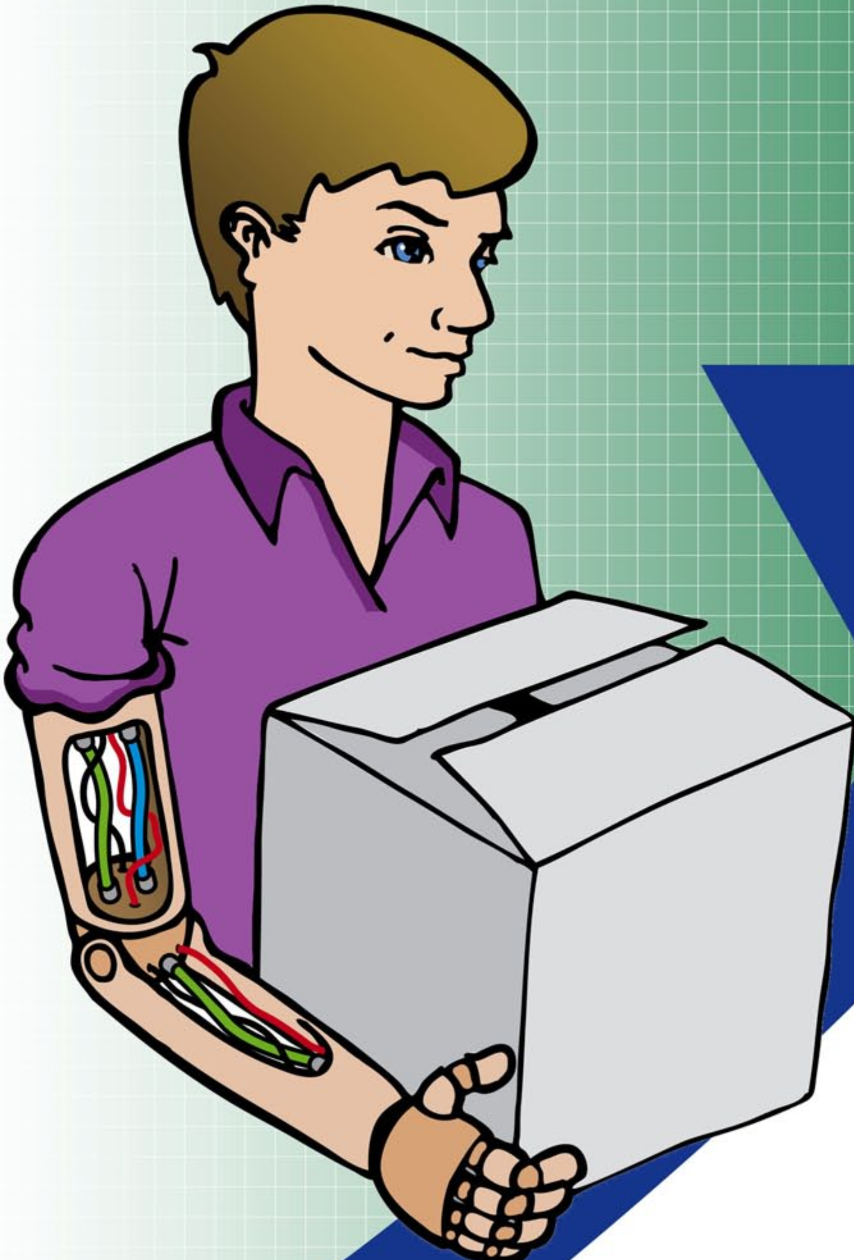


Bionic Arm

Facilitator's Guide

TechXcite Discover Engineering

Module Overview

This TechXcite: Discover Engineering module introduces youth to the ways in which engineers design technology to help people with disabilities. They explore the design considerations for developing a prosthetic arm to improve the quality of life for someone who has lost an arm. The module demonstrates ways in which design of assistive technology is interdisciplinary, combining mechanical, electrical, and biomedical engineering concepts.

This curriculum is intended for use with youth in middle grades in informal settings, such as after-school programs and summer camps. However, it has also been successfully implemented in formal school contexts, homeschool content, and with youth in elementary and high school.

Activity 1: Youth explore what it is like to perform everyday tasks without the use of one hand. They then learn that assistive technology refers to devices designed by engineers to improve the lives of people with disabilities.

Activity 2: Youth build simple hydraulic and pneumatic systems using syringes and plastic tubing.

Activity 3: Youth use what they learned about hydraulic and pneumatic systems to create a working prosthetic arm.

Activity 4: Youth build a simple circuit with a buzzer and switch.

Activity 5: Youth create a touch sensor for their prosthetic arm using the buzzer circuit.

At the end of this module, students will have designed and built a prosthetic arm. They will have learned that engineers design devices to solve problems and help people.

Table of Contents

TechXcite: Discover Engineering

TechXcite is an informal engineering program partnering 4-H Youth Development/Family and Consumer Sciences at North Carolina State University, National 4-H Council and the Engineering K-PhD Program at Duke University's Pratt School of Engineering. It was initially funded by a five-year grant from the National Science Foundation.

In 2000, Drs. Ybarra and Klenk created an informal after-school engineering program at Rogers-Herr Middle School in Durham called Techtronics, which spread to additional schools across North Carolina and other states. The TechXcite: Discover Engineering curriculum builds on the Techtronics foundation by implementing hands-on, exploratory, engineering learning modules in 4-H Afterschool programs nationwide. Other after-school programs and even formal in-school and home-school programs have chosen to use the TechXcite curriculum. TechXcite is an engaging, substantive, experiential and inquiry-based curriculum centered on engineering, while using technology, applied science and mathematics learned in school. TechXcite's mission is to encourage youth in both rural and urban settings to pursue careers in engineering and technology.

TechXcite is the product of a collaboration of twelve 4-H leaders at land grant universities, two leaders at National 4-H Council and a team at Duke University.

Online Support

The TechXcite website (techxcite.org) contains additional material to facilitate implementation of this module. There are videos, Facilitator's Guides, Youth Handouts, and kit inventories with vendors and pricing for each item required. Although the curriculum is written with a focus on middle school youth, it has been successfully implemented at both the elementary and high school levels. Anyone can download copies of the Facilitator's Guide and Youth Handouts from our website. There are links to additional resources for information about the module topics and ideas for further activities and exploration.

Training Videos

Each module comes with a set of training videos found on its curriculum page (techxcite.org/curriculum). These videos serve as a companion to the Facilitator's Guide. An introductory video provides an overview of the material and concepts. The corresponding video for each activity then covers basic setup, procedure, and helpful tips for facilitating that activity. It's recommended that instructors watch all of the videos before starting the module.

Using this Guide

The Facilitator's Guide for each activity follows the same format. Below is what you can expect to find in each section. At the beginning, you will be given basic information about the activity. This includes:

- Time Required
- Group Size – Suggested number of students per group.
- Materials List
- Youth Handouts – These will need to be copied.
- Getting Ready– Includes what you need to do before the activity and approximately how much time it will take you.
- Education Standards
- Learner Outcomes
- Vocabulary

Introduction and Activity Closure

The Introduction and Activity Closure are scripted. You may read these sections verbatim to students. Instructions that are not to be read to students, as well as answers to questions, are in brackets/italics.

Facilitating the Activity

This section contains step-by-step instructions for facilitating the activity. Students have their own procedure in the Youth Handouts.

Exploration Questions

Provides possible answers to the Exploration Questions found at the end of each activity in the Youth Handouts. After the students have a chance to answer the questions individually, instructors should hold a class discussion. The main purpose of this section is to encourage critical thinking and to promote the exchange of ideas.

Apply

When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new knowledge and skills; however, the application of new knowledge or skills to independent, real-world situations is a critical factor in the learning process. To complete the cycle of experiential learning, this section provides youth with an opportunity to apply the concepts to authentic situations.

Activity 1: Assistive Technology

Time Required: 45 Minutes **Group Size:** 3

Materials List

Each group needs:

- 3 Rubber bands (Large enough to stretch around a closed fist)
- 3 Socks
- 6 Objects of various shapes and sizes (Not included in kit)
- Container (Box, trash bag, pillow case, etc; Not included in kit)

Youth Handouts:

- "Assistive Technology"

Getting Ready (20 minutes)

- Assemble a collection of "mystery containers" large enough to fit six common, recognizable objects. (Students must not be able to see the contents of the mystery containers.)
- Fill each group's container with an assortment of items. Feel free to use materials from this kit, including batteries, masking tape, protractors, paper clips, sandpaper or paper cups. Other examples: pens, small books, erasers, rolls of tape, old CDs, drink containers, sponges, etc. It is not necessary for each group to have the same items. Avoid sharp objects because students will be reaching blindly into the bag.

Education Standards

None

Learner Outcomes

- Define assistive technology.
- Identify examples of assistive technology.

Vocabulary

Word	Definition
Assistive technology	A device that helps people with disabilities by either making a task easier or by enabling them to perform a task they could not otherwise do.
Engineer	A person who applies scientific knowledge to solve practical problems. The work of engineers forms the link between scientific discoveries and their application to human needs and quality of life.
Prosthetic	An artificial device designed to replace a missing or injured body part.

Activity 1: Assistive Technology

Introduction

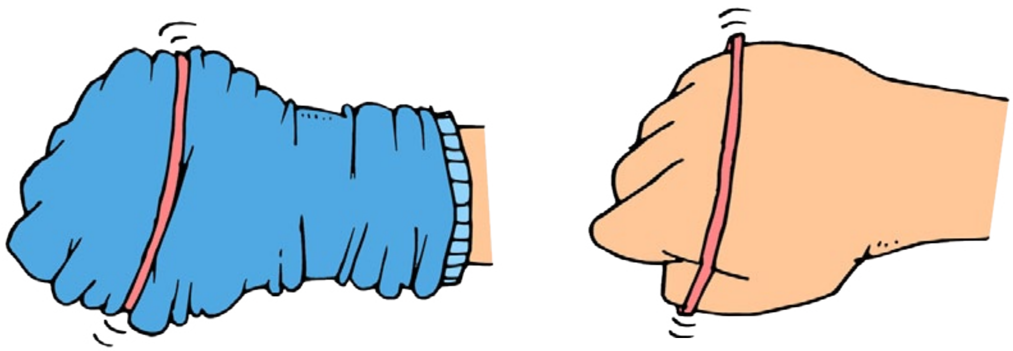
Have you ever thought about what you would do if you lost one of your hands? What tasks that are now easy might become difficult? Today you are going to try performing some common tasks without using one of your hands.

Facilitating the Activity

Part 1: One-handed Shoe Tying

1. Give one sock and one rubber band to each student.
2. Instruct youth to place their hand inside the sock and make a fist. Then have them wrap the rubber band around the sock-covered hand so their thumb and fingers cannot move. This is done just to keep the students from trying to use this hand in the next step.

   Use the illustration for reference and demonstrate for the class.



3. Instruct youth to keep the sock on and try tying their shoes with their other hand. Can they do it? It's possible to tie your shoes with one hand, but it takes practice.
4. Ask: "What are some other activities that would be difficult to do with one hand?" Lead a brainstorming session and write students' ideas on the board. This information will be revisited in the *Exploration Questions* section.

Part 2: Mystery Container

5. Place students into groups of three.
6. Provide each group with an *Assistive Technology* handout and a mystery container. Tell students not to look inside.
7. If the students removed the sock and rubber band from their hand after the previous activity, make sure they put them back on.
8. Instruct youth to take turns reaching into the container with the sock-covered hand and trying to identify the objects without opening the fist. They are not to look inside the container or remove any items. After each turn, students should write down the identity of the objects they touched. Have them continue taking turns until they've listed six items on their handouts.

Activity 1: Assistive Technology

9. After the groups have finished, ask them to name the items they're confident their group guessed correctly.
10. Have youth explore the containers using their uncovered hand and make any corrections to their list.
11. Finally, have the students open the containers and look at all of the items.

Activity Closure

How would your life be different if you lost the use of one of your hands?

People who lack the use of one hand can often do anything you or I can do. Typing on a computer is usually a two-handed activity, but if you had only one hand you might adapt to other methods of typing. For example, you might learn to type using one hand or you might use a device to help you type without using your hands at all, such as a computer program that dictates your spoken words. This is an example of **assistive technology**.

Assistive technology devices help people with disabilities by either making a task easier or by enabling them to perform a task they could not otherwise do. What other assistive technologies can you think of? [*Possible answers: eyeglasses, contact lenses, hearing aids, wheelchairs, etc.*]

Over the next few activities, we will be exploring options for creating assistive technology. Ultimately, you will be building a **prosthetic** arm—a device designed to help someone who has lost the use of an arm. We will also be examining the different functions of a prosthetic arm and learning how to make the arm move.

Exploration Questions

1. Which objects were hardest to identify with the sock-covered hand and why?

   [*Allow a few groups to respond.*]

2. What other tasks or activities would be difficult to do with one hand?

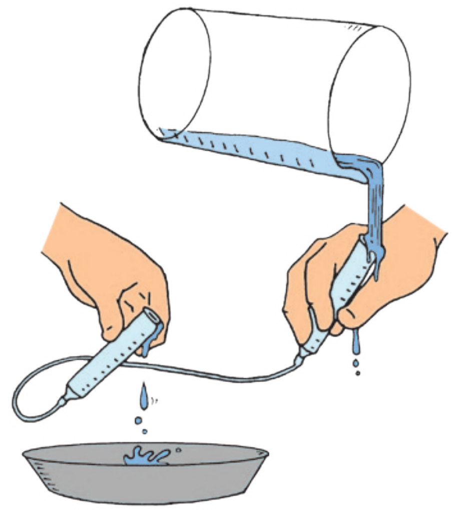
   [*Examples: swinging a baseball bat or lifting a heavy box.*]

Apply

Engineers use creative problem solving to design assistive technologies. As a class, choose one of the difficult tasks from question #2 (above) and design a device to help an impaired person complete this task. Sketch your idea and label its key features.

[*Give students about 10 minutes to sketch. Ask some students to share their designs with the class.*]

Activity 2: Pneumatics and Hydraulics



Time Required: 45 Minutes **Group Size:** 2

Materials List

Each group needs:

- 4 Oral syringes (10 ml)
- 2 Clear plastic tubes (1.5 ft long, 1/4" diameter)

Entire class needs:

- Water (Not included in kit)
- Catch basin (Sink, bucket, pan, etc; Not included in kit)
- Towels for spills (Not included in kit)

Youth Handouts:

- "Pneumatics and Hydraulics"

Getting Ready (25 minutes)

- Cut one 1.5-foot length of tubing for each student.
- Assemble a sample 1.5-foot system and practice filling it at the water source, following the instructions in the Youth Handout. If the group is large and workspace is limited, you may need to fill the syringes for students during the exercise to save time.
- Create a pair of demonstration systems using 5-10 feet of tubing for each. One model will use air and the other will use water. During the Activity Closure, you will demonstrate these systems to show that motion can be transferred over longer distances.

Education Standards

CCSS: RST.6-8.3

Learner Outcomes

- Explain that a hydraulic system uses liquid to transfer motion.
- Explain that a pneumatic system uses a gas to transfer motion.
- Explain that gases are compressible.
- Explain that liquids are incompressible.

Activity 2: Pneumatics and Hydraulics

Vocabulary

Word	Definition
Compressible	The ability of a material to be squeezed into a smaller space.
Hydraulic	The transfer of motion using liquids.
Pneumatic	The transfer of motion using gases, such as air.

Introduction

We all know cars and bicycles use breaks to stop or slow down, but how do brakes work? [*Allow students a chance to respond*]

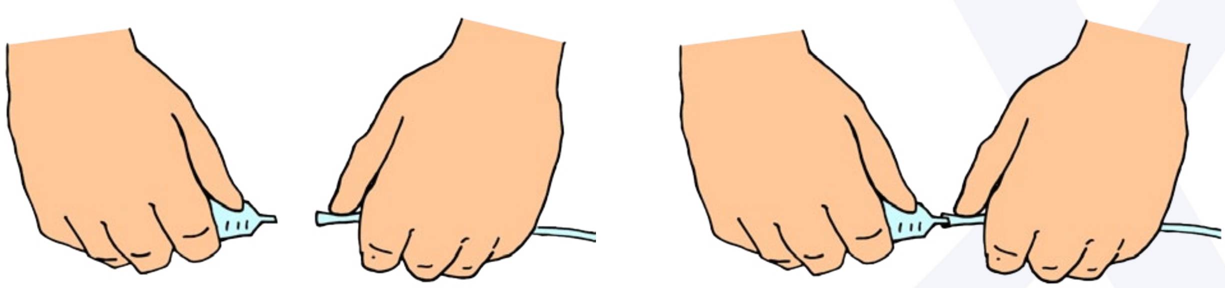
The driver's foot can't push directly against the wheels while driving, so the driver has to slow the wheels of the car by pushing down on a pedal inside the vehicle. The force on this brake pedal must then be transferred to the tires somehow. Motion transfer happens when an object at one location moves an object at another location.

Engineers use many different methods to transfer motion, including electronic signals, gears, gases, and liquids. Today we are going to explore how engineers use gases and liquids to transfer motion.

Facilitating the Activity

Part 1: Pneumatics

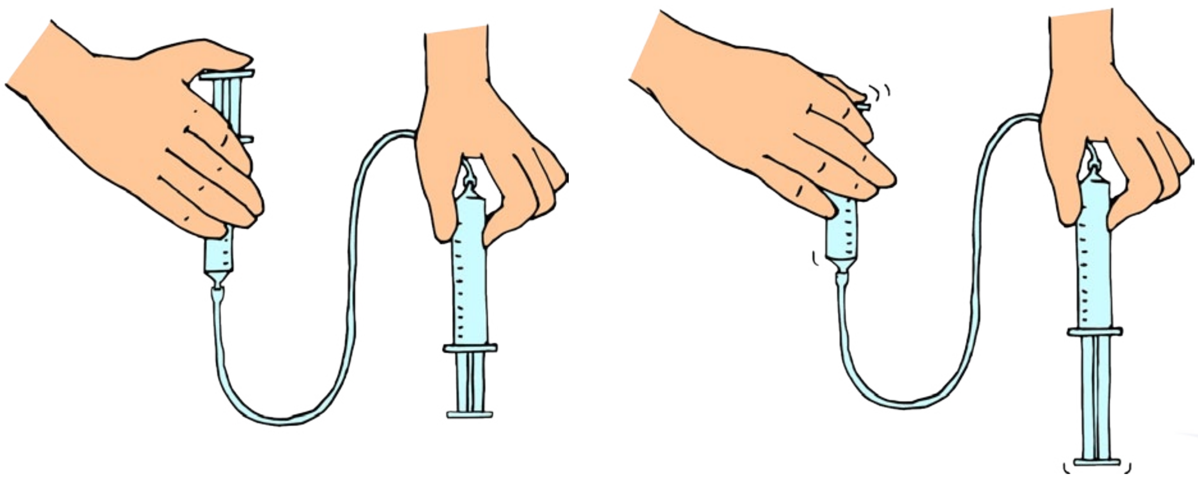
1. Place students in pairs.
2. Give each student two syringes (four per group) and one 1.5-foot section of tubing (two per group).
3. Instruct students to retract (pull out) the plunger of one syringe all the way and push the plunger of the other syringe in all the way.



4. Then have them attach the tips of the syringes to the ends of the tube (on both sides).

Activity 2: Pneumatics and Hydraulics

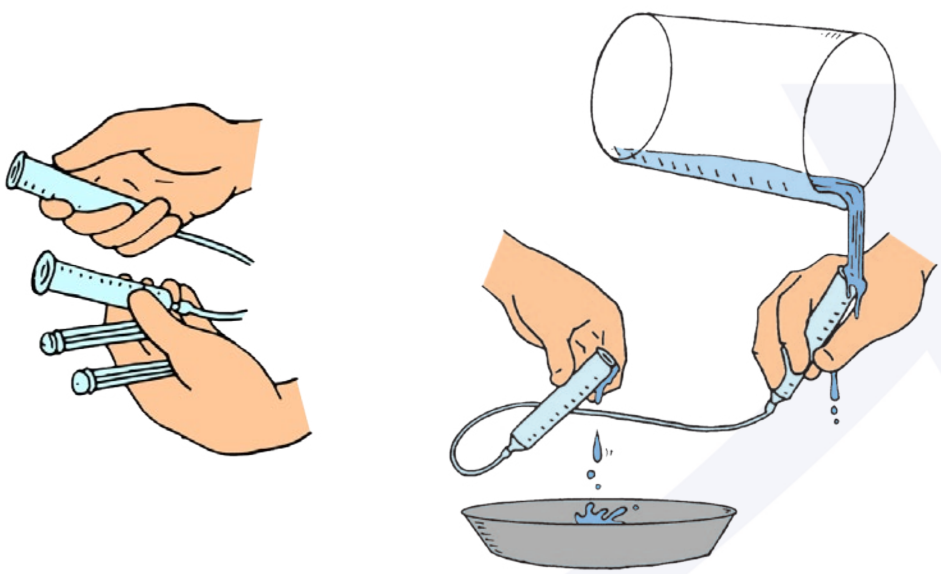
5. Once the systems are assembled, instruct students to push the retracted plunger completely into the syringe. This motion will push air through the tube and cause the plunger in the other syringe to retract.
6. Tell students they've just created a system that uses air pressure to transfer motion, called a **pneumatic** system.



Part 2: Hydraulics

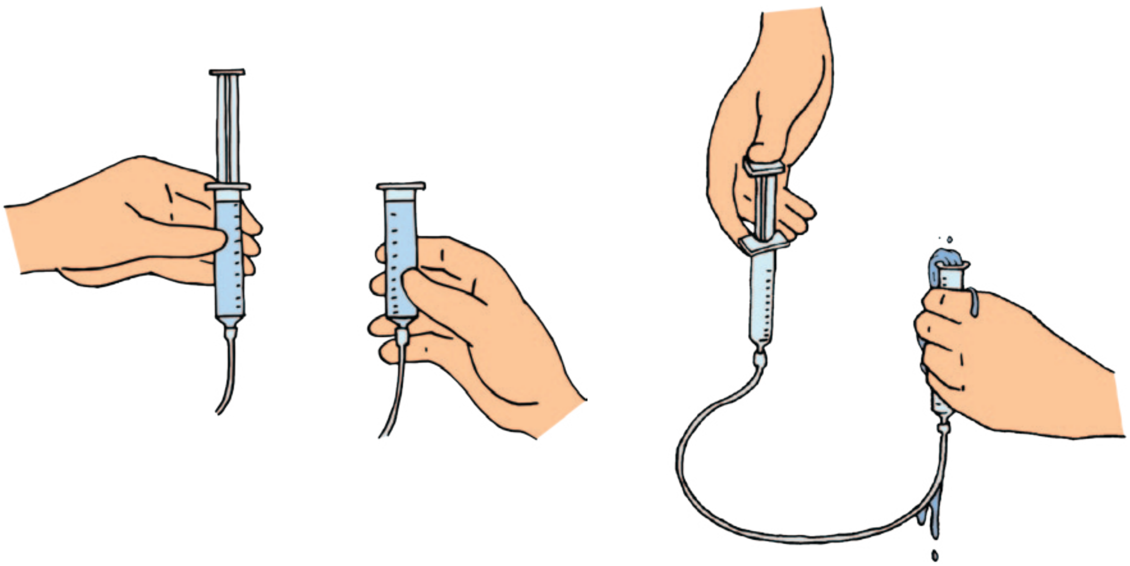
7. Fill half of the systems with water (one per group).

   First, remove the plungers from both syringes. Make sure the tube is securely attached to the syringes and have one student hold the end of the other syringe over a catch basin in case water spills out. Then pour water into one of the empty syringes until the entire system, including the other syringe, is filled.



Activity 2: Pneumatics and Hydraulics

8. Give each group a water-filled system and instruct them to hold both syringes level so that water doesn't spill from either end.
9. Instruct students to hold their systems level over a catch basin and push a plunger into one of the syringes. Excess water will flow out of the other syringe. Note: Try to remove any air bubbles.



10. Have them put the plunger back into the other syringe and press it down gently. Remind students not to apply so much pressure that the tube pops off. If the system was prepared properly, this motion will cause the plunger in the other syringe to retract.
11. Allow students to experiment with pushing the plungers to transfer water back and forth.
12. Tell students they've just created a system that uses water to transfer motion, called a hydraulic system.
13. Ask students to discuss the differences and similarities between the air-filled and water-filled systems. Give each pair of students enough time to adequately explore and experiment with the two systems.

Activity 2: Pneumatics and Hydraulics

Activity Closure

You probably noticed that air is easy to compress. Gases, such as air, are very **compressible**, which means that they can be easily squeezed into a smaller volume of space than they normally occupy. When gases are compacted in this way, they will push back. If you push the plungers in the air-filled syringes at the same time, you will feel a force pushing back due to increased pressure in the tube.

Liquids, on the other hand, are so hard to compress that they are usually considered incompressible for engineering purposes. Incompressible means that a substance cannot be squeezed into a smaller space. In the water-filled systems, you may have noticed that the plungers moved back and forth more quickly than the ones in the air-filled systems. The motion is transferred almost immediately because the water is nearly incompressible.

[*Show the pair of demonstration systems you prepared before the activity.*]

One of these systems is filled with air and the other is filled with water. What will happen when the plunger in the air-filled system is pushed? Why? What will happen when the plunger in the water-filled system is pushed? Why?

[*Ask students to explain their reasoning. Now do the demonstration. The second plunger in the water-filled system will move. The second plunger in the air-filled system might not move. Explanation: In the air-filled system, the motion from depressing the plunger goes into compressing the air inside the long tube. This causes only a slight increase in pressure that is not enough to overcome the friction of the plunger on the other side.*]

You have just learned about hydraulic and pneumatic systems. Hydraulic systems use a liquid, such as water, to transfer motion, and pneumatic systems use a gas, such as air, to transfer motion. When you build a prosthetic arm in the next activity, you will have to choose between using a pneumatic system or a hydraulic system to make the elbow bend.

Activity 2: Pneumatics and Hydraulics

Exploration Questions

1. What differences did you observe between the air-filled (pneumatic) system and the water-filled (hydraulic) system?

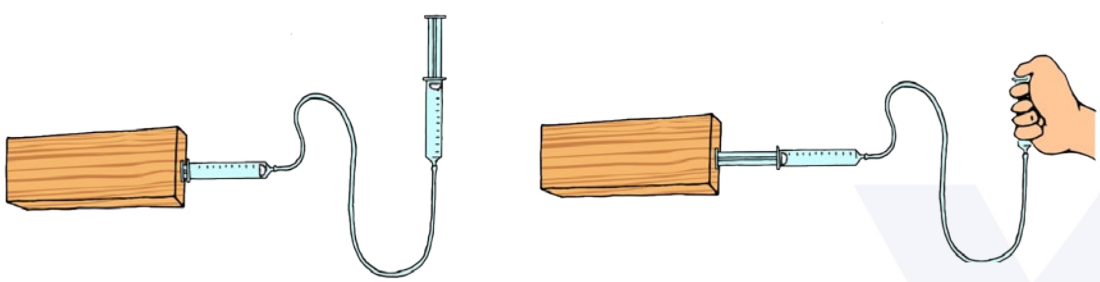
   [*They may have noticed that they were able to push both plungers in the air-filled system simultaneously but not the ones in the water-filled system; the water-filled system transfers movement faster than the air-filled system; there was a delay in the transfer of motion in the air-filled system; or it is easier to push air than water.*]

2. What are some examples of hydraulic and pneumatic systems that people use every day?

   [*Possible hydraulic systems: garage lifts or arms in heavy machinery. Possible pneumatic systems: height-adjustable office chairs or sliding doors in store entrances.*]

3. There are many ways to transfer motion. For instance, you could move a wooden block by pushing it with a rod. Or you could move the block using the system you just designed. Why might an engineer prefer to move an object using air or water pressure?

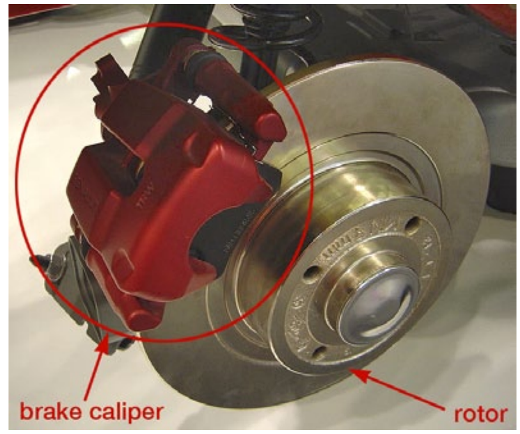
   [*Students may recognize that air and water pressure can transfer motion through curved pathways, which might be more practical and less difficult than using a rod or gears.*]



Activity 2: Pneumatics and Hydraulics

Apply

Now that you've learned a little bit about hydraulic and pneumatic systems, let's revisit our opening question: how do car brakes work? Can you figure out how the force of the driver's foot on the brake pedal is transferred to the wheels? Sketch your theory and describe the steps in the process. Be as detailed as possible.



Hint: Part of an actual car brake system is shown to the right. This is what you would see if you removed the car's tire.

Extra Hint: The rotor is attached to the wheel and the caliper pinches the rotor to slow the wheel down.

[*Give students plenty of time to sketch and read them the Extra Hint (above), if necessary. After they've shared their theories, redraw the car brake system diagrams (page 18) on the board (or make a copy to pass around) and read the answer to the class.*

Answer: Most vehicles use disc brakes (at least on the front wheels), which can be broken down into three major components: the rotor, the caliper, and the brake pads. The rotor is a metal disc attached to the wheel and the caliper is a "pincher" clamp that fits over the rotor. The brake pads fit in-between the caliper and the rotor and are designed to withstand intense friction without wearing out too quickly.

The brake pedal is connected to a master cylinder, which contains a hydraulic piston similar to the syringe plunger used in the previous activity. When the driver steps on the pedal, the piston pushes on the fluid causing it to transfer motion to the pistons in each of the calipers. This causes the brake pads to squeeze against the rotor—creating friction that slows down the wheels.

The disc brakes found in cars are similar to the brakes on your bicycle. Standard bicycle handbrakes use non-hydraulic calipers and rubber brake pads that clamp down on the rim of the wheel instead of a rotor. They also use a less expensive cable to transfer the motion from the hand lever to the caliper instead of hydraulics. Expensive high-end mountain bikes use rotors and hydraulic brakes identical to those found in automobiles.]

References

"An Arm and a Leg," www.teachengineering.org, Worcester Polytechnic Institute. 12/14/2007.

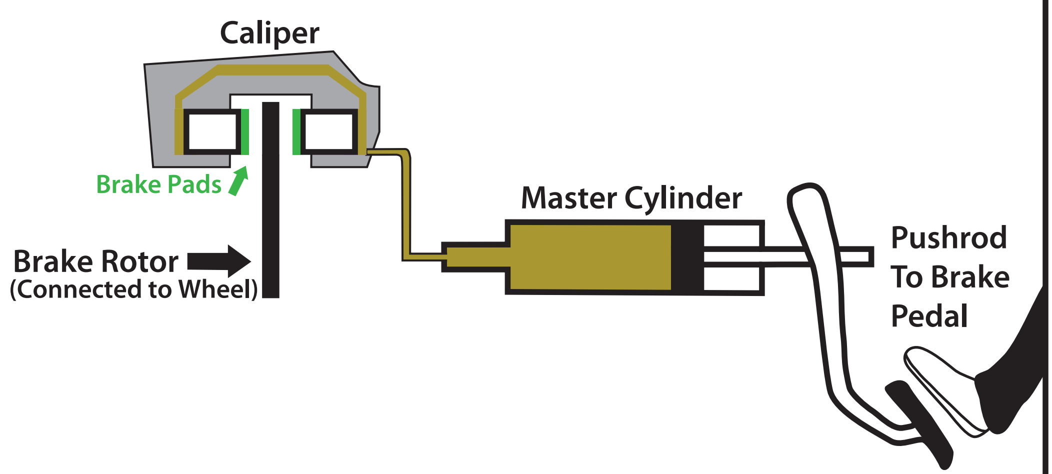
"How Hydraulic Machines Work," science.howstuffworks.com/hydraulic1.htm, How Stuff Works.

"How Disc Brakes Work," auto.howstuffworks.com/disc-brake.htm, How Stuff Works.

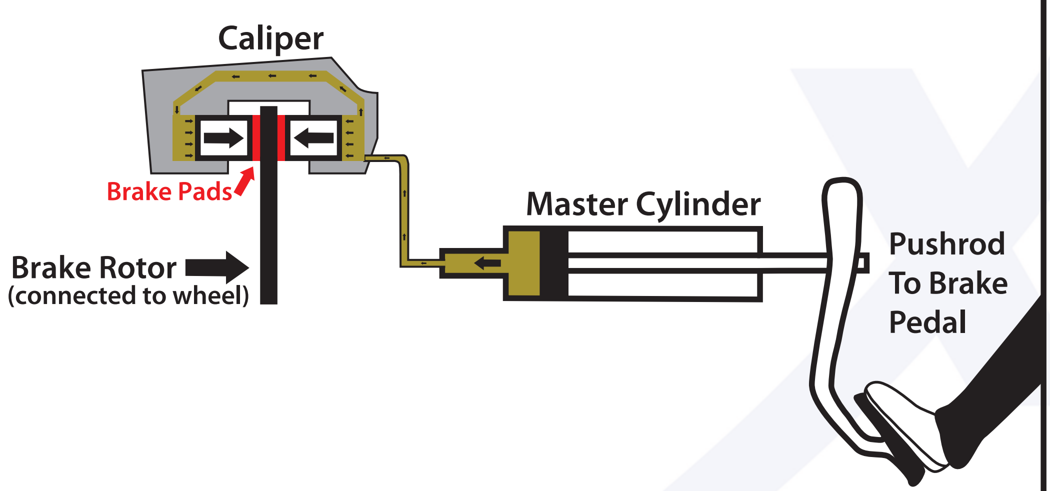
"Disc Brake" by David Monniaux, [CC-BY-3.0] commons.wikimedia.org/wiki/File:Disk_brake_dsc03682.jpg, Wikimedia Commons.

Activity 2: Pneumatics and Hydraulics

Car Brake System - Brakes Not Engaged



Car Brake System - Brakes Engaged



Activity 3: Making the Arm

Time Required: 45 Minutes **Group Size:** 2

Materials List

Each group needs:

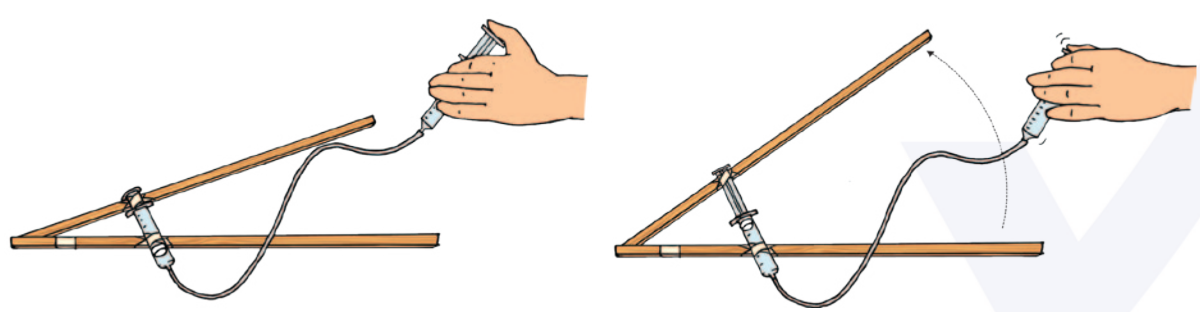
- Hydraulic system (From Activity 2)
- Pneumatic system (From Activity 2)
- 4 Rubber bands (Any size)
- Masking tape
- Protractor with ruler
- Scissors
- String
- Paperclips
- 4 Balsa wood strips (¼" x ½" x 18")

Youth Handouts:

- "Making the Arm"

Getting Ready (20 minutes)

- Build a demonstration arm by following the "Assembling the Arm" instructions in the Youth Handout. Attach a hydraulic syringe system from Activity 2 to the arm (as shown below). This will be the starting point for students to improve their designs.
- Refill any of the students' hydraulic systems that need water.



Education Standards

CCSS: 4.MD.C.6
NGSS: 3-5-ETS1-1, 3-5-ETS1-2

Learner Outcomes

- Design and build a hydraulic or pneumatic arm.
- Use a protractor to measure an angle.

Activity 3: Making the Arm

Vocabulary

Word	Definition
Protractor	A tool used to measure angles.

Introduction

Today we will be building a prosthetic arm. First, I'll demonstrate how to put together the basic skeleton of the arm. Then you will become engineers, devising a way to make the arm move by transferring motion from one location to another. You will be incorporating the hydraulic or pneumatic system you built last time to create your design. Just like real engineers, you will be given design constraints. This means that you will be allowed to use only certain materials, your completed product must meet specific criteria, and you will have a limited amount of time in which to work.

Facilitating the Activity

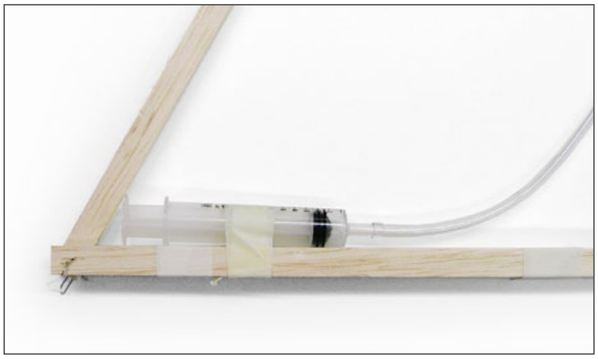
1. Distribute handouts and materials for building the basic arm.
2. Show the class what a basic assembled arm looks like. Allow students to look at it while they are building theirs. Guide them as necessary.

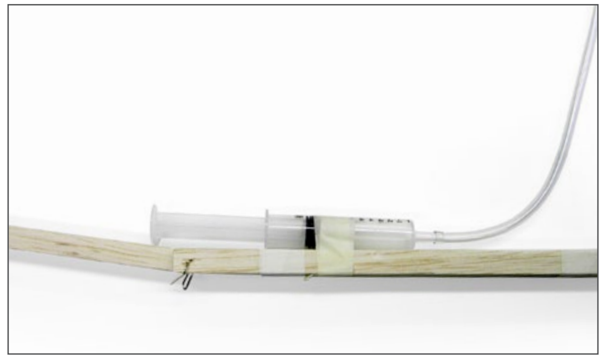
   Note: You may want to use a small nail or other sharp object to help youth create a hole in the balsa wood as some of the wood may be tough to pierce with the paper clip.
3. Demonstrate how to use a protractor and how to calculate the arm's angle of rotation (see Testing Procedure in the Youth Handouts). Note: angle of rotation is calculated by subtracting the angle created when the arm is bent from the angle at maximum extension, or

   Angle of rotation = Maximum angle (arm fully extended) – Minimum angle (arm fully retracted)
4. When they have finished building a basic arm, distribute the hydraulic and pneumatic systems from Activity 2.
5. Tell students that they will be devising a way to make a hydraulic or pneumatic arm move back and forth with the largest range of motion possible.
6. Go over the design constraints for the Engineering Design Challenge and specify the amount of time being provided to complete the activity [*10-15 minutes suggested*].

   Note: You may wish to explain/demonstrate to the students that their prosthetic arm shouldn't open farther than 180 degrees because most human elbows (with the exception of double joints and hyperextension) do not open farther than 180 degrees. They'll probably find it's it difficult to create a design outside of this constraint with the given materials anyway.

Activity 3: Making the Arm

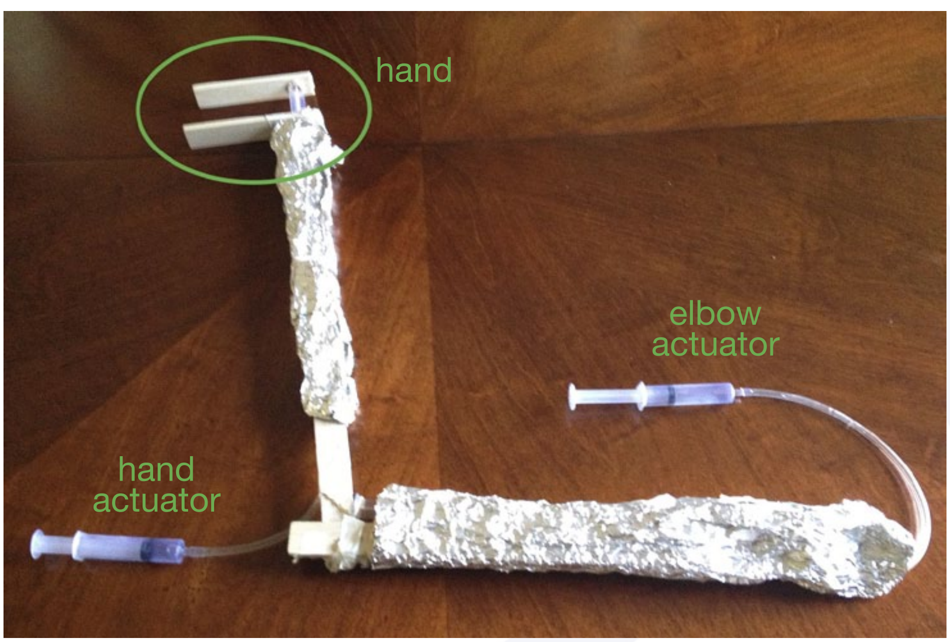




7. Circulate among the students to supervise, provide encouragement, and answer questions. Pay attention to anyone who may be stuck.
    - It's likely that students will be able to straighten the arm to 180 degrees relatively easily but they may have difficulty bending it back. An example is depicted above.
    - Encourage students to be ambitious but to strive for only the greatest extension position from which full retraction is possible.
8. Give a five-minute warning and two-minute warning to let students know how much time remains.

Variations

If time and materials permit, this activity is a great opportunity to allow youth to really show off their creativity. The photo below is of an actual bionic arm designed by students. This particular group added a second set of hydraulic actuators (syringes) to create a working "hand" for the bionic arm to grab things, and as a finishing touch, wrapped the arm in aluminum foil to give it a robotic look.



Activity 3: Making the Arm

Activity Closure

Now that you've tried to design a bionic arm of your own, you probably have a much better appreciation of how incredibly well a real human arm works. Even engineers working with the best materials available are not able to create a robotic design that can exactly match the performance of a real arm.

Since it's currently impossible to replicate the amazing versatility of the human body, engineers typically design robots that are specialized for a particular task, such as welding a car. The arm on a welding robot can only weld metal together. It doesn't know how to throw a baseball, tie shoelaces, button a shirt, or any of the things you may take for granted every day.

While it's true that robotic arms can be designed with an even greater range of motion than human arms, mechanical arms still wear out. Do you think that some day engineers will be able to design things that heal automatically, just like the human body?

Exploration Questions

1. What angle of rotation was your prosthetic arm able to attain? How does that compare to the angle of rotation of your own arm?

   [*Let various groups report their angle of rotation. Prosthetic arm numbers should range between about 30 degrees and 170 degrees. If a group reports something out of that range or the number doesn't seem quite right, have them show you how they measured and calculated that angle after class to make sure they understand how to correctly use a protractor.*]

2. What are the similarities and differences in performance between the pneumatic and hydraulic arms?

   [*Let the groups discuss the pros and cons of the two different methods. Example: Air doesn't transfer motion very efficiently because of its compressibility, but with air you don't have to worry about water leaks.*]

3. How did you decide on your design? What would you do differently next time?

   [*Allow a couple groups with particularly good examples to demonstrate their design and explain their thought process*.]

Apply

Use a ruler to draw two lines that form an angle and then measure the angle using your protractor.

If you were a real engineer and could use any materials you wanted, how would you design a better elbow joint? Note: Your design doesn't have to use a hydraulic or pneumatic system.

[*Let a few students present their ideas to the class and explain how they work. Possible ideas: better method of mounting or pivoting, gears instead of hydraulics, use lightweight but strong polymers, etc.*]

References

"An Arm and a Leg," www.teachengineering.org, Worcester Polytechnic Institute. 12/14/2007.

Activity 4: Buzzer Circuit

Time Required: 45 Minutes **Group Size:** 2

Materials List

Each group needs:

- 3 Wires with alligator clips
- Battery (9 volt)
- Battery snap (9 volt)
- Buzzer
- Push-button/momentary switch
- Aluminum foil

Youth Handouts:

- "Buzzer Circuit"

Education Standards

None

Learner Outcomes

- Explain that for electricity to flow, it must follow a complete loop.
- Build a circuit from a basic schematic diagram.

Vocabulary

Word	Definition
Conductor	Materials that allow the flow of electricity.
Insulator	Materials that block the flow of electricity.
Schematic diagram	A symbolic diagram that shows how to connect electronic components together to form a circuit.
Terminal	An accessible connection point on an electrical device (such as a battery) where electricity enters or leaves.

Activity 4: Buzzer Circuit

Introduction

In Activity 1, you tried to identify objects without looking at them, holding them, or picking them up. Although you couldn't see the items, you knew you were in contact with something because of your sense of touch. But if you were wearing a typical prosthetic arm, you would have no feeling in that arm.

What sensations do you usually have when you touch something?

[*Help students to recognize that people usually experience the following sensations: (1) Contact — Is something there? (2) Pressure — Is the object hard or soft? (3) Temperature — Is the object hot or cold? (4) Texture — Is the object wet, dry, sticky, rough, etc?*]

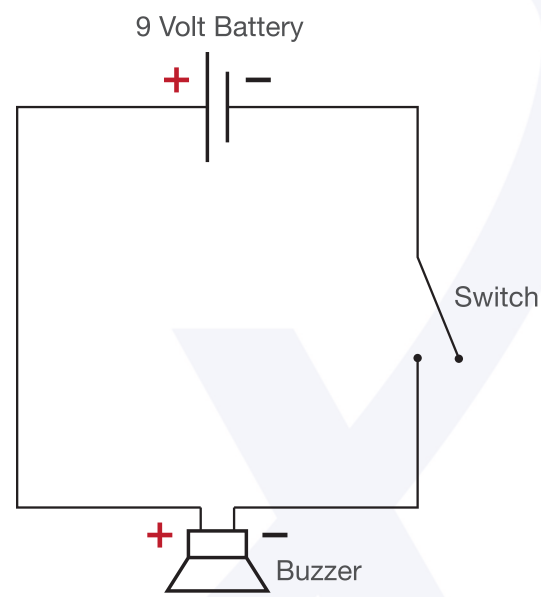
When you created your prosthetic arm, you used skills similar to those a mechanical engineer might use. Most modern engineering projects require different types of engineers to work as a team. Designing more sophisticated prosthetics requires the expertise of many types of engineers, including mechanical engineers, electrical engineers, and biomedical engineers. Their challenge is to enable the user of the prosthetic device to receive important sensory information when he or she touches something.

In the next activity, you are going to figure out a way to incorporate a sensory device into your prosthetic arm. But before then, we need to learn a little bit about electrical engineering by building a basic circuit.

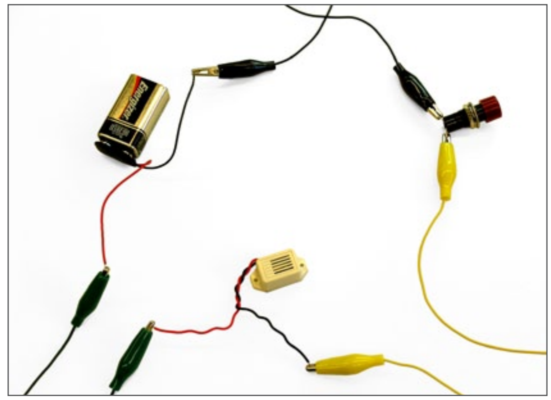
Facilitating the Activity

1. Place students into pairs (students should continue with their previous partner).
2. Draw the schematic diagram to the right on the board.
3. Tell students that you will be handing out some electrical components and asking them to build the electric circuit pictured in the diagram.

   Before distributing any materials, remind students to NOT let the red and black wires of the battery snap accidentally touch together (connecting the battery terminals directly to each other). This will cause a short circuit and the battery will get hot as it runs out of power, possibly leaking dangerous chemicals.
4. Distribute the parts and handouts.
5. Allow students to build the circuit shown in the schematic diagram. Explain that the red wires attached to the buzzer and the battery mean *positive* and correspond to the "+" signs on the diagram. The black wires attached to the buzzer and the battery mean *negative* and correspond to the "–" signs on the diagram. The alligator wire colors do not mean anything.



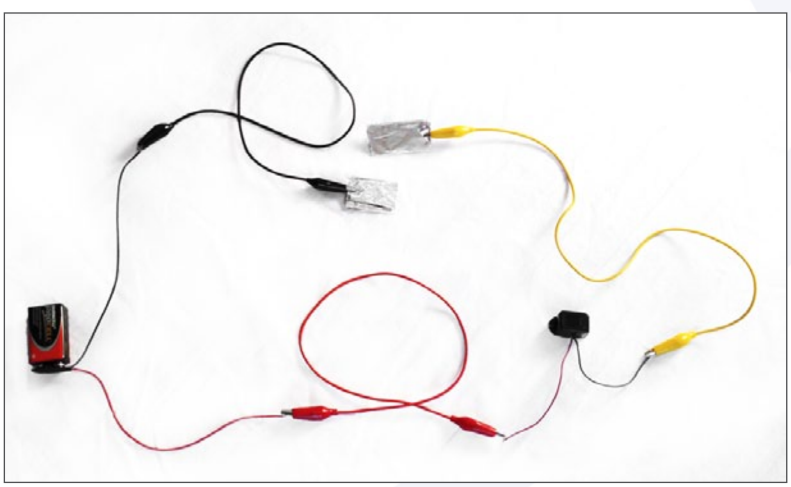
Activity 4: Buzzer Circuit



6. Circulate among the students and help them troubleshoot. If a group cannot figure out why their circuit doesn't work:
   - Try connecting the buzzer in the other direction by switching the red and black wires.
   - Substitute a spare battery in case the battery is dead.
   - Be sure metal is touching metal at each of the connections.
7. Once students have made functioning circuits, congratulate them on building a circuit from a schematic diagram like a real electrical engineer.
8. Next, have students disconnect the two alligator wires from the switch and make the buzzer turn on by simply touching the metal ends of the two alligator wires together.
9. Explain to students that electricity requires a complete path, or "closed" circuit, from the positive **terminal** of the battery, through the wires, switch, buzzer, and back to the negative battery terminal in order for any electricity to flow.

   If the alligator wires that were connected the switch don't touch (metal-to-metal), the electricity won't have a complete path around the circuit and the buzzer will not sound. This is called an "open" circuit.
10. Another important concept for students to learn is the difference between electrical **conductors** and **insulators**. Have them clip one of the alligator wires onto the insulation (plastic covering) of the other alligator wire. The buzzer does not come on because the electricity cannot flow through the plastic, which is an insulator.

    Electricity can only pass from one piece of metal to the next as long as they are touching and not separated by air, which is another excellent insulator.
11. Finally, give each group two small pieces of aluminium foil and instruct students to clip an alligator wire onto each piece (see photo below). Then, have them touch the two pieces of foil together. The buzzer should come on. This is another simple way to create a homemade switch.



Activity 4: Buzzer Circuit

Variations

Allow students to test a variety of different materials to find out if they are electrically conductive by clipping them between the two alligator wires and seeing if the buzzer turns on.

For example, did you know that pencil "lead" will conduct electricity? If you shave a pencil back (exposing a long piece of the black graphite core) and clip the alligator wires on each end, the buzzer should sound. However, a very dark pencil mark on a piece of paper clipped between the alligator wires will not work, because the thin layer of graphite isn't quite conductive enough to handle the amount of electricity needed by the buzzer.

Activity Closure

As you just found out, electrical switches really aren't complicated at all. They simply contain two pieces of metal inside that touch together—just like the two wires you touched together—to let the electricity flow through the circuit when the button is pressed. Metal conductors and components, like wires and the buzzer, provide a path for electricity to flow, while insulators, like the plastic covering on the wires, prevent the electricity from accidentally going where we don't want it. Electrical engineering design requires careful use of conductors and insulators to control where the electricity flows.

Now that you've learned some basics about electricity and how to construct a simple buzzer circuit, let's see if you can use this knowledge to design a touch sensor for your bionic arm in the next activity!

Exploration Questions

1. Does the color of the insulation covering the wire affect the electric circuit?

   [*The color of the insulation does not affect the way a circuit works. Engineers use different color wires to help keep track of circuit connections.*]

2. What are some common items that might contain a buzzer circuit like the one you built today?

   [*Possible answers: door bell, washing machine/dryer/oven that beeps when finished, alarm clock*]

3. How might you use the circuit you built to improve the function of a prosthetic arm? Could you incorporate it in such a way that a user would know when he or she had touched something?

   [*Give students some time to think about the problem and encourage them to share their solutions. As an example, an engineer might place a sensor, such as a switch, on the hand of the prosthetic arm and place a buzzer at another location to produce a noise or vibration. The buzzer could be anywhere, though putting it near where the prosthetic device is attached would allow the user to feel the vibration of the sensor in addition to hearing it.*]

Apply

Now that you've learned how an electronic buzzer circuit works, what kind of useful invention could you create with it? Sketch your idea.

[*Give students 10 minutes to sketch. Possible answers: an alarm system for your bedroom or a game like Operation (http://en.wikipedia.org/wiki/Operation_(game))*]

Activity 5: Designing a Touch Sensor

Time Required: 45 Minutes **Group Size:** 2

Materials List

Each group needs:

- 3 Wires with alligator clips
- Battery (9 volt)
- Battery snap (9 volt)
- Buzzer
- Push-button/momentary switch
- Small paper cup (3 oz)
- 10 Paper clips
- 5 Rubber bands
- Masking tape
- Aluminum foil (2 square feet)
- 4 Index cards (3x5)
- Foam ball (2-inch diameter)

Each class needs:

- Extra paper clips
- Extra rubber bands
- String
- Optional miscellaneous supplies: small springs, corrugated cardboard, foam, poster board, etc. (additional supplies may encourage even more creative problem solving)

Youth Handouts:

- "Buzzer Circuit" (from Activity 4)
- "Designing a Touch Sensor"

Education Standards

NGSS: 3-5-ETS1-1, 3-5-ETS1-2

Learner Outcomes

- Explain that metal conducts electricity.
- Explain how a prosthetic device could provide the user with a sense of touch.

Activity 5: Designing a Touch Sensor

Introduction

The final part of this project will be using electrical engineering concepts to create a touch sensor for your prosthetic arm. As a review, what four sensations do you experience when you touch something?

[*Help them to recall, if necessary:*

1. *Contact: Is something there?*
2. *Pressure: Is the object hard or soft?*
3. *Temperature: Is the object hot or cold?*
4. *Texture: Is the object wet, dry, sticky, rough, etc?*]

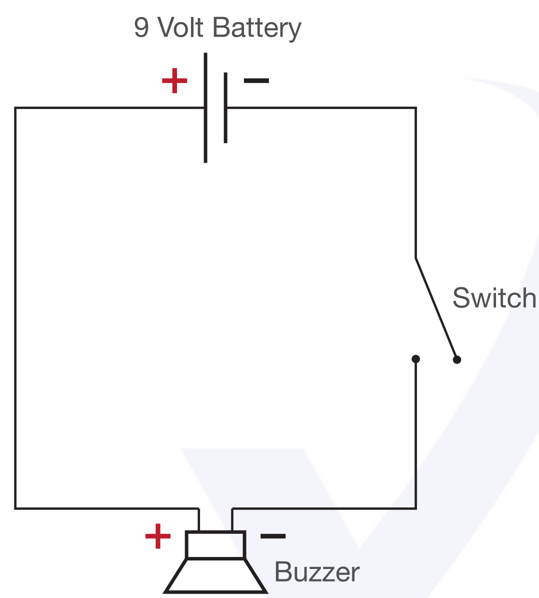
In Activity 4, we discussed how a buzzer circuit might be incorporated into a prosthetic arm to alert the user when the arm is touching something. Can anyone recall some ideas about how that would work?

[*Help them to recall that they might attach a switch to the hand and put a buzzer at another location. The buzzer could be anywhere, though putting it near where the prosthetic device is attached would allow the user to feel the vibration of the sensor in addition to hearing it.*]

Facilitating the Activity

Part 1: Recreate Buzzer Circuit

1. Place students back into the same pairs.
2. Redraw the schematic diagram on the board.
3. Tell students that you will be giving them the electrical components they used in Activity 4 (plus a few extra components if you added some) and that you want them to recreate the buzzer circuit.
4. Distribute the parts and "Buzzer Circuit" handouts.
5. Allow students to build the circuit. Notice which groups are having trouble. This will help you assess what they learned in Activity 4.

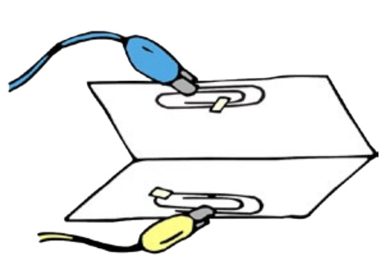
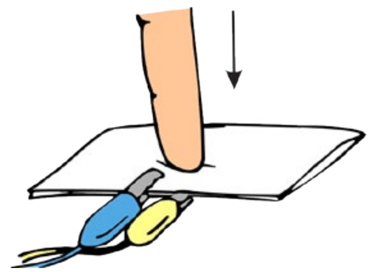


Activity 5: Designing a Touch Sensor

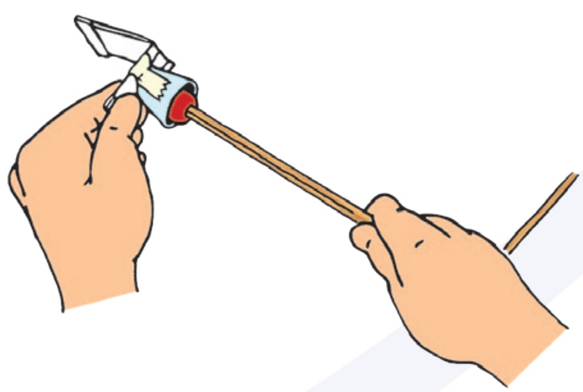
Part 2: Design the Sensor

6. Distribute "Designing a Touch Sensor" handouts.
7. Show them one of the push-buttons and review how switches work. Explain that the switch they design must do these two things:
   - It must create an electrical connection when pressed. The alligator clips must connect to the two metal conductors, which come together to close the electric circuit. The metal conductors can be made with aluminum foil or paper clips.
   - It must have some sort of spring-release that causes the metal conductors to separate when the switch is not being pressed. You may demonstrate options for making a spring, some of which are shown on the handout. Other options might incorporate paper clips folded in various ways, folded index cards, or a small piece of foam. Students may be able to devise their own solutions.
8. Ask students to design and build a switch for their prosthetic arm.

   Below is an example of a possible switch design. Do not tell students what the switch should look like. When advising students, be open-minded about ideas that might not look viable to you at first. Their ingenuity might surprise you.

9. Once students have finished their switches, have them stick the foam ball onto the end of the arm and then place the cup securely over the ball.
10. As students finish, encourage them to walk around to see how other students approached the problem.



Activity 5: Designing a Touch Sensor

Activity Closure

What other types of devices might you incorporate into a prosthetic arm to let the user know when the arm is touching something? [*Possible answers: light or vibration.*]

For a prosthetic sensory device to be effective, the user must have functioning senses in another part of the body, such as sight, hearing, or a sense of touch. Some types of sensory devices may have drawbacks. For example, it may take time for the user of the prosthetic to associate a sound or light with contact. If touching something triggers a sound or light, it might also be disruptive. If you were in a meeting, for example, you would not want a buzzer sounding every time you moved your chair.

Doctors and scientists are studying the human body to develop the next generation of prosthetics. In 2006, doctors at the Rehabilitation Institute of Chicago performed a unique type of surgery on a woman who had lost her arm in an accident. The doctors were able to surgically reroute nerves that would have gone to the hand to other muscular tissue. By using the muscles to amplify the electrical nerve signals, she can now control her prosthetic hand in the same way she once controlled her real hand.

Now that doctors have identified the nerve pathway to the hand, biomedical engineers may one day be able to design a prosthetic arm that would enable a user to sense pressure and temperature through artificial sensors attached to nerves in healthy parts of the body. The next generation of this technology incorporates sensors on the fingertips that will push on the point where the arm is attached, providing a sense of pressure.

Exploration Questions

1. How did you decide on your design?

   [*Allow a few groups with particularly good designs to demonstrate their solutions.*]

2. How might you improve your touch sensor?

   [*Allow a few groups to share their ideas.*]

Apply

If you were a real electrical or mechanical engineer with the ability to design any electronic circuit or mechanical device, what would your dream bionic arm look like? Sketch your idea. Label and describe its features.

[*Give students plenty of time to sketch. Let a few individuals present their ideas to the class.*]

References

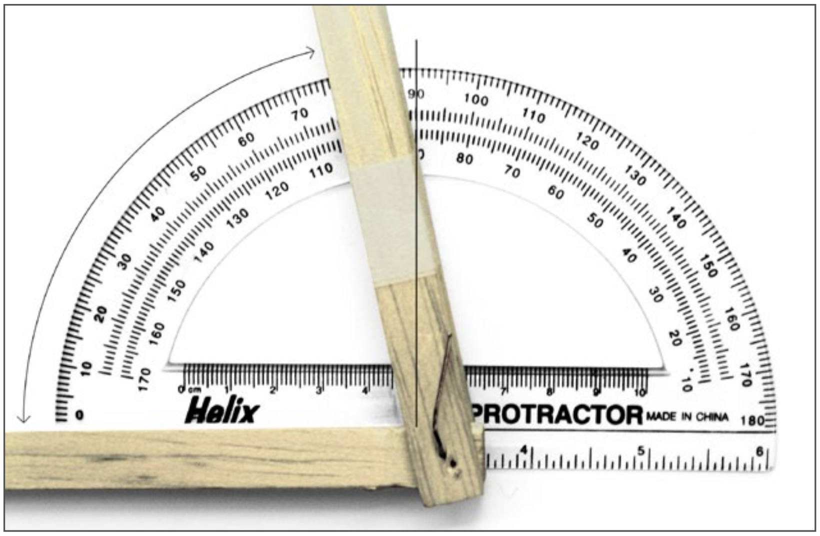
Bionics by Josh Fischman, http://ngm.nationalgeographic.com/2010/01/bionics/fischman-text/1

Tools Used in this Module

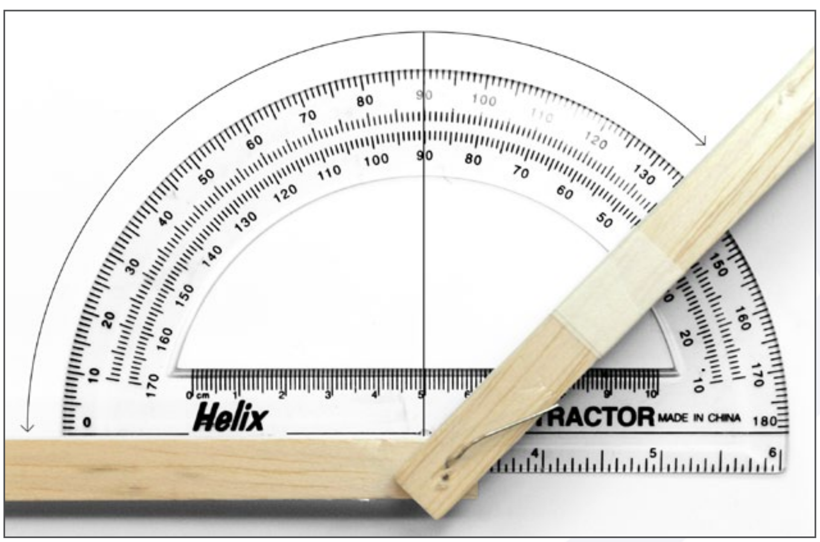
Protractor

In Activity 3, students use a protractor to measure angles. Instructions for using the protractor are included in the Youth Handout for that activity. However, you might want to take some extra time between Activities 2 and 3 to introduce the protractor so everyone will be familiar with it.

To measure the angle of rotation, line up one of the sticks along the baseline near the straight edge of the protractor. Then align the inner "elbow" with the tiny hole at the center of the baseline. Read the number where the inner edge of the second stick crosses the top of the arc. Use these pictures to show some sample measurements.



76 Degree Angle



135 Degree Angle

Glossary

Assistive technology
A device that helps people with disabilities by either making a task easier or by enabling them to perform a task they could not otherwise do.

Compressible
The ability of a material to be squeezed into a smaller space.

Conductor
Materials that allow the flow of electricity.

Engineer
A person who applies scientific knowledge to solve practical problems. The work of engineers forms the link between scientific discoveries and their application to human needs and quality of life.

Hydraulic
The transfer of motion using liquids.

Insulator
Materials that block the flow of electricity.

Pneumatic
The transfer of motion using gases, such as air.

Prosthetic
An artificial device designed to replace a missing or injured body part.

Protractor
A tool used to measure angles.

Schematic diagram
A symbolic diagram that shows how to connect electronic components together to form a circuit.

Terminal
An accessible connection point on an electrical device (such as a battery) where electricity enters or leaves.

Education Standards

Activity 1: Assistive Technology

None

Activity 2: Pneumatics and Hydraulics

CCSS: RST.6-8.3 – Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

Activity 3: Making the Arm

CCSS: 4.MD.C.6 – Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.

NGSS: 3-5-ETS1-1 – Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

NGSS: 3-5-ETS1-2 – Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

Activity 4: Buzzer Circuit

None

Activity 5: Designing a Touch Sensor

NGSS: 3-5-ETS1-1 – Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

NGSS: 3-5-ETS1-2 – Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

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