisions along the way, adding to your experience with engineering a soft robot.

Meetings 4 and 5: Build a Soft Tentacle-Arm Robot

Leveraging the lessons learned in prior meetings, you and your team will design and build a soft, tentacle-like robotic manipulator over the course of two meetings. Meeting 4 will focus on the design-build process of the robot structure and allow you and your team to explore designs at your own pace. The steps are open-ended to allow for maximum creativity and independent exploration. In Meeting 5, you will refine and modify your designs using notes you made in Meeting 4, and then you will add electronics to turn your tentacle arms into fully fledged robots. This meeting specifically focuses on the iterative aspect of the design process, which requires testing and experience to improve designs.

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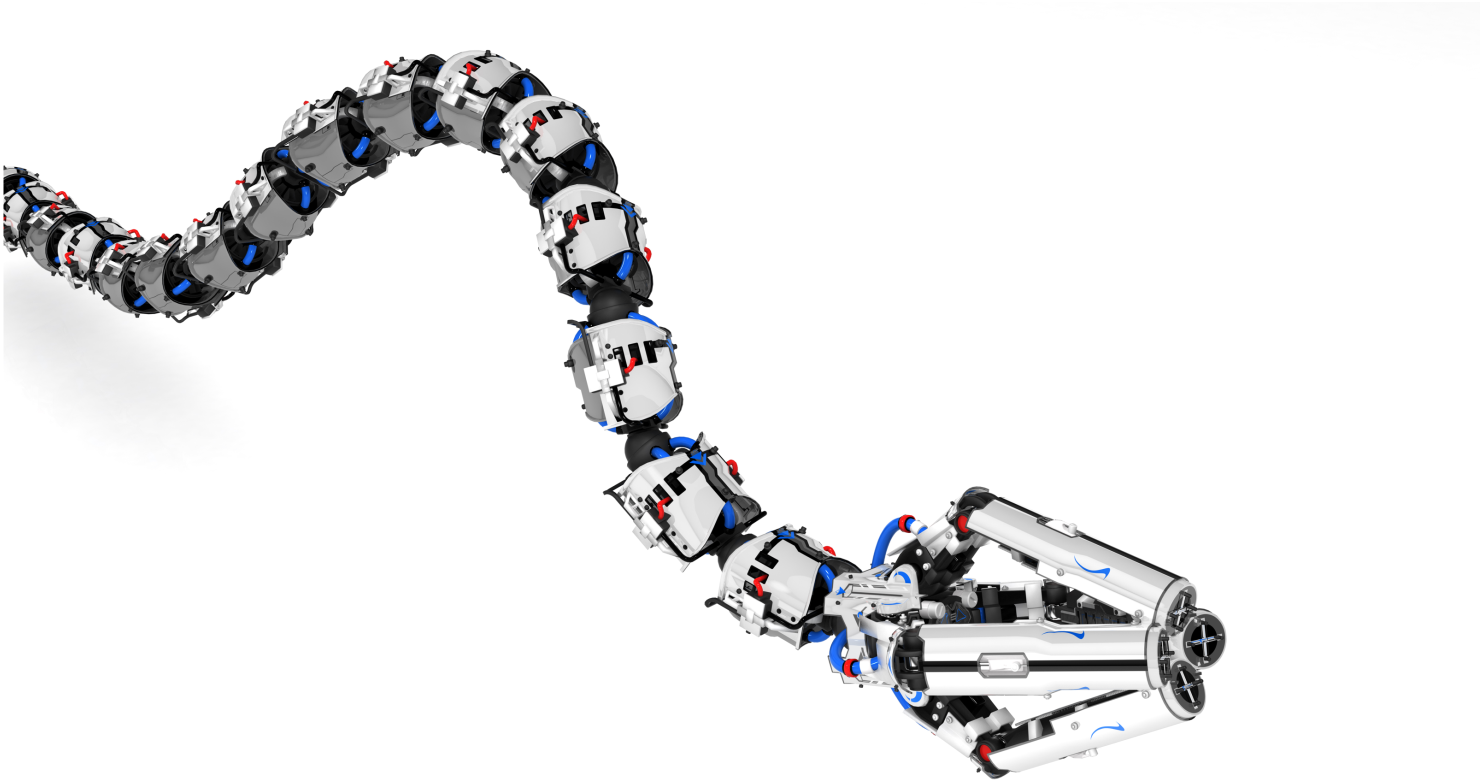
Soft Robotics

Meeting 6: Programming Motions
Using specialized software and your completed robots, you and your team will program your soft tentacle arms to perform a task. Options include making your robot dance, performing pick-and-place tasks, trying to make your robot hold a pen and write, and anything in between.

Meeting 1: Soft Robot Structures



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Meeting 1: Soft Robot Structures

Opening

The Principal Investigator will lead the group in reciting the Pledge of Allegiance and the Scout Oath and Scout Law.

Scout Oath (Scout Sign)	Scout Law (Scout Sign)
On my honor I will do my best To do my duty to God and my country and to obey the Scout Law; To help other people at all times; To keep myself physically strong, mentally awake, and morally straight.	A Scout is trustworthy, loyal, helpful, friendly, courteous, kind, obedient, cheerful, thrifty, brave, clean, and reverent.

Applying the Scout Law

Today's theme is *clean*, as in *I will help keep my workspace clean and neat, and make sure it is spotless when we are done.*

Meeting 1: Soft Robot Structures

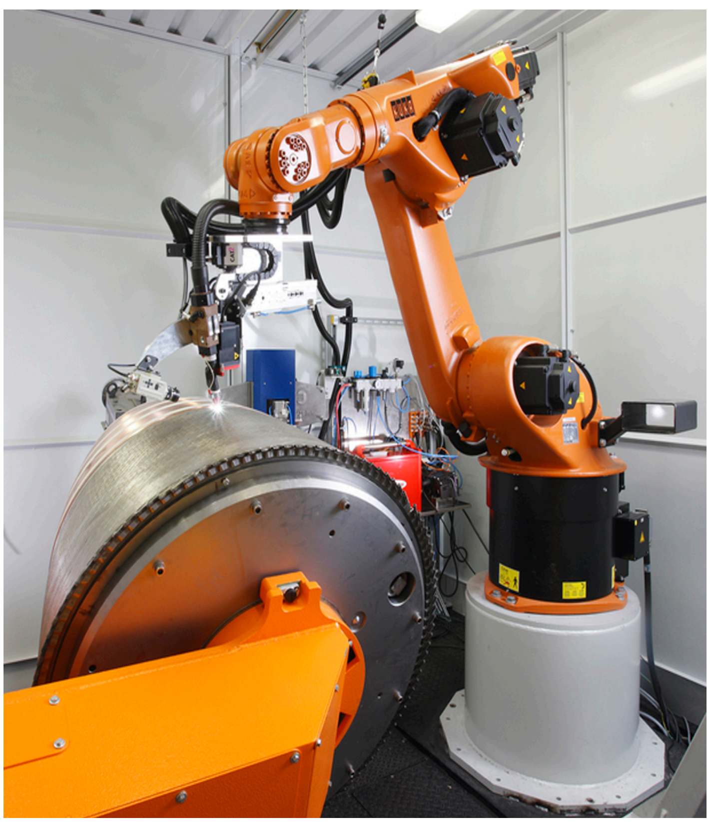
Activity Overview

In this meeting, you will learn about the concept of a soft robot and why they are needed. You will also learn about material properties and will test the flexibility of soft structures. You will be using thermoplastic beads that soften to a moldable, clay-like state in hot water in order to create flexible components and then will test their flexibility. Your team will need to share certain tools with other teams. You will be using the STEM Scouts Scientific Method to investigate the properties of flexible components.

The basic knowledge gained in this meeting will be useful in subsequent meetings where you will use the STEM Scouts Engineering Design Process to design soft robots. This mirrors the way basic scientific research is related to engineering and technology development. You should therefore take good notes and draw diagrams as you investigate material properties.

Background

"What is a soft robot?" To answer this question, we would first need to ask: "What is a robot?" The Building With mBot module explores that question in more detail, but you'll learn about robots in this module, too. One standard answer is "a robot is a machine that senses, thinks, and acts." The "thinking" part can be anything from following simple predefined instructions, to basic if-then logic, to independent planning and reasoning in uncertain scenarios. If a robot does most things on its own without input from a human, it is called "autonomous." Autonomy varies by robot: Some robots are completely remote-controlled (with no autonomy) while others are completely autonomous and act without any human input.



By KUKA Systems GmbH (KUKA Systems GmbH) [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

There are broadly two categories of robot designs. **Mobile robots** are machines that move their entire body around. These are the kinds of robots you'll see on shows like "BattleBots" or competing in obstacle courses. The type of robot we will focus on in this module are manipulators. **Manipulators** are designed to stay in one place while moving (manipulating) various objects within its reach. The space that the robot can reach from one spot is also called its workspace. Manipulators mainly handle objects by moving, assembling, or packing them, but they can also carry tools at the end of their arm to do welding, stamping, and spray-painting. The one to the left is a rigid-link manipulator that has a welding tool on its tip. Most factory robots are manipulators, and their bases are commonly fixed to the floor since they don't need to move away from the assembly line. Sometimes a manipulator is mounted on top of a mobile robot platform, like NASA's Curiosity rover on Mars. While it roams the deserts of Mars, Curiosity uses the manipulator to drill for rock samples, take pictures, and monitor its environment.

Meeting 1: Soft Robot Structures

The main focus of this module is on soft robots. A soft robot is simply a robotic machine that is not rigid but instead is made of a pliant, flexible, or soft material. Rigid-link robotic manipulators look like your arm, with joints and links, but soft robots often look more like snakes and tentacles. Instead of having well-defined links or joints, they typically bend at any point on their body and have a changeable, curvy shape, like an octopus tentacle. Many soft robot designs are inspired by things found in nature like elephant trunks, worms, and even vines. Your Lab Manager will play a video that shows some examples of soft robots.

In this meeting, you'll work with a **thermoplastic polymer** called Coolmorph beads, which soften to a moldable state when put in a cup of hot (not boiling) water. **Thermoplastic** means that while the plastic is warm, the material can be shaped, rolled, kneaded, cut, and folded into any form, much like modeling clay, and when it cools, it hardens to its original stiffness. You can do this over and over, reheating and reusing the plastic as many times as you want. Coolmorph beads stiffen into a strong but soft and flexible plastic that will work well for robots. You will reuse all of the Coolmorph material in subsequent meetings, so be sure to save it after each meeting. Your Lab Manager will play a video that shows a demonstration of how to use Coolmorph beads.

WARNING: The warm Coolmorph is very sticky. It will stick to any plastic surface, and any paper, clothing, and other porous materials. It does not stick (very much) to glass and wood, so be careful where you put your warm Coolmorph. Also, as long as it is warm, it will flow and change shape on you. Cooling the shapes quickly in ice water makes it easier to avoid these effects.

In this experiment, you'll determine what factors influence the flexibility of soft robot parts made of Coolmorph beads, investigate the properties of the plastic, and take notes to use in future soft robot design.

Safety Moment

The water in the glass beaker that is softening the Coolmorph beads is very hot. Be sure to use the craft sticks to fish the plastic out of the water bath and mold it until it is cool enough to touch.

Keep all water-sensitive items, like cellphones, away from the water!

Be careful about spilling water on your table and the floor. If you do spill water, please clean it up right away so that nobody slips and falls.

Experiment

Get into teams of four. You will stay in these teams for all six meetings in this module.

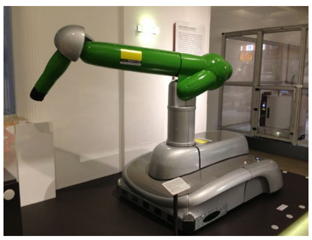
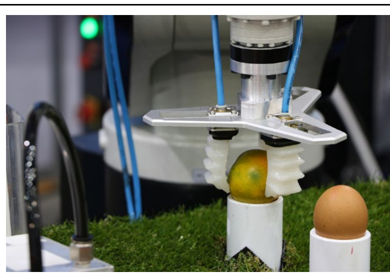
Activity 1: Classifying Robots (5 minutes)

Materials List

- None for this activity

Meeting 1: Soft Robot Structures

Several robots are shown below with descriptions of what they do and how they do it. Use the provided space to write down their characteristics. What levels of thinking do you think these types of robots do (that is, are they autonomous or nonautonomous)? Are they mobile or a manipulator? Soft or rigid?

Robot	Description	Classification(s)
 *By Projekt ANA [CC0], from Wikimedia Commons*	Executes programmed tasks, covered in hard plastic, fixed to the floor, handles objects	
 *By Assistiveinnovations [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)], from Wikimedia Commons*	Human makes all decisions, moves entire body, handles objects	
 *A prototype soft robotic tentacle wrapping around a wrist. Image courtesy of the SSSA Biorobotics Institute.*	Deforms around delicate objects, fixed to the wall, requires human commands for actions	
 *Shutterstock.com, courtesy—©Punchita Aisuriyasomporn*	*Gripper:* Can handle delicate objects like an egg, deforms under applied force *Arm:* Made of hard metal Robot uses sensor info to make decisions and carry out tasks.	

Lab Notebook

Meeting 1: Soft Robot Structures

Activity 2: Testing Material Properties (60 minutes)

Materials List

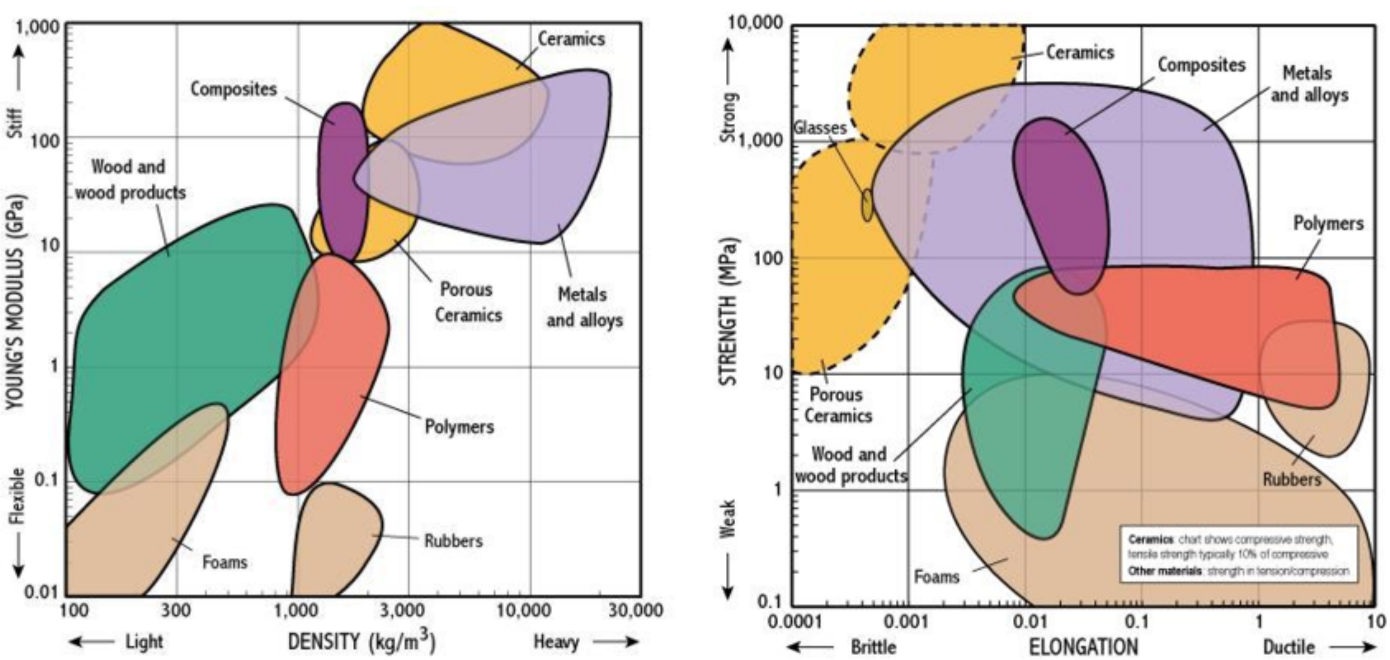
- 1 electric kettle (shared across Lab)
- 1 glass beaker
- Small handful of Coolmorph beads, about the size of a golf ball (you will need to reuse all of this material in subsequent meetings, so keep it)
- 1 pair of scissors
- 1 20N spring force scale
- 1 foot of thread (cut from spool)
- 10 craft sticks
- 1 English/metric ruler
- Bowl of ice water

Step 1: State Your Question

For this experiment, you and your team should try to answer the following question:

> How does geometry (for example, the diameter) influence the flexibility of a bar made of reshaped Coolmorph beads?

Step 2: Conduct Background Research



Source: University of Cambridge Department of Engineering

Material selection charts can be used to find groups of materials that have certain characteristics you want.

Meeting 1: Soft Robot Structures

Choosing what material to use for a soft robot can be a complicated task, so engineers and researchers use material selection charts like the ones shown above to help them. The one on the left shows Young's Modulus, a property engineers and scientists use to describe how stiff or flexible a material is, on the y-axis versus the density of a material along the x-axis. They're lumped together in large groups labeled metals, plastics, ceramics, and so on because materials within these groups often share similar properties, as the chart shows. Most metals are on the upper-right part of the chart because most have a high Young's Modulus (meaning they're very stiff) while also being very dense (they're typically very heavy). Meanwhile, polymers (a scientific name for plastics) are all grouped together in the middle because plastics are wide-ranging in stiffness but all around the same density. Soft robots are flexible, so the materials used for them would more likely be on the bottom half of this chart than the top half.

The chart on the right compares strength, which is related to how much force the material can handle before breaking, and elongation, which is how much a given material will stretch before it breaks or deforms permanently. Flexible materials should be able to stretch a lot, so they're on the right-hand side of the chart. Polymers again sit in the middle and right side of the graph, so it's no surprise that they're the most common type of material used for soft robots.

Step 3: Formulate Hypothesis and Identify Variables

As a team, you should define what you are going to vary (your variables) as you run tests to answer your question. You should also define what your hypothesis is. A hypothesis is your best guess as to the results. Scientists use their knowledge and experience to predict the result of an experiment, and this helps them in designing the tests. Then they run the experiment and observe the result to see if it matches their prediction or not.

A good way to organize this is to write down a statement using the form: *If I ... then ... because ...*

An example of a hypothesis could be:

- *If I* cut the diameter in half, *then* I should see the flexibility double, *because* diameter of a material should influence its flexibility, and that flexibility should be inversely proportional to the diameter.

What are the variables for your experiment? There are three types of variables: independent, dependent, and control.

An independent variable is the one thing you are changing. A dependent variable is what you are testing that will change when you change the independent variable. All the things that do not change are your control variables.

Example:

- **Hypothesis:** *If I* cut the diameter in half, *then* I should see the flexibility double, *because* diameter of a material should influence its flexibility, and that flexibility should be inversely proportional to the diameter.
- **Independent variable:** diameter of a cylindrical bar
- **Dependent variable:** flexibility (how much a bar bends when a load is applied)
- **Control variables:** length of bar, material, temperature, loading conditions

Meeting 1: Soft Robot Structures

Discuss this with your team and write down your agreed-upon hypothesis, your variables, and why you chose the independent and dependent variables.

Hypothesis	
Independent Variables	
Dependent Variables	
Control Variables	

Step 4: Design Experiment and Establish Procedure

Now, with your team, plan your experimental procedure. How could you measure flexibility of a part in a simple test with a force scale? What changes in your independent variable are you going to test, and what data will you collect?

Write down the procedure, including all steps and measurements and calculations needed.

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Meeting 1: Soft Robot Structures

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Step 5: Conduct the Experiment

Once you and your team have your experiment procedure defined, go ahead and follow that procedure. Be sure to set up your data tables and record all your measurements and observations using the blank pages provided.

If time allows, you can test other variables.

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Meeting 1: Soft Robot Structures

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Step 6: Analyze Results and Draw Conclusions

Review your data and observations and determine the answer to your initial question.

> How does geometry (for example, the diameter) influence the flexibility of a bar made of reshaped Coolmorph beads?

Step 7: Communicate Results

Be prepared to present to the rest of the Lab how you and your team solved the problem, and then present your results and conclusions.

Cleanup

After the experiment, put your unused Coolmorph beads and the melted pieces back in the kit container. They will be remelted and used again in the following meetings.

Save the craft sticks for the next meeting.

Also be sure to put back all of your string scraps and supplies that you didn't use.

Clean your area, and be sure no trace is left behind.

STEM Innovator Moment Notes

Meeting 2: Powering Soft Robots

Meeting 2: Powering Soft Robots

Opening

The Principal Investigator will lead the group in reciting the Pledge of Allegiance and the Scout Oath and Scout Law.

Scout Oath (Scout Sign)	Scout Law (Scout Sign)
On my honor I will do my best To do my duty to God and my country and to obey the Scout Law; To help other people at all times; To keep myself physically strong, mentally awake, and morally straight.	A Scout is trustworthy, loyal, helpful, friendly, courteous, kind, obedient, cheerful, thrifty, brave, clean, and reverent.

Applying the Scout Law

Today's theme is *obedient*, as in *I will obediently follow the instructions as I learn how to build and power soft robotics structures.*

Meeting 2: Powering Soft Robots

Activity Overview

You will learn how to set up and use the Maestro controller with the servo motors. You will explore different types of actuation using Coolmorph beads as a flexible building material and use thread and servo motors to control the movement.

Background

Robotics is an interdisciplinary field, meaning that it brings together different types of engineering backgrounds such as mechanical engineering, electrical engineering, and computer science. The overlap in electrical and mechanical engineering comes from the need to power the robot and make it move, which is done using actuators. An **actuator** refers to a component of a machine that is responsible for making the machine move. In a car, the combustion engine is the actuator. A car jack is also an actuator because using the lever arm lifts the car up and down. For robots, electric motors, which can be highly controlled with electronics, are most commonly used, but soft robots can use pneumatic pumps and other unique actuation designs.

In order for the actuators to move the robot, they must be connected to it in some way. A **transmission** is a mechanism that converts the power into a usable form. A mechanical example would be the transmission on a car. It transfers the power of the engine to the wheels in order to move the car forward.

Electric motors work based on a physical principle called **induction**. Induction occurs when a magnetic field creates an electrical current. For example, if you take a magnet and move it across a wire, electrons will flow through the wire. **Current** is a measure of how many electrons are moving through the wire every second. This is how electric generators at steam plants and dams convert motion into electricity. This law also works in reverse and is the principle behind electric motors. If current runs through a wire, a magnetic field will form around the wire and exert torque on a magnetic rotor, thus creating rotary motion.

In this meeting, you will be using **servo motors,** which are electromechanical packages that include (1) a simple DC electric motor, (2) a position sensor called a potentiometer, (3) a geared transmission to increase torque, and (4) a control circuit, all of which are integrated inside a plastic housing. The control circuit receives a signal from an external source representing the desired angle of the motor shaft. It reads the actual position from the potentiometer and varies the current running through the motor in order to quickly move the motor shaft to the desired position. This process goes on continually while the servo is operating and is called **closed-loop control**.

To use a servo motor, we need to supply a power source (e.g., a battery pack) and a signal to specify the desired motor shaft angle. Servos commonly use a system called **Pulse Width Modulation (PWM)** to specify the desired angle. In this system, a series of repeating voltage pulses of varying width is sent to the servo. The width of the pulses is used to specify the desired position to the servo's internal control circuit. The Maestro controller from Pololu is a microcontroller that can be programmed to continually send PWM signals to many servos at once. This allows you to command the motors to move in any way you wish using the Pololu software and a laptop.

Safety Moment

The water in the glass beaker that is softening the Coolmorph beads is very hot. Be sure to use the craft sticks to fish the plastic out of the water bath and mold it until it is cool enough to touch.

Keep all water-sensitive items, like cellphones, away from the water!

Be careful about spilling water on your table and the floor. If you do spill water, please clean it up right away so that nobody slips and falls.

Meeting 2: Powering Soft Robots

Experiment
Get back into the same teams of four that you were in for the previous meetings.

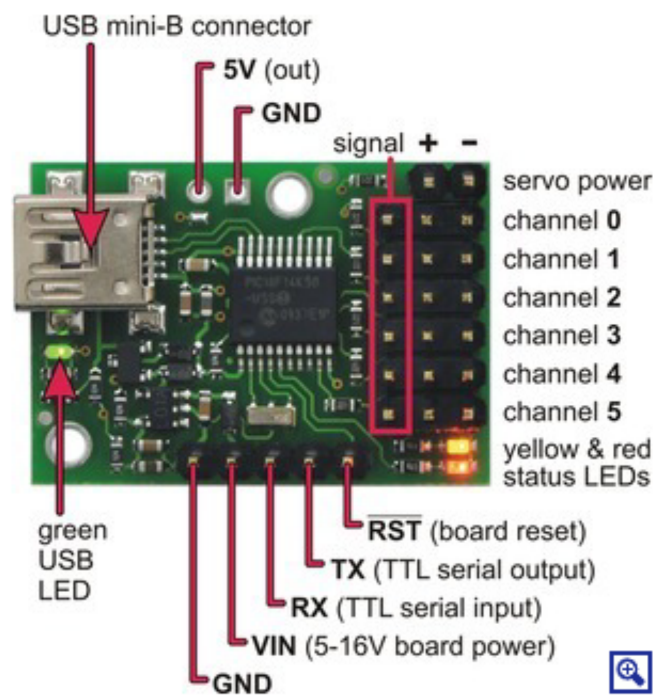
Activity 1: Setting Up the Actuators (20 minutes)

Materials List

- 1 Mini Maestro
- 1 copy of the pin layout
- 3 servo motors
- 1 4-cell battery holder
- 4 AA batteries
- 1 laptop

The makers of the controller made a tutorial video to help teach you how to use it. Watch the first part of the video to learn how to use your servos and the Maestro program. You only need to watch until 3:37: www.youtube.com/watch?v=AqToEWmTVXA&feature=youtu.be.

Now that you're familiar with the setup, open the Pololu Maestro Control Center software on your team's laptop. Take the supplied micro USB cable and connect the Maestro to the laptop. On the top left corner of the Control Center window, the serial number for the Maestro should appear.



Micro Maestro 6-channel USB servo controller (fully assembled) labeled top view.

After verifying that the Maestro is working, you can connect the servo motors. Before you do this, take a moment to look at the users guide and specifications for the Mini Maestro. Using a specifications sheet is a vital part of engineering. When working on a project like a robot, it is common practice to use off-the-shelf components like this to minimize the difficulty in the design process and manufacturing. Take a look at the specifications and consider why the Mini Maestro was chosen for this project.

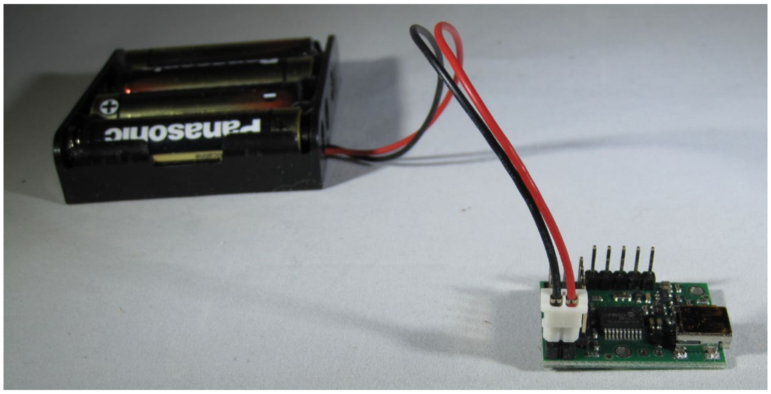
Look at the pin layout of the Mini Maestro. It is important to take note of where the servo power terminals are. Notice that the terminals are indicated on the bottom of the board with a + and –. What does this indicate? This indicates the direction of the flow of the current. It is a physical principle that current always flows from areas of high voltage to low voltage. The + signifies high voltage and the – signifies low voltage, or ground.

Notice that the channels (where you will attach the servos) have three pin inputs. There is a + and –, which

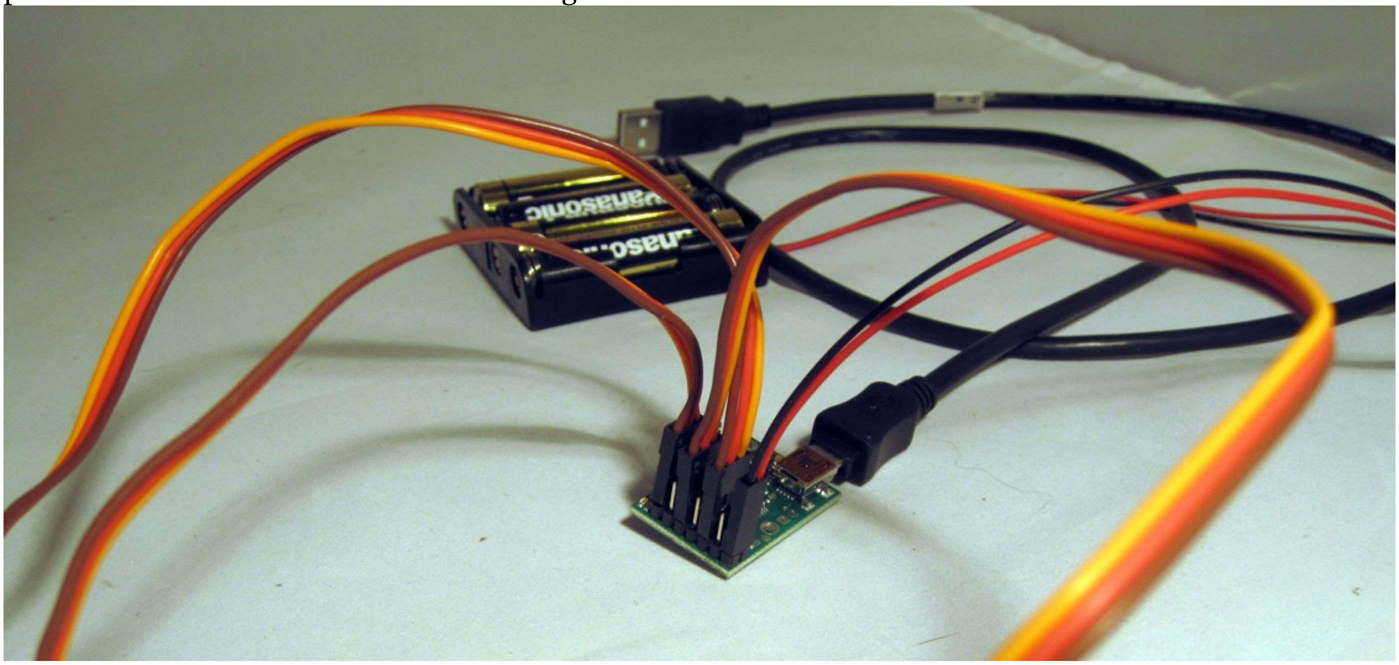
Meeting 2: Powering Soft Robots

indicate that this is the power supply for the servo. What is the third “signal” pin for? This pin is what sends commands from the Maestro controller to the servo motor, using the Pulse Width Modulation system discussed previously.

Now that you are familiar with the pins, let’s attach everything, starting with the power supply. First, make sure the Maestro is no longer plugged into the computer to verify that the power is off. Next, the battery pack plugs into the two pins on the edge of the Maestro board labeled “servo power” in the pinout diagram. The black wire should be on the outside of the board as shown in the photo on the right. The black wire is usually what is called the ground, and the terminal for the ground is often noted as such or noted by –. In most projects, you want to connect the ground first.



Next, attach the servo motors to the Maestro by using the pins labeled as channels. It is important that you check the wiring diagram for the servo motor to ensure that the correct pins are connected to the correct wires. Notice that the servo motor also has three wires coming out of it that are connected together. These wires correspond to the three pins on the Maestro. An example can be seen in the figure below. When you plug the servo into the Maestro, make sure the orange wire, which is the control wire, is on the innermost pin and the brown wire is on the outside edge of the board.



At this point you should be able to control the motors. Plug the Maestro back into the computer and try it out as shown in the video.

Meeting 2: Powering Soft Robots

Activity 2: Setting Up the Transmission (35 minutes)

Materials List

- Servo controller setup from Activity 1
- 1 No. 0 Phillips head screwdriver
- 4 craft sticks
- 1 glass beaker
- Coolmorph beads and scraps from previous meeting
- 1 box of paper clips
- Paper towels
- Bowl of ice water
- 1 laptop

Now that you have functioning motors, you need to be able to use them to create a robot; this is where a transmission comes into play. You need to use the rotation of each motor shaft to move a different part of a robot. Disconnect the Maestro from the computer, disconnect the red power supply wire, and remove the servo motors from the Maestro. This is important because you will be working with water to form your soft robots. Also remove the servo horn from the motor using the Phillips head screwdriver.

Let's explore two different types of actuation: direct and offset. In **offset actuation**, there's some kind of extended transmission that allows your motors to be placed away from the body of your manipulator. A particularly useful form of offset transmission is **cable-driven actuation**, where you connect a string or cable to your motor and then to some point on your robot. This is sometimes called **tendon-driven actuation**, and you'll learn more about it in the next meeting. In contrast, **direct actuation** works by the actuator being directly connected to a joint or flexible leg. This is the type of actuation you'll explore in this activity using the Coolmorph beads.

Pour some hot water from the kettle into the glass beaker and put a small (golf-ball size) amount of Coolmorph beads into the water—two people should work together on each robot, so they will share the Coolmorph. Once the plastic has softened, use one of the craft sticks to carefully remove it from the water. Try to get it as dry as you can, but a little moisture is fine.

Take a small portion (less than a quarter) of the plastic and set it aside for later. Roll the remaining material into a shape that has two skinny legs on either side and a much thicker section in the middle. Be sure to roll the legs as smoothly and evenly as possible. Try to make them close to the same diameter and length, but it's OK if they're a little different.

Meeting 2: Powering Soft Robots

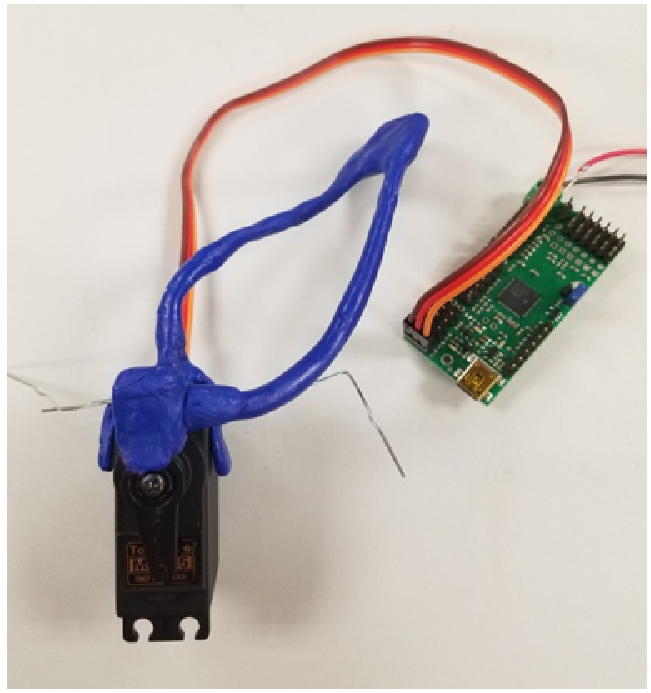
Next, take the thicker middle section of the rod and let it sit in the water to soften, but don't let it melt. Once it's soft, bend the legs around 90 degrees so that they're parallel to each other and on the same side of the thicker part. Take the small piece of plastic you set aside earlier and soften it in the water. Split it in two and use half to make a T-shape at the bottom of one of the legs (if one of the legs is shorter, use that one). Wrap the other half around one side of the servo horn. Do NOT do this while the horn is on the motor—the plastic may still be wet, and you don't want water near your motor.

Finally, stick the bottoms of both legs and the end of the plastic on the horn into the hot water and let them soften. Take them out and shake them dry quickly. Merge the servo horn and the straight leg, kneading the connection to make sure the material integrates well. Then, press the T-shaped leg against the back of the screw mounts on the top of the servo motor (near the attachment for the horn). Do NOT wrap the plastic around the mounting frame or the motor wires, as it will be very difficult to get off once the plastic hardens. Slip the horn onto its gear and work the plastic joins while they're still soft to get everything to align straight. Use folded-out paper clips to pierce the warm plastic and clamp it to the servo mounts.

Let everything cool and harden, and then use the Phillips head screwdriver to secure the horn in place. Follow the steps in Activity 1 to reconnect your servo and test your manipulator. Make notes on how it bends—it may look strange, but it bends in the least stiff direction. If there's a sharp angle in one or both legs, it may be that the cross-section is thinner there. Investigate if there are any other reasons your robot makes the shape it does.

Meeting 2: Powering Soft Robots

Activity 2 Options: Take your manipulator and soften the legs in hot water. Flatten the legs so that they'll both bend more easily in the direction the motor turns—it should make a different shape when actuated. Make notes on how this changes and try this out with as many different leg shapes as you have time for.



Meeting 2: Powering Soft Robots

Cleanup

Close out of the Maestro software and unplug the Maestro from the computer. Unplug all of the servo motors and put them away.

Shut down all applications on the computer and power it off completely.

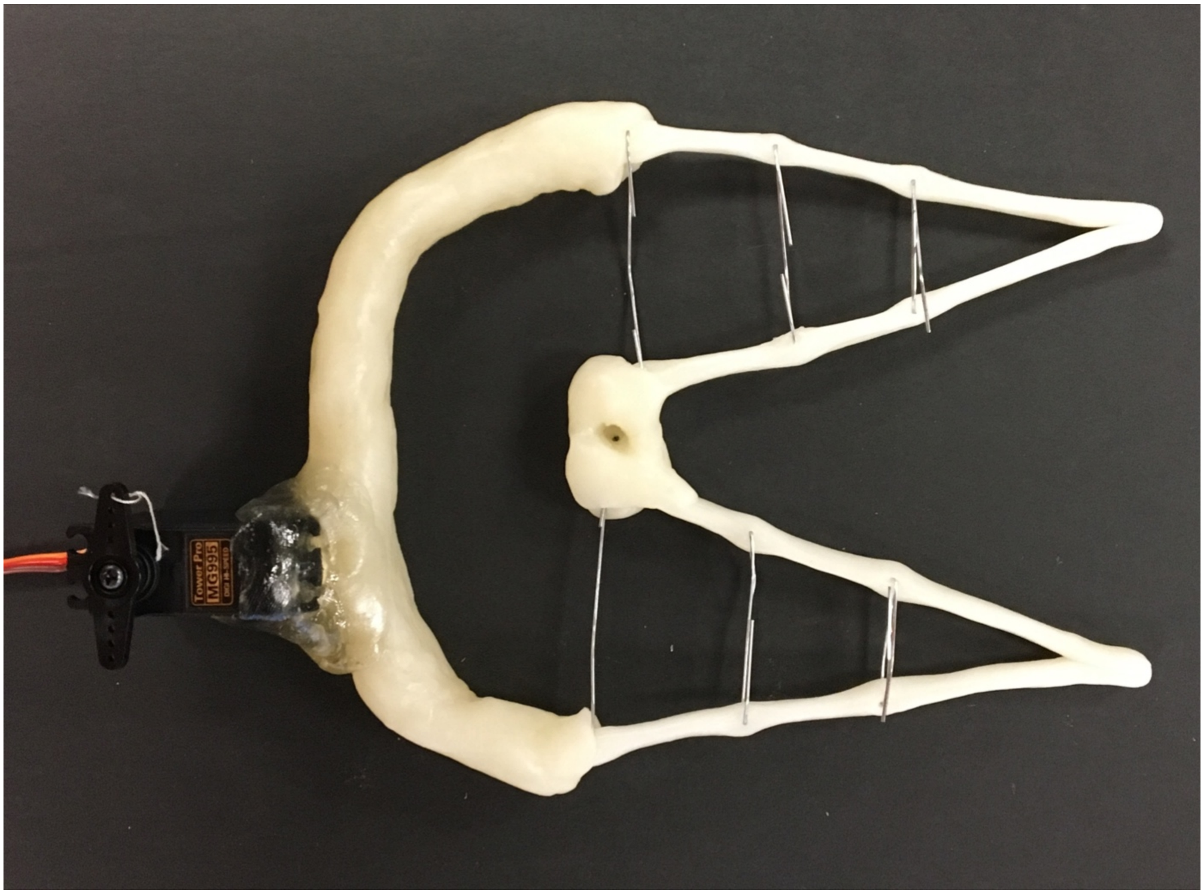
Finally, collect all of the Coolmorph parts and place them in a box. Keep your different actuation designs if you can. They might be helpful for the next meeting.

Save the craft sticks for the next meeting.

Clean your area, and be sure no trace is left behind.

STEM Innovator Moment Notes

Meeting 3: Build a Soft Robotic Grasper



Meeting 3: Build a Soft Robotic Grasper

Opening

The Principal Investigator will lead the group in reciting the Pledge of Allegiance and the Scout Oath and Scout Law.

Scout Oath (Scout Sign)	Scout Law (Scout Sign)
On my honor I will do my best To do my duty to God and my country and to obey the Scout Law; To help other people at all times; To keep myself physically strong, mentally awake, and morally straight.	A Scout is trustworthy, loyal, helpful, friendly, courteous, kind, obedient, cheerful, thrifty, brave, clean, and reverent.

Applying the Scout Law

Today's theme is *courteous*, as in *I will be courteous to my teammates and fellow Scouts as we share resources to build our grasper*.

Meeting 3: Build a Soft Robotic Grasper

Activity Overview

In this meeting, you will be building a soft robotic grasper. Like in the previous meetings, you will be using a thermoplastic that melts in hot water in order to mold and shape your structure. You may have to melt down and reuse structures you built in previous meetings.

Background

Meeting 1 introduced soft materials and showed some examples of soft robots, and Meeting 2 provided insight on how these robots move when attached to motors through both offset and direct actuation. The kinds of robots you have seen thus far have been made almost completely with soft, flexible materials (aside from the motors). That isn't always the case with soft robots—they can be a hybrid of soft and rigid materials. In this meeting, you will be making a gripper from both flexible plastic and rigid paper clips to see how the combination of materials can create some interesting behavior.

The primary job of grippers is to pick up a variety of objects, and grippers are usually designed to pick up only very specific things. Particularly when those things are fragile, the amount of force applied by the gripper can be crucial to performing a task. Rigid grippers can rarely sense how hard they grip something—they only know how far they're supposed to close their "fingers" to pick up an object. If that object is larger than it expects, the gripper won't know how hard it's squeezing when it reaches the position it's been programmed to go to, so it won't know if it breaks or deforms the thing it's trying to pick up. Soft grippers, however, are typically more flexible than whatever they're handling. Instead of the gripping force changing the object's shape, the gripper itself will deform, naturally conforming to the object and applying just enough squeezing force to pick it up. This protects the object from damage, even if it's not quite the size the gripper thinks it is.

The ability to flex around objects gives soft grippers another advantage over rigid ones—they can pick up a wider variety of shapes. A rigid gripper with flat sides will be good at picking up flat objects like boxes, but it would struggle to grab hold of a baseball. Meanwhile, the same gripper made with soft materials can handle flat-sided boxes just like the rigid version, but by using its flexibility to bend and curve around the baseball, it can pick that up, too.

Grippers and manipulators don't have to be made of purely rigid materials or purely soft materials. They can be a hybrid of the two. For example, rigid pieces are used in a soft gripper to make it form a certain shape when it's actuated or while it's gripping. The differences in stiffness will cause the weaker, more flexible parts of the gripper to bend while the stronger parts will stay largely undeformed. In a robot made of completely flexible material, this can be done by making parts of the structure thinner or thicker than others. As you learned in Meeting 1, thinner cross-sections are much less stiff than thicker ones, and so making parts of your gripper thinner will cause those parts to bend first.

Your Lab Manager will play you some videos showing a type of gripper called a fin-ray, which is a hybrid of flexible and rigid materials and was originally designed by a company called Festo. The fin-ray gripper demonstrates how the combination of materials creates a very versatile gripper that can handle all kinds of objects.

The gripper you'll be making today is most like the one in the last video. While it has three fingers, yours will have two. Also, the video's manipulator has direct actuation—the gripper is attached to the piston—but yours will use a string to transmit the motor motion to the gripper, so it will have offset actuation.

Meeting 3: Build a Soft Robotic Grasper

Safety Moment
The water in the glass beaker that is softening the Coolmorph beads is very hot. Be sure to use the craft sticks to fish the plastic out of the water bath and mold it until it is cool enough to touch.

Keep all water-sensitive items, like the Maestro servo controller, away from the water!

Experiment
Get back into the same teams of four that you have been in for previous meetings.

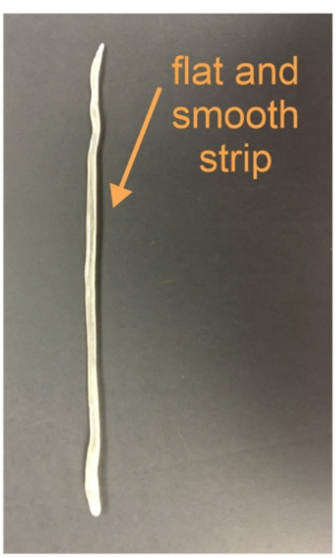
Activity 1: Build a Soft Gripper Structure (40 minutes)

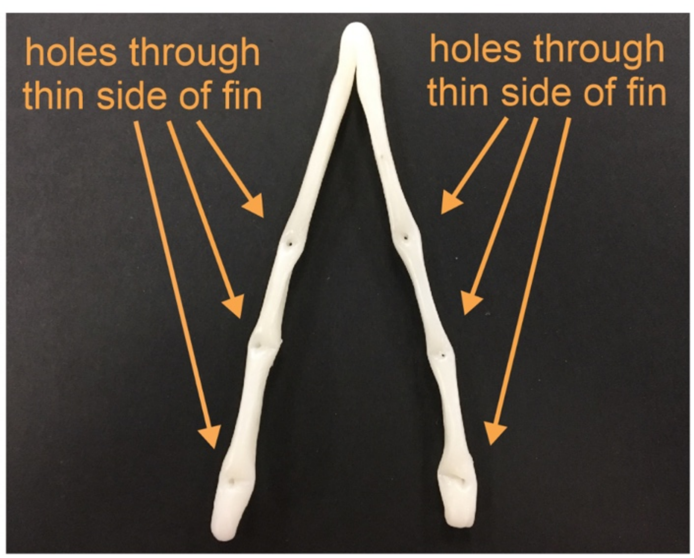
Materials List

- Coolmorph beads and scraps from previous meetings
- 4 craft sticks
- 1 glass beaker
- 1 pair of scissors
- 1 spool of thread
- 1 box paperclips
- Bowl of ice water
- Paper towels

1. Take a small amount of Coolmorph beads (about one-fourth of a golf ball) and make a flat strip with it. Try to make it as flat and smooth as possible. Along the skinny side, pierce three small holes using a paper clip.

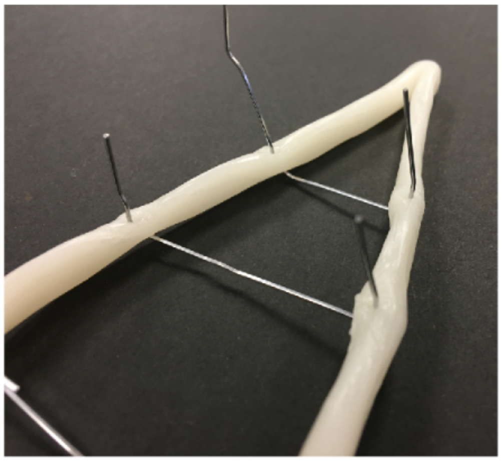
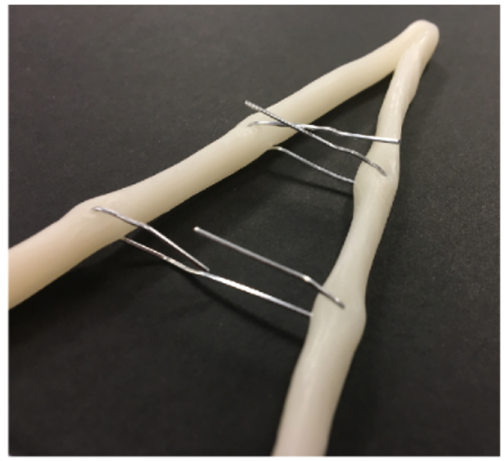
2. Make a second strip and then join the strips at their tops where the wide sides are facing each other. Use some extra plastic or stick the ends in hot water until they can meld together.



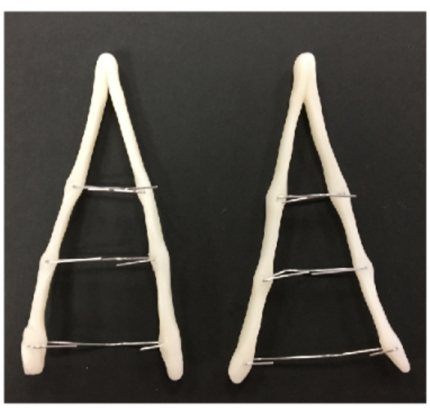


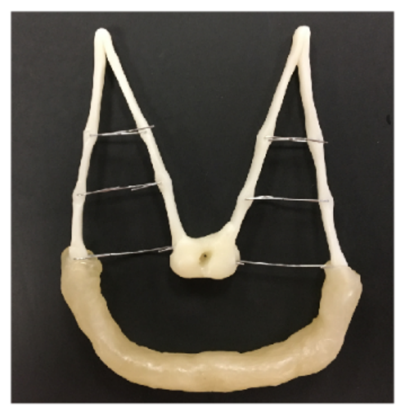
Meeting 3: Build a Soft Robotic Grasper

3. Take three paper clips and fold them outward into U-shapes. Put them into the holes you made on your strips. Fold the paper clips closed. You've made your first fin.

4. Make a second fin and join one leg of each fin together using a small amount of melted Coolmorph beads. Try to make this joint as thin as you can. Make a small hole in the middle of the new joint while it's still warm so you will be able to put a thread through it. It works best if the hole goes the same direction as the holes for the paper clips.





5. Again, using melted Coolmorph beads, make a U-shape that connects the two farthest fin legs. This will be your handle. Make it thicker than the fins so that it won't bend before them.
6. Cut a piece of thread that's long enough to reach from the joint between the two fins to a few inches past the edge of your handle. Then, tie it through the hole you made between the two fins.
7. While holding on to the gripper handle, pull on the thread and watch your gripper close!
8. Take some time (5-10 minutes) picking up objects. Write down what the gripper is and isn't good at picking up.

Meeting 3: Build a Soft Robotic Grasper

Activity 2: Motorize Your Gripper (20 minutes)

Materials List

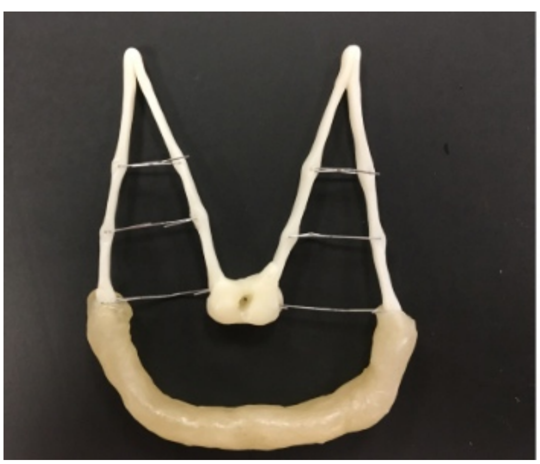
- Coolmorph beads and scraps from previous meetings
- 4 craft sticks
- 1 glass beaker
- 1 pair of scissors
- 1 spool of thread
- 1 servo motor
- 1 4-cell battery holder
- 4 AA batteries
- 1 Pololu Maestro servo controller
- 1 USB cable
- Bowl of ice water
- Paper towels
- 1 laptop

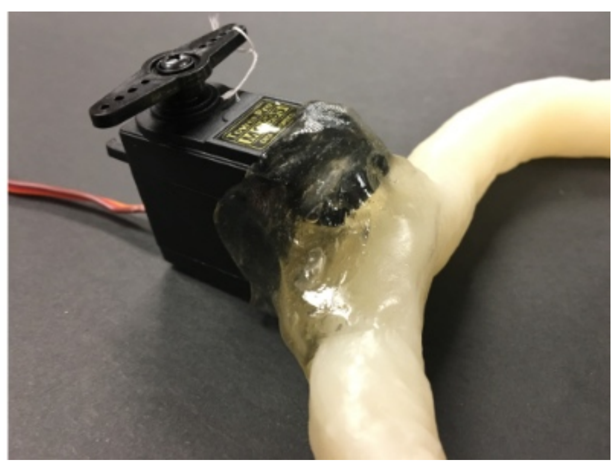
1. Take the bottom of the motor (the side without wires) and fix it to the U-shaped motor handle. Tie your thread to the servo horn. It's best to tie it to a hole on the farthest edge of the horn, as that's the point that will move the most as the motor rotates.

2. Boot up the computer with the Maestro software and make sure you can connect to your Maestro board. Be sure that you have power.

3. Plug the servos into the motor controller and use your gripper!

4. After you're done with that, try various fin shapes and different numbers of paper clips and see what else you can make! Try taking the paper clips out and seeing how the gripper behaves.





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ENGINEERING
MATH

Lab Notebook

Meeting 3: Build a Soft Robotic Grasper

Cleanup
Gather all of the plastic pieces and store them for use at the next meeting, where they will be remelted and reused. Do the same for any other materials, especially the thread.

Clean your area, and be sure no trace is left behind.

STEM Innovator Moment Notes

Meeting 4: Build a Soft Tentacle-Arm Robot – Part 1

By Pseudopanax at English Wikipedia [Public domain], via Wikimedia Commons.

Meeting 4: Build a Soft Tentacle-Arm Robot – Part 1

Opening

The Principal Investigator will lead the group in reciting the Pledge of Allegiance and the Scout Oath and Scout Law.

Scout Oath (Scout Sign)	Scout Law (Scout Sign)
On my honor I will do my best To do my duty to God and my country and to obey the Scout Law; To help other people at all times; To keep myself physically strong, mentally awake, and morally straight.	A Scout is trustworthy, loyal, helpful, friendly, courteous, kind, obedient, cheerful, thrifty, brave, clean, and reverent.

Applying the Scout Law

Today's theme is *brave*, as in *I will be brave and not let myself get frustrated as I work with my team to build a tentacle-arm robot*.

Meeting 4: Build a Soft Tentacle-Arm Robot – Part 1

Activity Overview

In this meeting, you will be building a soft, tentacle-like arm to show how it relates to a robotic manipulator. You will again be using Coolmorph beads, a plastic that melts in hot water, in order to mold and shape your very own manipulator structure. The teams will need to share certain tools as indicated above, but each team will decide what type of manipulator—whether parallel or tendon-/cable-driven—to create. You will be using the STEM Scouts Engineering Design Process to define your requirements, brainstorm ideas, and plan and execute a design.

Background

Building a tentacle arm is the start of the process of building a robotic manipulator. As we learned in Meeting 1, a **robotic manipulator** is a robotic arm that can reach out and manipulate, or move, various objects. Manipulators usually have an **end effector**—essentially, a tool at the end that helps the manipulator perform tasks just like your hand at the end of your arm. The gripper you made in Meeting 3 is an example of an end effector. Today, you're going to focus on manipulators, though those need electronics and motors to be robotic, and you won't be working with those yet. The manipulator will be made from Coolmorph beads, the same flexible material you've worked with in the previous meetings, and so your manipulator will be soft.

Any Scout who finds a good way to form certain shapes (like a leg with a near-constant diameter) should demonstrate their skill to the group so that everyone can be successful in making their own manipulator.

Rigid-link robotic manipulators look like your arm, with joints and links, but soft robots look more like snakes and tentacles. Many soft robot designs are inspired by things found in nature like elephant trunks, octopi, and even vines. Researchers and engineers liked how, for example, an octopus can reach into small, tight spaces by curving and curling anywhere along its tentacle, so they began to build robots that can do the same thing. Then, that robot could work in spaces similar to the octopus, like a surgical robot that navigates through the colon to get to a surgical site so that doctors don't have to make any cuts; another example is an inspection robot for nuclear power plants that twists and turns along the pipes in the system to examine them for cracks. These types of activities are best done with soft manipulators that use offset actuation since their bulky motors can be kept at the base of the arm; they're also the kinds of jobs that rigid-link robots just aren't good at performing. When thinking about a robot doing a task, ask yourself: Would my arm be good at doing this (rigid links), or would an octopus be able to do this better (soft links)?

While you're designing your tentacle arm, be sure to follow the STEM Scouts Engineering Design Process:

Step 1: Define the Problem (What is it that you're trying to accomplish?)

Step 2: Conduct Background Research (How have others before me accomplished this? What do I already know that can help?)

Step 3: Specify Requirements (What do I need to do in order to solve my problem from Step 1?)

Step 4: Create Alternative Solutions (Is there any other way to solve this problem?)

Step 5: Build a Prototype (Build something that meets your requirements from Step 3.)

Step 6: Test and Redesign as Necessary (Verify that your prototype does what you wanted it to and adjust it if it doesn't. Be sure to write down any changes you make!)

Meeting 4: Build a Soft Tentacle-Arm Robot – Part 1

Step 7: Communicate Results (Tell everyone else about the design you made to solve your problem. Diagrams are a bonus.)

There isn't time in this meeting to go through all of the steps, so you'll be skipping the "Redesign" part of Step 6, instead writing notes on how you may want to change your design for future use. You'll be using today's design as the basis for the next meeting, where you can redesign as needed and make your arm into a robot with motors.

Safety Moment

The water in the glass beaker that is softening the Coolmorph beads is very hot. Be sure to use the craft sticks to fish the plastic out of the water bath and mold it until it is cool enough to touch.

Keep all water-sensitive items, like the Maestro servo controller, away from the water!

Experiment

Get back into the same teams of four that you have been in for previous meetings.

Materials List

- 1 mini hot glue gun
- Coolmorph beads and scraps from prior meetings
- 1 glass beaker
- 1 pair of scissors
- 1 spool of thread
- Bowl of ice water
- Paper towels
- 10 craft sticks
- 5 mini hot glue sticks

STEM Scouts Engineering Design Process

Step 1: Define the Problem

Today, you and your team are trying to solve the problem of making a flexible manipulator.

Step 2: Conduct Background Research

Discuss the questions below with your team and others in the Lab.

How can you create a flexible section?

Does your whole robot have to be flexible?

What kind of shapes do you think you can get your robot to make?

Meeting 4: Build a Soft Tentacle-Arm Robot – Part 1

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An important concept in robotics is **degrees of freedom** (DOF). Degrees of freedom is a count of how many directions you can independently move. A cart on a track only has 1 degree of freedom because it can move along the track in only one direction. The electric claw game you might play in a restaurant or arcade to win a stuffed animal has 3 DOF—you can move left and right, and back and forth, and you can drop the claw to grab a prize. In robotics, the number of motors is what defines your degrees of freedom.

While an octopus tentacle can move every which way, you will have only three motors at your disposal, so when you're designing your soft tentacle arm, aim to get actuation from combining movement in three different directions. Then, you can combine those independent directions to get all kinds of robot shapes. Don't forget what you learned in Meeting 3 about hybrid rigid-soft robots, either, and think about whether or not you want to embed rigid components to get a specific shape. Draw on what you learned in Meeting 2 in order to decide on cable-driven actuation, direct actuation, or a combination of the two for this new design.

Step 3: Specify Requirements

What do you think will make a successful manipulator? Do you want one that can hold a heavy object, or would you prefer one that curves a lot? Think about the characteristics required to make it do one or the other—a stronger manipulator would need to be thicker while one that curves will need a lot of thin, flexible places (or have the entire thing be thin and flexible). Do you think you should add rigid pieces to strengthen certain parts of it?

Lastly, don't forget to think about how you plan to actuate it or how you plan to build the base. You have craft sticks and hot glue available for building a sturdy base.

Meeting 4: Build a Soft Tentacle-Arm Robot – Part 1

Step 4: Create Alternative Solutions

With your team, discuss and design your initial solution. Draw it out and write down the materials and specifics of your design. During your discussion, it is likely that several options will be raised. After picking the best option to try first, identify what other options you want to try in case the first one does not work as expected.

Step 5: Build a Prototype

Once you are satisfied with your designs, go ahead and build the primary design. As you build it, make notes of changes you have to make, observations, and any thoughts for improvements as you go. Drawings and diagrams are good ways to quickly communicate designs.

Step 6: Test and Redesign as Necessary

Now, test your primary design, by moving it by hand. How well does it work? Make notes on what changes you might want to make at the next meeting and where you will be attaching motors. If this design is not working the way you want, and you have time, start modifying it or building an alternate design.

Step 7: Communicate Results

Present to the rest of the Lab how you structured your design-build process as well as your results and conclusions.

Troubleshooting Problems

- Issues making tendon holes:
  - It's best to use a thin rod or tool to cut a tendon path while the plastic is hot, then insert the tendon after it's cool. If you wrap plastic around the thread, it will simply get stuck.
- Plastic shapes splitting in the middle or at seams:
  - Reinsert the plastic into hot water until it's partially melted. It does not need to be as hot as when you initially melted it. Pull the softened shape out and re-form it before it cools. Check for any seams that may exist along the length and reheat it as necessary until they disappear.
  - This problem can be avoided by not folding the plastic over on itself after it's cooled off; the plastic is not reintegrating with itself because it's cooled off too much.

Cleanup

Leave the arm intact to be used later in Meetings 5 and 6, and label it with your team information. If you do need to unplug or disassemble anything, take a picture of your final prototype to use as a guide when you're putting it back together in the next meeting.

Clean your area, and be sure no trace is left behind.

Meeting 4: Build a Soft Tentacle-Arm Robot – Part 1

STEM Innovator Moment Notes

Lab Notebook

Meeting 5: Build a Soft Tentacle-Arm Robot – Part 2

A prototype soft robotic tentacle wrapping around a wrist. Image courtesy of the SSSA Biorobotics Institute.

Meeting 5: Build a Soft Tentacle-Arm Robot – Part 2

Opening

The Principal Investigator will lead the group in reciting the Pledge of Allegiance and the Scout Oath and Scout Law.

Scout Oath (Scout Sign)	Scout Law (Scout Sign)
On my honor I will do my best To do my duty to God and my country and to obey the Scout Law; To help other people at all times; To keep myself physically strong, mentally awake, and morally straight.	A Scout is trustworthy, loyal, helpful, friendly, courteous, kind, obedient, cheerful, thrifty, brave, clean, and reverent.

Applying the Scout Law

Today's theme is *loyal*, as in *I will be loyal to my team and help to make sure that all team members get to participate.*

Meeting 5: Build a Soft Tentacle-Arm Robot – Part 2

Activity Overview

Today, you'll turn the tentacle arm you built in the previous meeting into a tentacle robot. Using notes from that meeting, you'll be iterating on your design and adding motors and electronics. By the end, you should have a soft robot manipulator that can bend and move on command.

Background

The STEM Scouts Engineering Design Process was discussed in the previous meeting:

Step 1: Define the Problem (What is it that you're trying to accomplish?)

Step 2: Conduct Background Research (How have others before me accomplished this? What do I already know that can help?)

Step 3: Specify Requirements (What do I need to do in order to solve my problem from Step 1?)

Step 4: Create Alternative Solutions (Is there any other way to solve this problem?)

Step 5: Build a Prototype (Build something that meets your requirements from Step 3.)

Step 6: Test and Redesign as Necessary (Verify that your prototype does what you wanted it to, and adjust it if it doesn't. Make sure to write down any changes you make!)

Step 7: Communicate Results (Tell everyone else about the design you made to solve your problem. Diagrams are a bonus!)

However, there wasn't enough time in one meeting to go through all of the steps. You skipped the "Redesign" part of Step 6 and instead wrote notes on how you thought you might want to redesign it. In this meeting, you will be using those notes to complete Step 6, with an added modification to your problem statement in Step 1: You're going to add motors. Thus, you'll reframe the entire process with this new problem statement using the results from your prior design experience.

It's important that you have a sturdy base for your robot, where all of the motors are connected to one piece. Use the craft sticks, hot glue, and thermoplastic to build something strong. It doesn't have to be any particular shape, but the motors will need to be rigidly attached to each other in one way or another. Make sure to leave them enough room to move! Also, make sure you use only Coolmorph beads to attach the motors to the structure; if you use hot glue for this, you will not be able to get them apart later.

If you figure out a trick for forming your structure, share it with the entire group.

Safety Moment

The water in the glass beaker that is softening the Coolmorph beads is very hot. Be sure to use the craft sticks to fish the plastic out of the water bath and mold it until it is cool enough to touch.

Keep all water-sensitive items, like the Maestro servo controller, away from the water!

Dry the plastic as well as possible before attaching any electronics, and never have the motors on while you're building around them. Leave the motors unplugged until you're ready to make your robot move.

Meeting 5: Build a Soft Tentacle-Arm Robot – Part 2

Experiment
Get back into the same teams of four that you have been in for previous meetings.

Materials List

- Bowl of ice water
- Paper towels
- Coolmorph beads and scraps from previous meetings
- 1 glass beaker
- 1 pair of scissors
- 1 spool of thread
- 1 USB cable
- 1 laptop with the Pololu Maestro software installed
- 1 Pololu Maestro servo controller
- 3 servo motors
- 1 4-cell battery holder
- 4 AA batteries
- 1 No. 0 Phillips head screwdriver
- 10 craft sticks
- 1 mini hot glue gun
- 5 mini hot glue sticks

STEM Scouts Engineering Design Process

Step 1: Define the Problem

Take the problem statement from the last meeting and modify it to add motorized movement.

Step 2: Conduct Background Research

Discuss the following with your team and the rest of the Lab.

What are some ways to mount the motors?

How will you hold the robot base?

Did you see any good ideas from other teams? Do you think they could be applied to your robot?

Is there any specific task you want your robot to perform? How might you change your design to do that?

Make sure you DO NOT wrap the plastic around the motor wires or put hot glue on them. It will be very difficult to remove them and could damage the motor. Also check that you have your servos wired into the Maestro correctly before you plug in your battery, with the orange wire on the innermost side of the headers and the brown wire on the outside edge.

Meeting 5: Build a Soft Tentacle-Arm Robot – Part 2

Step 3: Specify Requirements

Recall what you did in the last meeting but think about it with motors now. What do you want to change about your manipulator, if anything? How should you design your base so that it holds your motors and your manipulator tightly? Ask yourself again what you think will make a successful manipulator.

Step 4: Create Alternative Solutions

With your team, discuss and design your initial solution. Draw it out and write down the materials and specifics of your design. During your discussion, it is likely that several options will be raised. After picking the best option to try first, identify what other options you want to try in case the first one does not work as expected.

Step 5: Build a Prototype

Once you are satisfied with your designs, go ahead and build the primary design. As you build it, make notes of changes you have to make, observations, and any thoughts for improvements as you go.

Step 6: Test and Redesign as Necessary

Now, test your updated prototype by plugging your motors into the board and testing the arm. Take pictures, if possible, or sketch the shapes your robot makes under various actuation modes. Do at least six different combinations of motor positions.

Step 7: Communicate Results

Present to the rest of the Lab how you structured your design-build process and explain your results and conclusions.

Troubleshooting Problems

- Issues making tendon holes:
    - It's best to use a thin rod or tool (like a paper clip) to cut a tendon path while the plastic is hot, then insert the tendon after it's cool. If you wrap plastic around the thread, it will simply get stuck.
- Plastic shapes splitting in the middle or at seams:
    - Reinsert the plastic into hot water until it's partially melted. It does not need to be as soft as when you initially melted it. Pull the softened shape out and re-form it before it cools. Check for any seams that may exist along the length and reheat it as necessary until they disappear.

      This problem can be avoided by not folding the plastic over on itself after it's cooled off; the plastic is not reintegrating with itself because it's cooled off too much.

Cleanup

Leave the arm intact to be used in Meeting 6, and label it with your team's information. It is preferable to leave the wiring from the motors to the Maestro intact, but if that's not possible, try to get someone to take a picture of the board and wiring to use as a guide for hooking it up in the next meeting.

Clean your area, and be sure no trace is left behind.

Meeting 5: Build a Soft Tentacle-Arm Robot – Part 2

STEM Innovator Moment Notes

Lab Notebook

Meeting 6: Programming Motions

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Meeting 6: Programming Motions

Opening

The Principal Investigator will lead the group in reciting the Pledge of Allegiance and the Scout Oath and Scout Law.

Scout Oath (Scout Sign)	**Scout Law (Scout Sign)**
On my honor I will do my best To do my duty to God and my country and to obey the Scout Law; To help other people at all times; To keep myself physically strong, mentally awake, and morally straight.	A Scout is trustworthy, loyal, helpful, friendly, courteous, kind, obedient, cheerful, thrifty, brave, clean, and reverent.

Applying the Scout Law

Today's theme is *trustworthy*, as in *I can be trusted to do my part in today's lab.*

Meeting 6: Programming Motions

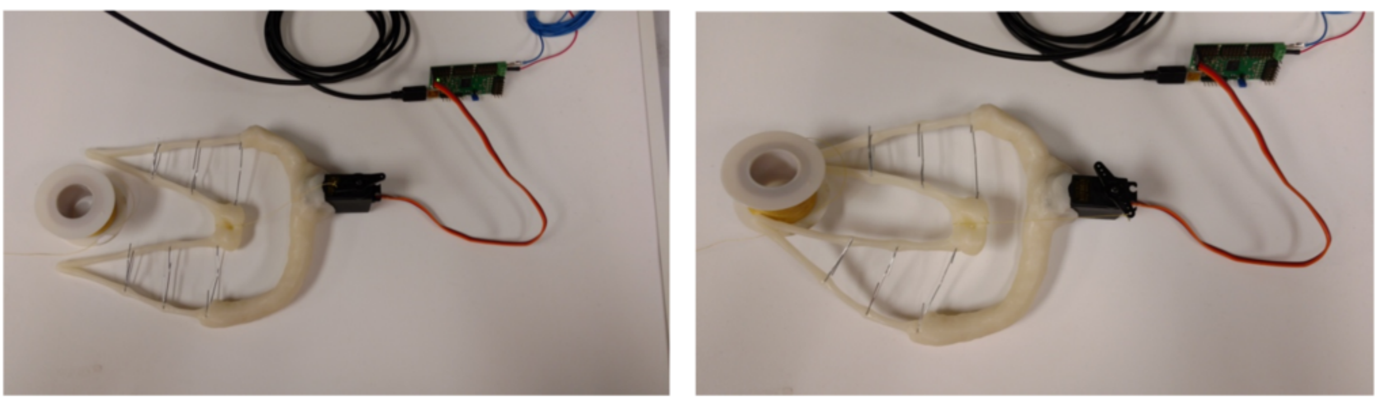
Activity Overview
Once a robot has been built, there are a few different approaches to tell the robot how it should move. One of the most straightforward techniques is “scripting,” where the robot follows a set of instructions, like an actor following a script. The goal of this lab is to create a script to move the robot along a path.

You will use the Maestro control software to record frames in a motion sequence. This program has slider bars to control the robot motors. Scripts are composed of “frames,” where each frame contains a set of motor commands telling the robot where it should go at that instant. By adjusting the sliders and clicking the Save Frame button, your team can compose a script of motion frames that the robot can play back. Once your team has successfully executed a script, it is left to your creative discretion to agree on a motion.

Background
The word “robot” comes from a 1920s play, *Rossum’s Universal Robots,* and is derived from the Slavic word “robota” for forced laborer. A central aspect of robots is the role of machine intelligence to perform complicated tasks. There are varying degrees of intelligence, and this meeting will examine one of the most fundamental methods of controlling a robot: scripting.

A robot following a motion script will precisely follow the instructions of the script. More sophisticated control methods would react to the environment; for example, a self-driving car follows the road and avoids other cars. However, the simplicity of scripting makes it a powerful tool for accomplishing basic tasks.

Scripting is a specific type of programming because a script should solve a single problem. For example, the Maestro program window has multiple buttons the user can press for different tasks, but a script has only one goal, such as closing a robot’s hand.



This robot hand is scripted to grab a spool of thread.

Safety Moment
Avoid sending commands to the robot while touching the motors. Being pinched by moving parts can be painful, and with more powerful motors can even cause harm.

The battery pack voltage of 6V is safe, but it is good practice to be aware of any hazards with electronic parts.

Meeting 6: Programming Motions

Experiment

Get back into the same teams of four that you have been in for previous meetings. You will be working with the tentacle robot arms constructed in Meetings 4 and 5. Inspect the structures and make any necessary repairs or modifications with the thermoplastic material before starting the experiment.

You will learn to make scripts for your robot and perform an automated task by following the STEM Scouts Engineering Design Process. You will complete a tutorial for scripting with the Maestro software. After learning to script, your team will brainstorm potential actions for the robot to execute.

Materials List

- 1 laptop with Maestro control software installed (internet connection is not necessary)
- Soft robot arm from Meeting 5
- 1 Maestro motor driver circuit board
- 3 servo motors
- 1 USB cable
- 1 4-cell battery holder
- 4 AA batteries

Although this lab is all about scripting, there is a chance you and your team may need to make modifications or repairs to your robot arm, so be sure to have the following materials available if needed.

- 1 electric kettle
- 1 mini hot glue gun
- Bowl of ice water
- Paper towels
- Coolmorph beads and scraps from previous meetings
- 1 glass beaker
- 1 pair of scissors
- 1 spool of thread
- 1 No. 0 Phillips head screwdriver
- Extra craft sticks
- Extra mini hot glue sticks

STEM Scouts Engineering Design Process

Step 1: Define the Problem

Write down the problem you're trying to solve: to script your robot to perform a task autonomously.

Step 2: Conduct Background Research

Discuss the following questions with your team and the rest of the Lab.

What is the range of motion for the robot your team constructed?

What goal do you want to accomplish with your robot?

Will the goal involve modifying the robot?

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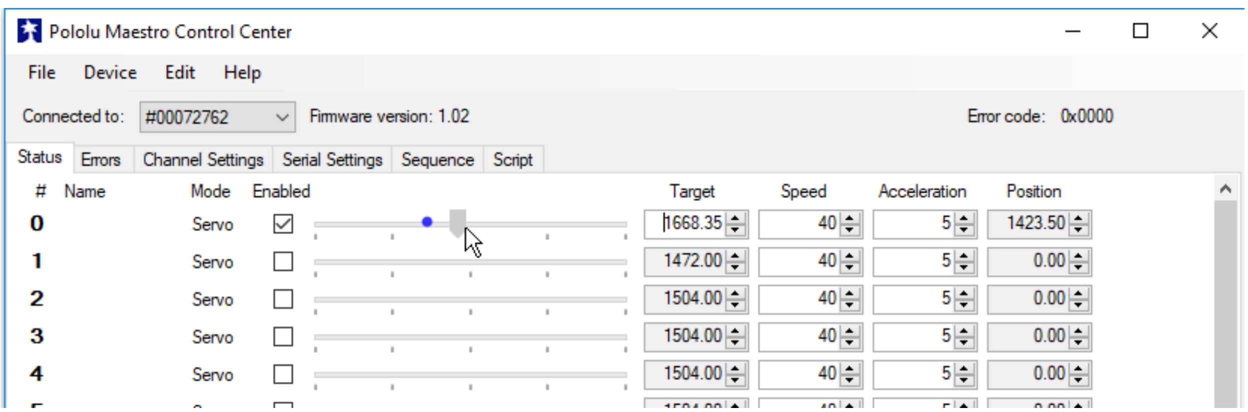
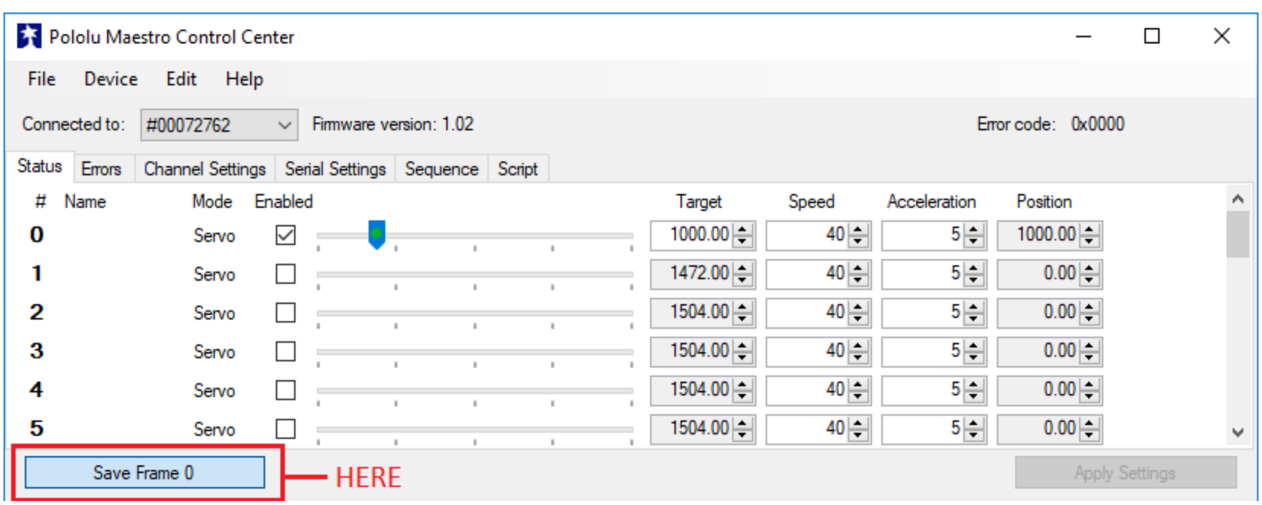
Work through the following tutorial to familiarize yourself with the scripting environment.

Simple Example Script:

- Connect the Maestro board to the computer and start the Maestro Control Center program.
- Load batteries into the battery pack.
- Look at the number on the back of the Maestro to figure out how the motors are numbered in the program.
- Move a slider bar for one of the connected motors to make sure that the motors are working. The motor should move as you move the slider. The blue dot on the line is the motor's current position.



- Configurations can be saved by clicking on the **Save Frame** button in the lower left corner, shown below.



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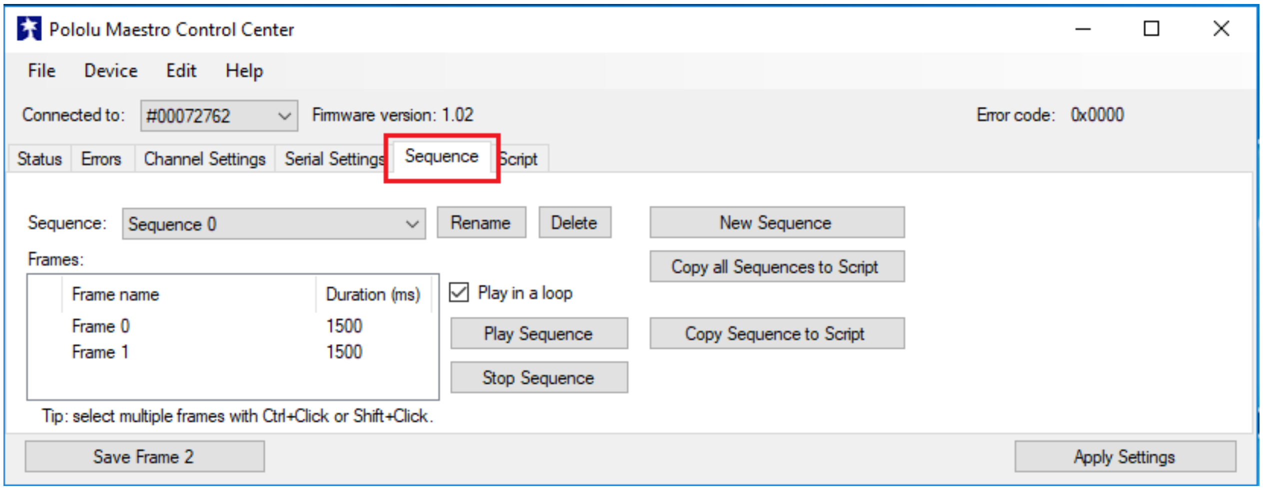
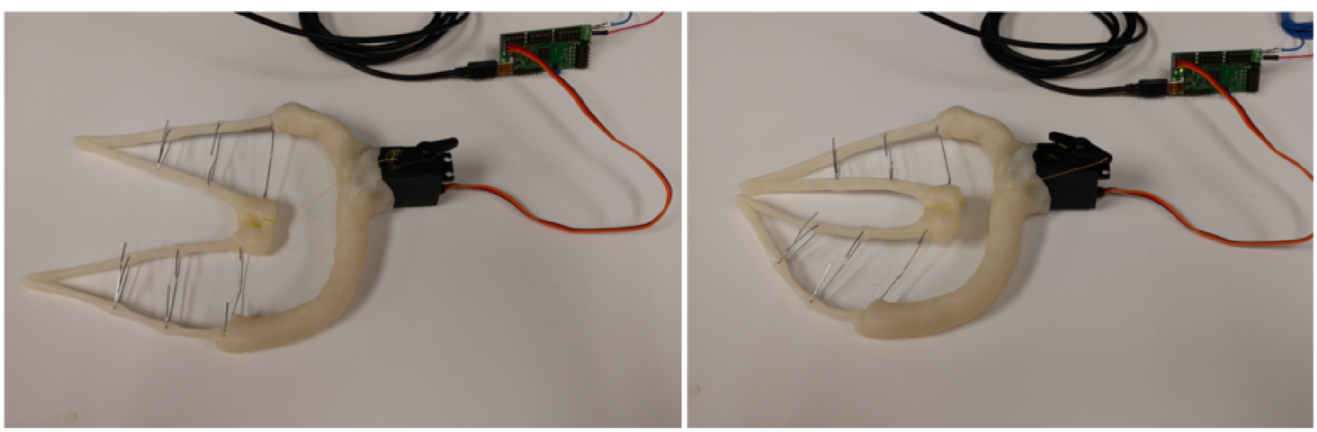
- Save a frame, move a motor slider, then save another frame. Click on the **Sequence** tab. You can click **Play Sequence** to have the robot run through the motor frames you saved.



- You may want to change the amount of time spent on each motor command, which can be done by double-clicking the **Duration** field. If the duration is too short, the movement may not be completed before the script moves on to the next frame.

- Clicking **Play in a loop** causes the script to restart at the beginning. The simple two-frame script here causes a soft gripper to open and close repeatedly.



Step 3: Specify Requirements

Review the criteria for your solution. What are the parameters it must meet, and where is there room to explore options? What resources are available? What will a successful outcome look like?

You must understand the scripting environment and achieve motion with the robot motors. There is room to explore the specific nature of the task you want to attempt. A successful outcome will have the robot performing some action autonomously.

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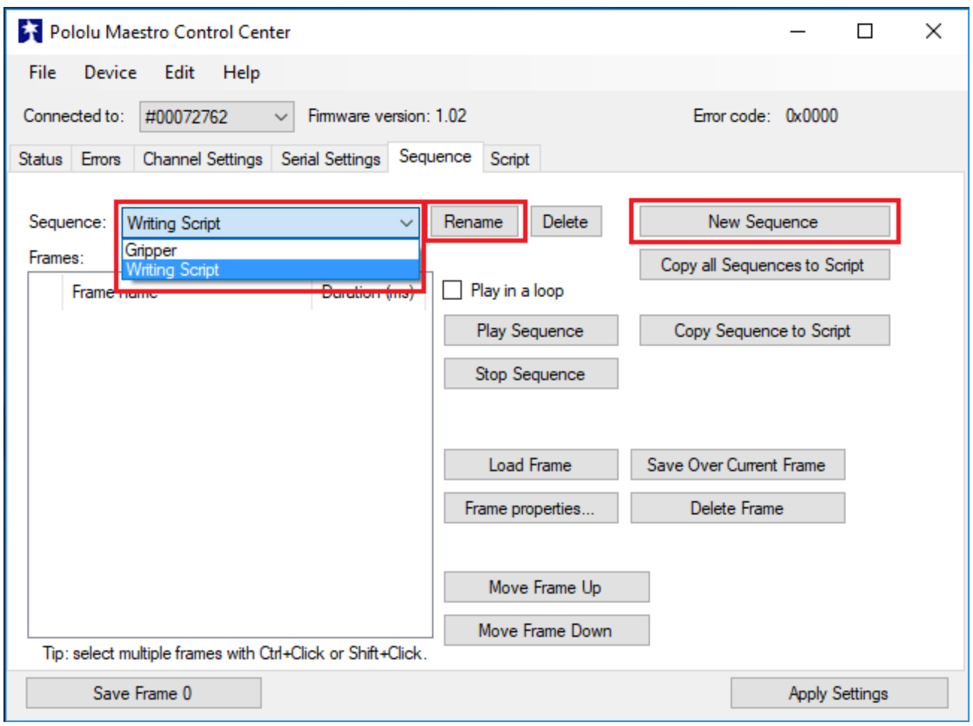
Step 4: Create Alternative Solutions

With your team, discuss and design your initial solution. Draw it out and write down the materials and specifics of your design. During your discussion, it is likely that several options will be raised. After picking the best option to try first, identify what other options you want to try in case the first one does not work as expected.

Step 5: Build a Prototype

Follow your plan to build a simple first script. You should record what you do, your observations, and any thoughts for improvements that could be made. Multiple scripts can be created by using the **New Sequence** button, and scripts can be renamed for organization.



Step 6: Test and Redesign as Necessary

Now, test your primary design, by running the script. How well does it work? Discuss with your team how you might modify the script to do a better job. Try making changes in the script; save each version and see what works best. Remember, in engineering and science, you are better off making one or two small changes and re-evaluating, rather than changing too much each cycle.

Step 7: Communicate Results

Present to the rest of the Lab how your team structured your experimental procedure and then present your results and conclusions.

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Troubleshooting Problems

- The motor does not move when controlled from the Maestro software:
  - Look at the back of the circuit board where the pins are numbered. Make sure the command is being sent to the correct motor.
  - Troubleshoot the battery pack. Inadequate voltage can cause the motors to perform poorly; try a different set of batteries.

Cleanup

Your Lab Manager will tell you if they want to salvage the Coolmorph beads. You should salvage the servos and wires and put them away in the kits for future use.

Clean your area, and be sure no trace is left behind.

STEM Innovator Moment Notes