FESTO

Bionics4Education: Bionics Kit

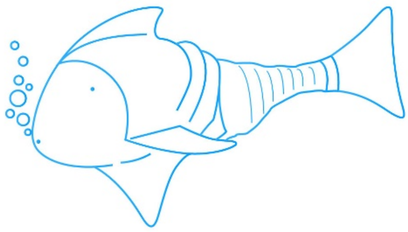
Student Activities

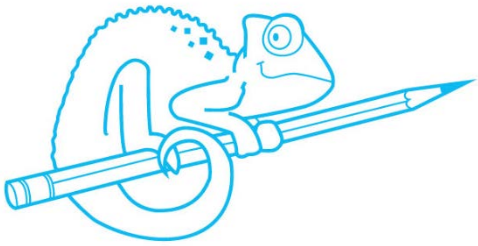
Table of Contents

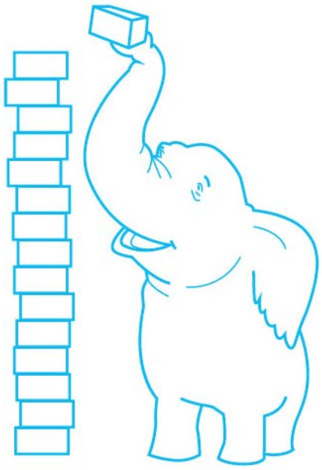
Introduction

This document contains activities and other resources for use with the Festo Bionics Kit. These activities are meant to be attempted and completed after you have familiarized yourself with the instructions and assembly process of the three bionics-inspired robots you can make with the Kit (Fish, Elephant gripper, Chameleon tongue).

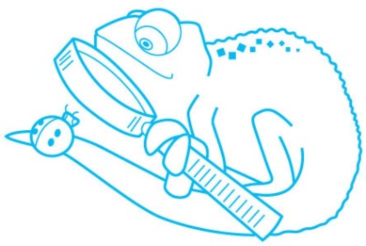
With the exception of the Biomimicry Design Process activity, the activities in this document require one of the fully assembled Bionic robots in order to complete them. Refer to the bionics4education.com website for instructions on how to assemble and operate the three robots. Purchasing information for the Bionics Kits are also available on the site.







Biomimicry design process



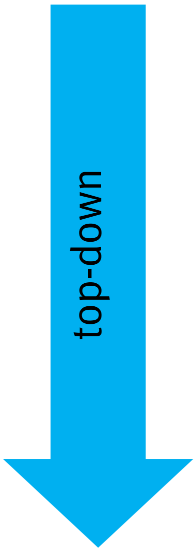
There is so much valuable information that humans can gain from studying nature and how different species of animals have evolved and adapted to their environments. So many different species of animals, over the course of millions of years, have developed characteristics and physical designs to help them thrive in their environments. These natural designs can be fascinating, and they can also be studied by humans to see if there is anything we can learn from them and use ourselves.

Bionics, or biomimicry, is the branch of science that studies biological systems or functions, and their application to mechanical systems or to solve engineering problems. There's a vast number of these functions present in living things that can be used artificially and beneficially.

There are two different approaches one could take to explore potential bionics solutions: the top-down method, and the bottom-up method. The two approaches differ regarding their starting point.

Top-down method

In the top-down method, "engineers look to biology". In this approach, an existing problem is first defined or identified, and then engineers look to see if there is anything existing in nature that addresses or overcomes this type of problem. A step-by-step explanation of the top-down process is shown in this diagram:



Step 1: Define problem

Step 2: Look to nature to see how other organisms solved this problem

Step 3: Select most promising biological model and identify principles

Step 4: Abstraction: detachment from biological model

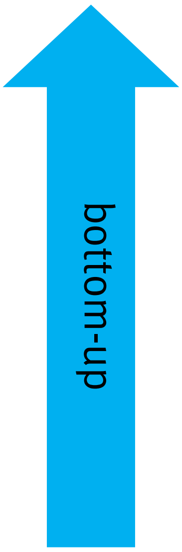
Step 5: Test technical implementation, prototype, analyze, feedback

Step 6: Design solution

To use an example that relates to the robots used in the Bionics Kit, say that engineers decided they needed a type of mechanical gripper that was capable of picking up oddly shaped or spherical objects. They would then look to living organisms in nature that, say, are able to grasp or pick up those types of objects. The engineers would identify those as their natural models, select what they decide is the best model to use (in this example, a chameleon's tongue), then attempt to make a similar mechanical representation of this natural model. By analyzing, building prototypes, testing, and retesting, the engineers can arrive at their final design solution, which in this case would be the Bionic Chameleon gripper.

Bottom-up method

The other approach, the bottom-up method, involves a reverse starting point compared to the top-down method. Here, "biology looks to engineers". So instead of starting by identifying an existing problem and then looking to nature to solve it, the bottom-up method starts by looking to nature and then trying to figure out what we can learn from nature's design. After identifying and analyzing an aspect of natural design that works well, we then look to see how we can use it and implement it using technology.



Step 5: Design solution

Step 4: Technical implementation

Step 3: Abstraction: detachment from principles found in the biological model

Step 2: Analyze biomechanics and functional morphology of the biological system

Step 1: Biological research

Remember the chameleon tongue example used for the top-down method? If that bionics solution was instead developed using the bottom-up method, we would first look at the chameleon and see if there was something distinct about what it does and how it does it. Does it do anything that is particularly effective or efficient? Its tongue is very unique in terms of what it can grab and how it grabs objects. After identifying this, engineers can then study the principles of how the tongue works and develop a design solution based on a mechanical or technical application of the tongue. Using this method, the engineers could also arrive at the Bionic Chameleon tongue as their bionics solution.

Biomimicry project

For this activity, you are tasked with taking the role of a bionics engineer and are to develop a bionics solution using either the top-down or the bottom-up method. Your solution should be based on a natural design (something that already exists in nature), and should solve some sort of problem humans have or should make something humans do easier or more effective.

Once your bionics solution is developed, you or your team will present your proposal to the rest of the group. Be sure to emphasize and explain what your solution is based on, how you adapted it, and what your solution ultimately achieves for human use.

Project management

Working in teams can help people collaborate in order to better achieve specific goals and to achieve these goals more efficiently. Especially in the case of bionics and biomimicry, more people working together can help to navigate the vast amount of possibilities and ideas involved with designing, adapting, and developing solutions derived from nature.

Therefore, it is suggested that you work in teams to develop your bionics solution. Multiple minds working together to come up with ideas is likely to be much more effective than individuals working alone. There are different approaches you can take in terms of assigning roles to different people within the project team. At the very least, you'll want to assign a project manager, with the rest of the team being contributing project members. Depending on how extensive you're planning on making your biomimicry project, you can also assign specific roles to each project member. Descriptions of the specific roles are provided below.

Project leader: You will want to assign a project leader that can lead the team and help make decisions when necessary (such as deciding which natural solution to develop if a team comes up with multiple ideas). The project leader should keep the team focused on the goals and individual steps of the project as it goes along.

Project member: Everyone besides the project manager will be considered members of the project team. Depending on how extensive you plan on making the scope of your project (whether you will be conducting extensive research, whether you will be formally presenting your bionics solution, etc.), more specific roles can also be assigned to these team members. Some options for these roles are listed below. As a group, decide whether it will be beneficial to assign any of these specific roles to your project team members, or whether it would be better for everyone to work together to achieve each aspect of the project goals:

> Analyzer: An analyzer can be assigned to further develop and look into a concept or idea that the project team comes up with. For example, if the team identifies an animal to model their bionics solution after, the analyzer's role would be to look closely at the animal to analyze how its biological system functions. Or if the team starts by identifying an existing problem, the analyzer would be focused on looking to a biological model that solves this problem and looking closely at how it solves it. The analyzer would be focused on steps 2 and 3 of either the top-down or bottom-up method.
>
> Researcher: No one working with the biomimicry design method is expected to work with information purely from memory. Therefore, a certain amount of research is expected during the process. The researcher would be in charge of conducting this research as the team needs it. Research could be needed as early on as the brainstorming step, during the middle steps of the process where biological models and principles are being examined, up to the design of the solution.
>
> Presenter: Depending on what your instructor asks for and how much time you are given for the project, you may be tasked with presenting the team's solution once it is completed. The presenter would be responsible for the presentation of the team's solution to the rest of the class/group. Again, depending on what you are tasked with by your instructor, the presentation given can involve a spoken presentation, discussion with the rest of the class, visual presentations of the solution, or even demonstrating the solution if your team managed to actually make some sort of prototype.
>
> Illustrator: If your team decides that it would be beneficial to have sketches or illustrations to help portray or visually explain your biomimicry concept, you can assign an illustrator role to a team member to draw or produce those pictures.

If you are assigned a specific role and find yourself waiting for something to do at certain parts of the process, try to help out other members in your group. It is important for everyone to cooperate and communicate with each other throughout the project.

Brainstorming

Brainstorming can be very helpful as a starting point when attempting to come up with an idea or concept. There are different methods for brainstorming, and different methods can work better for different people. The main goal for brainstorming is trying to come up with as many viable ideas as possible, then afterwards you can narrow them down or select the ideas that may work best. Some questions to ask yourself or work through with your project team are listed below; answering these questions could help to develop ideas for your bionics solution.

Brainstorming questions:

Approach 1: Start thinking about animals that have characteristics that you think are interesting or effective. What do these characteristics let the animal do or achieve?

Once you identify what the animal does with these characteristics, try to look at it from the perspective of natural design. Try answering questions like: How does the animal do or achieve these things? Is there anything notable about the design or structure about these characteristics? If these characteristics are able to be mimicked by something mechanical, are there any existing problems for humans that this could help solve?

Approach 2: Or you can take the opposite approach: first try to think of a problem that humans have or something that humans have trouble doing. Are there examples in nature where natural design has addressed or solved this problem?

How can these natural design examples serve as models of how humans can solve the problems you identified?

Notes and organization:

You can use the table on this page to help organize your ideas and take notes. Once your group is finished brainstorming ideas, decide as a group which of the ideas you want to use and move forward with.

Animal	Natural design	Human use

Research

To develop a successful bionics solution, conducting research can help you gain valuable insight and knowledge regarding your ideas. Outside information can also help to reinforce ideas you have and help improve their credibility. There any many resources available on the Internet, and you likely could find information related to your bionics solution and its natural model. Types of reliable sources may be books, scientific journals, magazine articles, encyclopedias, or government articles. It is important that you evaluate where your information is coming from; there are plenty of reliable sources out there, but also a lot of unreliable information out on the "open-Internet". If you have access to a school library website with scientific resources, that would be a good place to start to find trusted, reliable sources.

Remember that through researching, you are looking for information to support or reinforce your ideas, not to take ideas from other people. Your bionics solution should ultimately be based on ideas that you or your group comes up with on your own.

If you plan on using information from an outside source in your discussion or presentation of your bionic solution, make sure you save the web link to the source or a copy of it with the publication information so you can give the original source proper credit.

Presentation

Once you have conceptualized, researched, and developed your bionics solution, the final step is to present your team's work to your instructor and/or the rest of the group. Decide which members of the team will speak during the presentation, what presentation materials you will be using (if any), and what information the presentation will cover.

As emphasized in the original project requirements, make sure your presentation includes an explanation of what your solution is based on, how you adapted it, and what your solution ultimately achieves for human use.

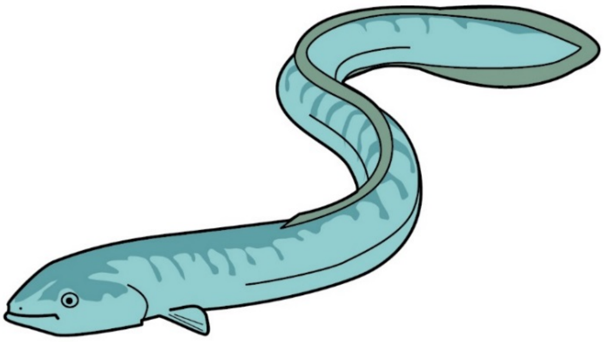
Fish types

Note: This activity requires a fully assembled Bionic Fish. It is also suggested to have a tank filled with enough water to buoy the Fish.

Different types of fish move in different ways, and there are three general categories in which fish motion can be classified. Keep in mind that all three of the different types of motion are effective in moving a fish through the water.

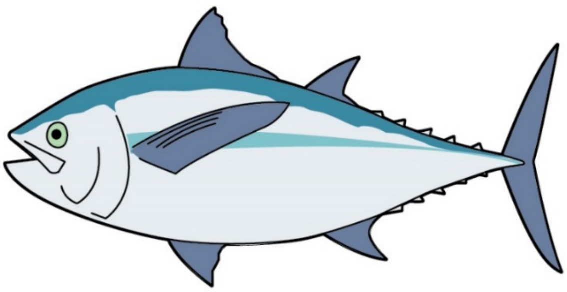
Anguilliform motion

First, there is anguilliform motion, where a fish moves all of its body, from the head down to the tail. An example of a fish that uses anguilliform motion would be an eel. The flexibility of an eel's body allows it to move this way.



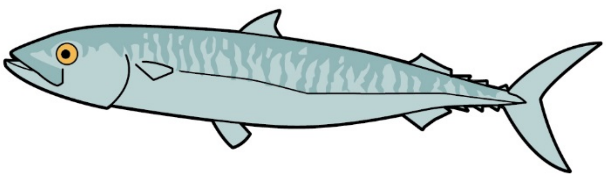
Thunniform motion

A second type of motion is call thunniform swimming. This type of motion is named after the genus *thunnus* that tuna belong to. Unlike anguilliform motion, fish that use thunniform motion (such as a tuna) propel themselves primarily through the movement of just their tail.



Carangiform motion

The third category is carangiform motion. This motion involves the head moving slightly, but most of the motion is generated by the tail; think of it as a type of movement that is in between that of the anguilliform and thunniform motions. This is the motion that is used by most fish; an example would be a mackerel.



Movement of the Bionic Fish

The Bionic Fish mimics the construction and movement of a real fish. While observing how the Bionic Fish moves through water and how it is shaped and put together, can you identify what type of the three real-life fish motions it uses? What type of fish would you say the Bionic Fish most-closely resembles? Explain your answer.

Chameleon tongue activity

Note: This activity requires a fully assembled Bionic Chameleon and objects of various shapes and sizes that the Chameleon gripper could feasibly pick up.

The elasticity of a chameleon's tongue allows it to form to the shape and size of the object it is trying to grab. As the tongue is about to reach, for example, an insect the chameleon is trying to eat, the tip of the tongue retracts (or moves inward). While the middle moves inward, the areas on the outside of the tongue move outward. This lets the chameleon's tongue surround the target and adjust to the target's shape in order to grab hold of it.

The Bionic Chameleon gripper uses a similar principle, where the center of the tip moves inward when grabbing an object, while the outside of the tip outwardly surrounds the object.

One of the notable characteristics of the Bionic Chameleon gripper is the material on its surface. It helps to maintain friction with the objects it picks up.

Picking up objects

Your Bionic Chameleon gripper is designed to pick up objects that other types of mechanical grippers would not be able to. Experiment with the gripper by trying to pick up a variety of objects. You can use the table below to keep track of the type of objects you try to pick up, the characteristics of the objects, and a section to take notes on whether you were successful in picking up that object.

Object	Object characteristics	Successful pickup? (yes/no)

Observations and analysis

What objects was the chameleon gripper able to pick up? Did these objects have anything in common in terms of what type of objects they were, their shape, or the material they were made of?

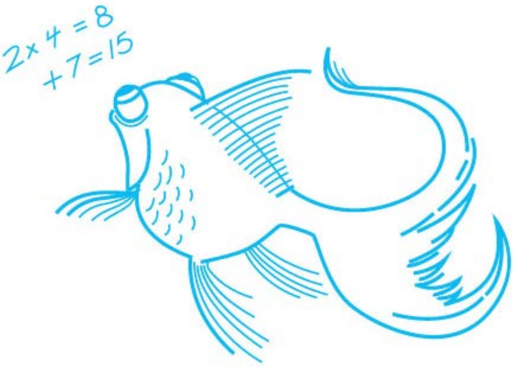
Were there any objects that the chameleon gripper failed to pick up? What do you think prevented the gripper from successfully picking up these objects?

What types and shapes of objects was the chameleon gripper able to pick up that other more rigid and less malleable types of grippers would not be able to?

Did you attempt to pick up anything that was fragile? How did the chameleon gripper's design allow for a gentler grip on objects?

Fish tail movement

Note: This activity requires a fully assembled Bionic Fish.



Most boats and ships are designed to move through the water by resisting as much unsteady motion as possible. This makes for smoother propulsion, but it also requires a good amount of energy to achieve. Fish, on the other hand, have a much more efficient way of moving through the water. Instead of resisting the natural unsteadiness of moving water, fish embrace this unsteady movement and coordinate their body motion with it. This movement of fish requires much less energy compared to the way boats attempt to resist and negate the unsteady movements.

Despite using so much less energy, it's obvious that fish are still able to move very well in the water and are able to generate a lot of quick propulsion. The main reason fish are able to do this is through the natural design of their tails. The tails push water in the opposite direction in order to generate thrust and move the fish forward.

Fish swim speed

How fast a fish can swim through the water depends on a few factors, including the length of the fish and how quickly its tail can swing. The estimated top speed of any fish can be calculated using the following equation:

$$V = \frac{1}{4}[L(3f - 4)]$$

Where:

V is the top velocity of the fish (in centimeters per second [cm/s]).

L is the length of the fish (in centimeters [cm]).

f is the frequency of tail beats per second.

Measure the length of the Bionic Fish (in centimeters) from the front of the head to the back of the tail. Also find the frequency of tail beats per second of the Bionic Fish at its maximum speed setting.

Imagine that a real fish has the same characteristics and measurements of the Bionic Fish. Use the velocity equation to calculate how fast could this real fish could move.

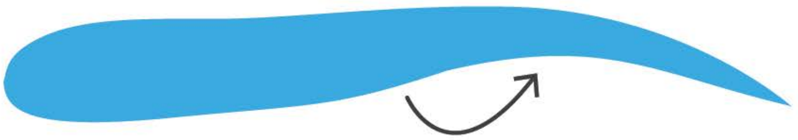
Fish propulsion

Note: This activity requires a fully assembled Bionic Fish and a tank of a sizeable length filled with enough water to buoy the Fish.

A more detailed look at the shape and structure of a fish tail makes clear just how the design of the tail allows a fish to propel itself forward and move through water.

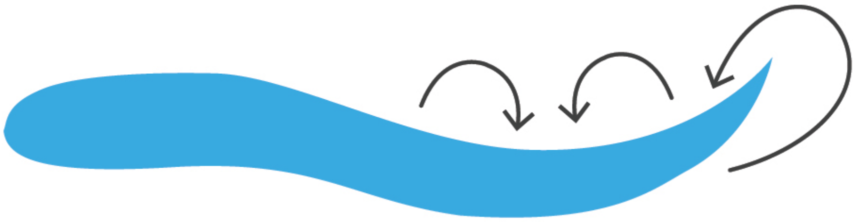
These illustrations show a fish tail's movement in water. Just like a propeller on a boat generates a jet of water behind it to move it forward, a fish tail's movement also generates a jet that achieves forward motion. The illustrations below represent the movement of a fish tail to propel it forward.

Step 1: Tail moves inward in one direction.

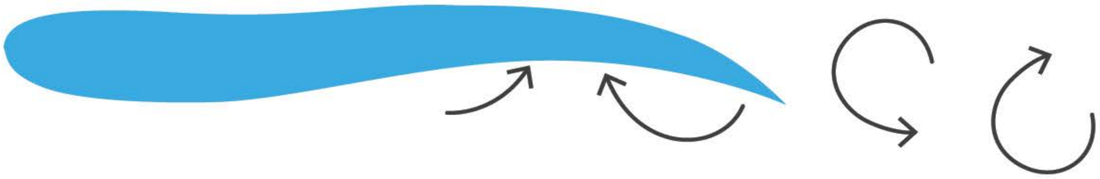


Step 2: Tail starts to move in the opposite direction.

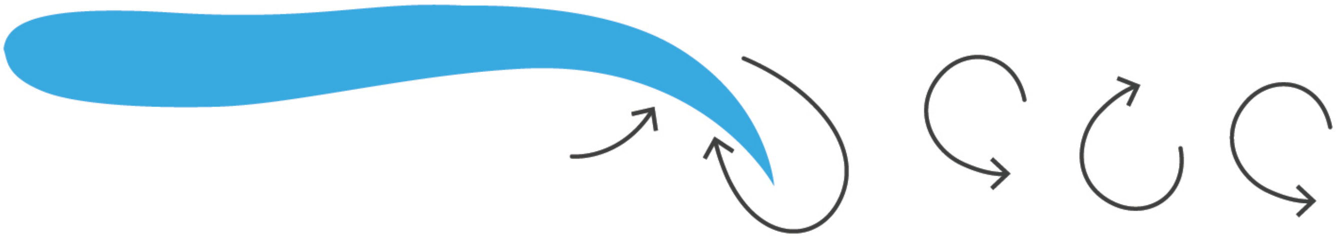
Step 3: As the tail continues to move in that direction, a vortex starts to form behind it.



Step 4: Tail again moves in the opposite direction, forming more vortices and starts to propel the fish forward.



Step 5: Tail movement continues, with orderly vortices forming behind the fish to achieve propulsion through the water.



In order to propel itself forward in the water, a fish must overcome the drag on its body. To do so, it needs to push water in the opposite direction of its body. The movement of the fish demonstrated in the steps above show that vortices (plural of "vortex") are shed from the tail, and the formation of these vortices are what allow the required amount of water to be pushed away from the fish.

A vortex can be defined as a mass of swirling flow. The vortices that a fish generates and sheds behind it are actually very orderly and consistent. And because they are so consistent, a jet of water forms behind the fish from these vortices. This jet works much like a jet of water that the propeller from a boat would produce.

Tail swing and speed experiment

The way a fish tail moves allows a fish to move quickly and efficiently through water. The tail propels the fish as it moves back and forth. With the Bionic Fish, you have the ability to control both the speed of the tail and the size of the tail's swing. Experiment with 5 different speed settings and 5 different swing sizes, and determine if this has any visible effect on how fast the Bionic Fish moves through the water. Use the table below to keep track of your results and notes.

	Swing size 1 (small)	Swing size 2	Swing size 3	Swing size 4	Swing size 5 (big)
Tail speed 1 (slow)					
Tail speed 2					
Tail speed 3					
Tail speed 4					
Tail speed 5 (fast)					

Analysis and conclusions

Based on your results, what can you conclude in terms of the effects of the tail speed and the tail swing rate on how fast the fish is able to move through the water?

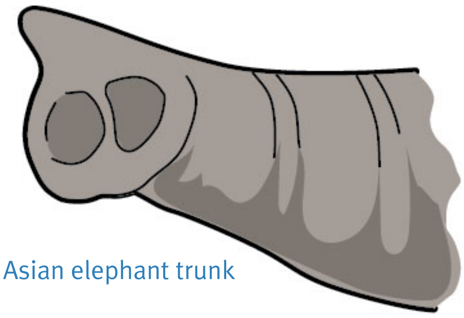
Elephant trunk activity

Note: This activity requires a fully assembled Bionic Elephant trunk and objects of various shapes, sizes, weights, and materials.

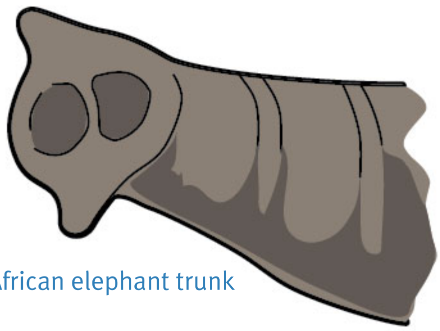
The trunk of an elephant is fascinating for many reasons. The trunk is very unique, especially the way an elephant is able to move it. It is sensitive but also strong. An elephant can bend and stretch it to reach things above its head, so high that it can even reach things the elephant can't see. The trunk allows elephants to access food that is out of the reach of many other animals that share their habitats.

Not only is it amazing how far elephants are able to reach with their trunks, the way the elephant is able to pick items up is also very impressive. The tip of the trunk functions much like a "hand". The trunk tip is very sensitive (it contains a lot of nerves) and it is very dexterous (this means that the trunk tip is very skillful and can pick up objects very delicately).

Different types of elephants have slightly different trunk tip shapes. For example, the Asian elephant has one "finger" at the upper half of the tip of its trunk. If an Asian elephant wants to pick something up, it usually "grasps" the object by curling the object under and around the tip. The African elephant has two "fingers" on the tip of its trunk; think of it like a thumb and index finger on a human hand. This allows the African elephant to "pinch" objects they want to pick up, holding the object between the two "fingers".



Asian elephant trunk



African elephant trunk

Look at the characteristics of the Bionic Elephant trunk and use the trunk to try to pick up an object. Does the design of the Bionic Elephant's trunk tip most closely resemble an Asian elephant's trunk tip or an African elephant's trunk tip? What method does the Bionic Elephant trunk use to pick up objects?

Picking up objects

Scientists have studied how real elephants are able to pick up and carry objects of different shapes, sizes, and weights. Elephants are able to bend their trunks in a way that allows them to support the weight of an object while pointing the tip of their trunk downwards to better grip it and pick it up. Elephants can adjust the amount of downward pressure they apply in order to pick up more delicate objects.

Your Bionic Elephant gripper is designed to mimic the functionality of a real elephant trunk, where you can pick up objects of different shapes and sizes, and even items that are delicate (without breaking them). Experiment with the gripper by trying to pick up a variety of objects. You can use the table below to keep track of the type of objects you try to pick up, the characteristics of the objects, and a section to take notes on whether you were successful at picking up that object.

Object	Object characteristics	Notes

Observations and analysis

Once you have picked up a number of objects, analyze your results. Are there similarities between the objects that the gripper was successful in picking up? What about any similarities you can find between objects that the gripper could not pick up?

What kind of objects do you think the design of the gripper allows you to pick up that other gripper design may not be able to?