Modeling & Designing a Sensory Substitution Device

A STEAM Curriculum Unit for Middle School Science Classes

CENTER FOR
SENSORIMOTOR NEURAL
ENGINEERING

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About the RET Program & the CSNE

About the Research Experience for Teachers (RET) Program
The Research Experience for Teachers (RET) program is a summer research experience for middle and high school STEM teachers, hosted by the Center for Sensorimotor Neural Engineering (CSNE) on the University of Washington's Seattle campus. Each summer cohort is selected through a competitive application process. Accepted teachers work in a CSNE lab alongside a team of researchers conducting cutting-edge neural engineering research. They enhance their understanding of lab safety, bioethics, engineering education, and curriculum design. Together, the teachers work to develop innovative neural engineering curriculum materials, which are then pilot-tested in their own classrooms the following academic year.

About the Center for Sensorimotor Neural Engineering (CSNE)
The CSNE's mission is to develop innovative neural devices and methods for directing engineered neuroplasticity in the brain and spinal cord, which will improve sensory and motor function for people with spinal cord injury, stroke, and other neurological disorders. Engineered neuroplasticity is a new form of rehabilitation that uses engineered devices to restore lost or injured connections in the brain, spinal cord, and other areas of the nervous system.

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Neural Engineering Skill Sets
The CSNE has identified the following skill sets as essential for students to achieve neural engineering competency. All education activities supported by the CSNE are designed to teach one or more of these skills.

1. **Fundamentals of neuroscience, neural engineering, and neuroethics research:** Knowledge of core concepts in neuroscience and neural engineering, designing and conducting experiments, analysis and interpretation of results, problem solving, understanding primary scientific literature, building scientific knowledge, and ethical and responsible conduct of research.
2. **Neural engineering best practices:** Oral and written communication of neural engineering knowledge and research, confidence, working independently, working on a team, participating in a learning community, innovation, and persistence.
3. **Connections to neural engineering industry and careers:** Awareness of career options in neural engineering and pathways

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NSF

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Unit Description

The nervous system is an integral part of the human body. It receives information from the environment through sensory neurons, processes that information, and results in a response through motor neurons. Communication in neural networks occurs through both electrical and chemical signals. Similarly, electrical circuits can involve sensory input (temperature, pressure, light), processing of the input using logic gates, and a resulting output (light, motor). This parallel of the nervous system and electronic circuits is central to the field of neural engineering.

Engineers identify a problem based on a need (in this case, the loss of a sense), design solutions (sensory substitution), test and evaluate their solutions, and modify their solutions. When senses are impaired or not functioning, devices can be designed to aid with sensory substitution.

In this unit, students will explore the integral role of the nervous system in the human body. Students will learn about the basic structure and function of the nervous system, explore the relationship between electrical circuits and the nervous system, and then construct a simple, sensory substitution device, used in aiding individuals with a missing or impaired sense. After building the device, students will test and present a work-in-progress prototype to peers, and then modify the design based on the test results and peer feedback, an essential practice in the field of engineering. Finally, students will explore other perspectives, including the needs of end-users, budget, type of materials, ease of use, maintenance, and accessibility.

Learning Outcomes

Unit-level learning outcomes are presented in this section. Each lesson plan highlights the learning outcomes aligned to the particular activities incorporated into that lesson.

Big Ideas & Enduring Understandings

- **Circuits & Nervous System:** The nervous system receives information through sensory neurons, processes that information, and may cause a response through motor neurons. Communication in neural networks occurs through both *electrical* and chemical signals. Similarly, electrical circuits can involve sensory input, processing of the input using logic gates, and a resulting output. This parallel of the nervous system and electronic circuits is central to the field of neural engineering.
- **Neural Engineering:** Neural engineering is a field with a goal of restoring impaired senses and functions.
- **Sensory Substitution:** A device can be engineered to substitute one human sense for another. This can be used to aid individuals with a missing or impaired sense or to provide an enhancement.

Essential Questions:

- What is the basic structure and function of the nervous system?
- What are the components of an electrical circuit and how are they arranged to work together?
- How are the nervous system and electrical circuits similar?
- How can the parallels between the nervous system and electrical circuits be used in neural engineering?
- How can Arduinos be programmed to vary output based on varying inputs from sensors?
- What are the needs of a person with an impaired or missing sense?
- What is the difference between an assistive device and a neuroprosthetic?
- How do engineers use the engineering design process to create, test, and modify solutions to meet user needs?
- What ethical issues might be involved in designing a sensory substitution device?
- How are different criteria used to evaluate competing engineering design solutions?

Knowledge and Skills (Outcomes):

Students will know…

- The nervous system is an integral part of the human body. It receives information from the environment through sensory neurons, processes that information, and results in a response through motor neurons.
- Communication in neural networks occurs through both electrical and chemical signals.
- Electrical circuits can involve sensory input (temperature, pressure, light), processing of the input using logic gates, and a resulting output (light, motor). This parallel of the nervous system and electronic circuits is central to the field of neural engineering.

Students will be able to…

- Identify a problem based on a need (in this case, the loss of a sense), design solutions (sensory substitution), test and evaluate their solutions, and modify their solutions.
- Explain the functions of the components in Snap Circuits, Breadboards, and Arduinos.
- Program and assemble simple circuits controlled by Arduinos.
- Describe the iterative steps of the engineering design process.
- Use Pugh Charts to evaluate an engineered design.

Helpful prerequisite skills include:

- General knowledge of computers including turning on, opening programs, and typing with a keyboard.

Key Vocabulary:

- **Parts of neuron:** dendrite, cell body, axon, axon terminal, synapse, neurotransmitter
- Divisions of the nervous system: central nervous system (brain and spinal cord), peripheral nervous system (sensory/afferent neurons, motor/efferent neurons)
- **Types of communication:** electrical signal, chemical signal, *(action potential, ion channels, voltage difference, threshold)
- Electromyogram (EMG)
- **Engineering design:** criteria, constraints
- Assistive device
- Neuroprosthetic
- Sensory substitution
- End-user
- **Parts of a circuit:** circuit, electricity, battery/power, electrons, current, switch, open/closed, conductor, insulator, load, positive/negative terminals, resistor, LED, motor, diode
- Parallel, series
- Arduino
- Arduino sketch
- Pugh chart

**more advanced terms*

Sensory Substitution Unit Matrix

Lesson (hours)	Learning Outcomes	Materials	Activities	Assessment	Extensions/ Adaptations
L1 **1 hour**	Basic structure of nervous system and neurons	-Neuroseeds lesson -Diagrams of nervous system and neuron	-Neuron model -Discussion of nervous system diagrams	-Explanations of nervous system diagrams -Neuron analogy	Action potential and ion channels
L2 **1 hour**	Muscles generate electrical signals that are similar to electrical signals sent to/from brain; this electricity can be used in a circuit to drive outputs	-Robot gripper hand -Arduino Muscle Shield -EMG electrodes	-Robot gripper hand demo Experiment: use different muscles, grip different objects, fatigue, attach different motors	-Exit ticket connecting electricity in circuit with that in nervous system -Recording of variables manipulated and observations in lab notebook	Record and analyze electrical signals using software

L3 **2 hours**	Prosthetics can be made to replace missing body parts. There are pros and cons to prosthetics in terms of their structure and function.	-Alginate -Silicone, curing agent & accelerator -Popsicle sticks -Paper cups -Permanent markers	-Make alginate mold of finger and pour in silicone cast. -Remove mold, compare cast to real finger. -Decorate finger.	-Reflection on similarities and differences of prosthetic and real body part	Make prosthetics of other body parts
L4 **2 hours**	Assistive devices help someone with disability; neuroprosthesis is a special type of assistive device that interfaces with brain signals. Sensory substitution devices help restore an impaired/missing sense.	-Articles and videos -David Eagleman TED Talk	-Read articles and watch videos on assistive devices and neuroprostheses -Watch video on Sensory Substitution	-Notes from articles or videos -Definitions and examples of devices -Brainstorm of possible sensory substitution devices	
L5 **1 hour**	Ethical issues must be considered. Students will come away with some idea of what aspects neural engineers need to bring into design process.	-Stella Young TED Talk	-Reflection on what "normal" is -Watch video -Class discussion	-Reflection on assumptions made about user needs and potential harm of engineered devices	-Guest speaker or someone to interview -FIXED video -Ethics of sensory enhancement
L6 **4 hours**	Circuits must be closed to functions. Current in circuits can drive outputs. Resistors are important in the functioning.	-Introductory circuit video -Snap Circuits -Online circuit simulation	-Discussion on prior knowledge and basic components of circuit -Build Snap Circuits to understand role of different components -Online simulation reinforces series/ parallel/diagrams	-Presentation of Snap Circuit (how it works, components, diagram) -Notes from online simulation	-More online animations -Act out circuit

L7 **1 hour**	Breadboards are useful to prototype circuits	-Breadboards -Batteries -Battery packs -Wires/cables -Push buttons/ switches -LEDs -Motors -Buzzers -Resistors	-Video -Breadboard exercises - create simple circuits	-Completed circuits and diagrams in lab notebook with reflection	
L8 **3 hours**	Arduinos can be programmed to produce a motor output based on electrical input	-Arduinos -Breadboards -Sensors (tilt, light, pressure, proximity) -Outputs (motors, LEDs) -Jumper wires -Computers	-Try out Blink sketch -Change variables in Blink -Write if/then statements to program into the Arduino	-Check-ins of code and circuitry -Self-assessment	
L9 **3 hours**	Neural engineering is a field with goal of restoring impaired senses and functions. Design model of sensory substitution device	-Engineering design process cards -Arduinos -Breadboards -Sensors (tilt, light, pressure, proximity) -Outputs (motors, LEDs) -Jumper Wires -Computers	-Design process cards -Design process video -Define problem, criteria, constraints -Write if/then statements to program into Arduino based on device design	-Notes on engineering design process -Design notebook prompts	Making it Real: other factors involved in design process (marketing, industry, aesthetics)
L10 **4 hours**	Assess and evaluate design (self and peer) using Pugh Charts. Present device in poster session	-Poster paper -Markers -Rulers -Outside audience	-Come up with criteria for class Pugh Chart -Create Pugh Chart with group and use to evaluate all designs	-Poster -Pugh Chart	Slideshows or videos instead of posters

Alignment to National Learning Standards

This unit is aligned to the Next Generation Science Standards (NGSS). Alignment to NGSS Performance Expectations and the three dimensions of science and engineering education (Disciplinary Core Ideas, Crosscutting Concepts, and Practices), as well as the Nature of Science, are outlined in the tables below.

Next Generation Science Standards: Performance Expectations

- **MS-LS1-8 Structure, Function, and Information Processing:** Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.
- **MS-ETS1-1:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **MS-ETS1-2:** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- **MS-ETS1-3:** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- **MS-ETS1-4:** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieve

Next Generation Science Standards: Middle School (Grades 6-8) Disciplinary Core Ideas

	1: Intro to Neurosci	2: Robot Gripper	3: Prosthetic Finger	4: Sensory Subs	5: End-Users	6: Circuits	7: Breadboards	8: Arduinos	9: Designing a SSD	10: Presenting SSD
Life Sciences										
MS-LS1.A: Structure and Function: Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.										
MS-LS1.D: Information Processing: Each sense receptor responds to different inputs, transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories.										
Engineering Design										
MS-ETS1.A Defining and Delimiting Engineering Problems: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specifications of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.										
MS-ETS1.B Developing Possible Solutions: There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of the problem.										
MS-ETS1.C Optimizing the Design Solution: Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.										

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS.

Next Generation Science Standards: Crosscutting Concepts

	1: Intro to Neurosci	2: Robot Gripper	3: Prosthetic Finger	4: Sensory Subs	5: End-Users	6: Circuits	7: Breadboards	8: Arduinos	9: Design a SSD	10: Presenting SSD
Cause and Effect—Mechanism and Explanation: Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.										
Systems and System Models: Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.										
Structure and Function: The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.										

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS.

Next Generation Science Standards: Science & Engineering Practices

	1: Intro to Neurosci	2: Robot Gripper	3: Prosthetic Finger	4: Sensory Subs	5: End-Users	6: Circuits	7: Breadboards	8: Arduinos	9: Designing a SSD	10: Presenting SSD
Asking questions and defining problems.			✓		✓				✓	✓
Developing and using models.	✓	✓				✓	✓	✓	✓	✓
Using mathematics and computational thinking.								✓		
Constructing explanations and designing solutions.									✓	✓
Engaging in argument from evidence.									✓	✓
Obtaining, evaluating, and communicating information.				✓						✓

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS.

Next Generation Science Standards: Nature of Science

	1: Intro to Neurosci	2: Robot Gripper	3: Prosthetic Finger	4: Sensory Subs	5: End-Users	6: Circuits	7: Breadboards	8: Arduinos	9: Designing a SSD	10: Presenting SSD
Influence of science, engineering, and technology on society and the world.										
Science is a human endeavor.										
Science addresses questions about the natural and material world.										

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS.

Lesson One: Introduction to Neuroscience
Center for Sensorimotor Neural Engineering
Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: 50+ minutes.

Lesson Plan Summary:
In this lesson, students will be introduced to the parts of the nervous system and neurons.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:
- The nervous system senses information, processes that information, and responds using different neurons.
- Neurons have a specialized structure that is related to their function.

Essential Question:
- How does the structure of the nervous system relate to its function?

Learning Objectives:
Students will know…
- The parts of a neuron: dendrites receive information, electrical signal runs through the axon, chemical signal is released through the axon terminal.
- Divisions of the nervous system: the central nervous system is composed of the brain and spinal cord, and the peripheral nervous system carries information to and from the central nervous system through sensory and motor neurons.

Students will be able to…
- Describe through words and diagrams the parts of a neuron and the divisions of the nervous system.

Vocabulary:
- **Parts of neuron**: dendrite, cell body, axon, axon terminal, synapse, neurotransmitter
- **Divisions of the nervous system**: central nervous system (brain and spinal cord), peripheral nervous system (sensory/afferent neurons, motor/efferent neurons)

- **Types of communication**: electrical signal, chemical signal, *(action potential, ion channels, voltage difference, threshold)
  *more advanced

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards (NGSS).

NGSS High School Disciplinary Core Ideas
- **MS-LS1.A**: **Structure and Function**: Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.
- **MS-LS1.D**: **Information Processing**: Each sense receptor responds to different inputs, transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories.

NGSS Cross-Cutting Concepts
- **Systems and Systems Models**
- **Structure and Function**

NGSS Science & Engineering Practices
- **SEP**: Developing and Using Models

MATERIALS

Material	Description	Quantity
Student Handout 1.1: The Problem	chart for students to brainstorm what might be challenging for someone with an impaired sense	1 per student
Student Handout 1.2: Nervous System Diagrams	diagrams for students to discuss relationship between PNS, CNS, parts of neuron	1 per student

Neuron Model	model using rope, buckets, pool float, and ping pong balls to simulate nerve impulse (from *Neuroscience 101* - lesson in Teacher Preparation section)	1
Student Handout 1.3: Neurons and Synapse Review	reviews parts of neuron through description and analogy	1 copy per student

TEACHER PREPARATION

1. Acquire/make neuron model (See the lesson plan *Neuroscience 101* at http://www.neuroseeds.org/Lessons/neuroscience101).
2. Copy handouts as listed in the materials section above.

PROCEDURE

Engage: Loss of a Sense (15 minutes)

1. *Student Handout 1.1: The Problem.* Have students brainstorm about the prompt: "If you lost or damaged your sense of ________, what might your world be like? Why?" Students can be assigned one sense to focus on, or students can brainstorm ideas for all senses.

2. Students can pair, then share their thoughts. Discuss as a class: Is this a "problem" to be solved? If this is a problem that can be solved, how do we engineer solutions and pick the best one?

3. Lead into the overview of the curriculum unit by discussing how we'll learn about the nervous system and how it processes inputs. Without a certain sense, how might we design a device to substitute the sense to get similar information? We will also be learning about circuits and engaging in the engineering design process.

Explore and Explain: Parts of the Nervous System (30 minutes)

4. *Student Handout 1.2: Diagrams of Nervous System.* In small groups, come up with a sentence for each diagram (A-E); discuss and review as a whole class (see *Teacher Resource 1.2*)

5. Conduct a class demo of the neuron model designed by Eric Chudler and described in the Sowing the Seeds of Neuroscience curriculum (See http://www.neuroseeds.org/Lessons/neuroscience101). This demo will help students to learn about the structure of neurons with a focus on the electric impulse along the axon versus the chemical signal between neurons. You will make/use your own model or alternatively, you may show the model in use in the following video: http://uwtv.org/series/brainworks/watch/CAKscnzkhHg/ (starting at 10:20 minutes).

Evaluate: Students Begin Homework in Class (5 minutes)

6. *Handout 1.3: Neuron and Synapse Review*. Ask students to label parts of a neuron and create an analogy for different parts of the neuron. *Teacher Resource 1.3* provides a key for this handout.

7. *Homework option:* students can draw/write/create some representation of the difference between the peripheral nervous system (PNS) and central nervous system (CNS), and between sensory and motor neurons in their lab notebooks.

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- Class discussions can be used to check for general understanding.
- The *Neuron and Synapse Review* handout can be used to check for understanding; students can develop an analogy.

Student Metacognition:

- Provide students opportunities to come up with questions, reflect on their initial ideas about what they know and understand, and write them down in their lab notebook. They can add new/changing ideas to their lab notebook.

Scoring Guide:

- If students are successful, they will meet learning objectives stated above. Evidence needed would be from student answers during the group and class discussions and from homework assignment. See the provided keys in *Teacher Resources 1.2* and *1.3*.

EXTENSION ACTIVITIES

Extension Activities:

- Students can learn in greater depth about the structure of the neuron and/or the nervous system. With neurons, they can explore action potentials, ion channels (chemical-gated versus voltage-gated). With the nervous system, they can learn about more divisions of the nervous system and compare sensory input between internal and external environments.

Adaptations:

- Kinesthetic adaptions:
    - Act out a neural pathway with students playing the part of individual neurons. Have students stand in a line. Left hand is dendrite holding a cup. Right hand contains neurotransmitter (coin, token, marble). When pathway is activated, student releases neurotransmitter into next student's dendrite. Following students cannot release neurotransmitter unless they receive one first. See a description of this activity within the lesson plan *Neuroscience 101* at http://www.neuroseeds.org/Lessons/neuroscience101).
    - Students can create their own model of a neuron using everyday supplies (pipe cleaners, straws, cups, glue, beads, etc.). For examples, see http://faculty.washington.edu/chudler/chmodel.html.
- For gifted or older students:
    - Students can explore how ion channels work to understand the chemical basis for the electrical signal along the axon.

TEACHER BACKGROUND & RESOURCES

Resources:

For introductory lessons and activities on neurons and nervous system, see the lesson plan *Neuroscience 101* at Sowing the Seeds of Neuroscience (http://www.neuroseeds.org/Lessons/neuroscience101) and visit the resources at Neuroscience for Kids (http://faculty.washington.edu/chudler/neurok.html).

Citations:

Sowing the Seeds of Neuroscience. Available: http://www.neuroseeds.org/.
Brainworks. UW TV. Available: http://uwtv.org/series/brainworks/watch/CAKscnzkhHg/

Student Handout 1.1: What is the problem we are trying to solve?
Name:_________________________________ Date:__________________
Period:__________

If you lost or damaged your sense of ________________....

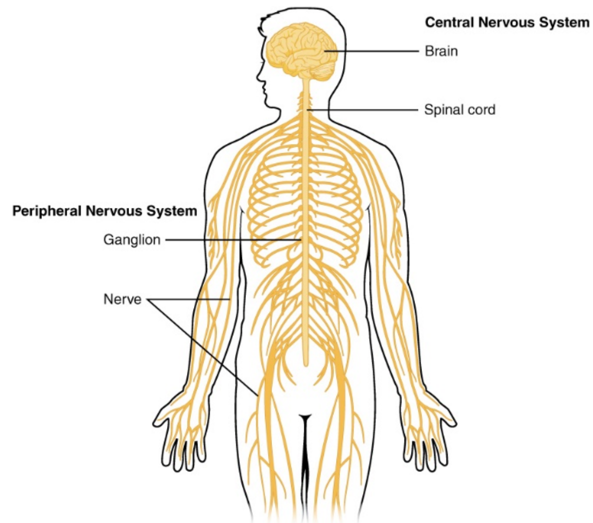
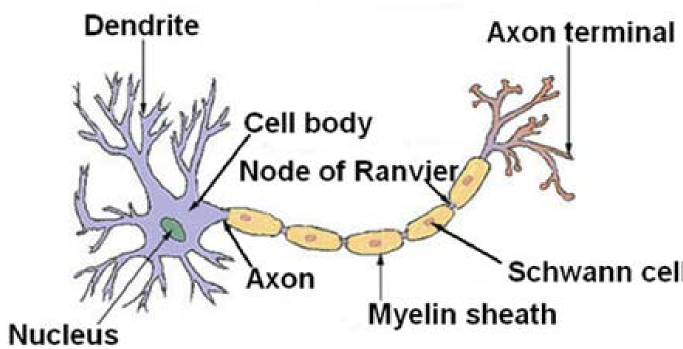
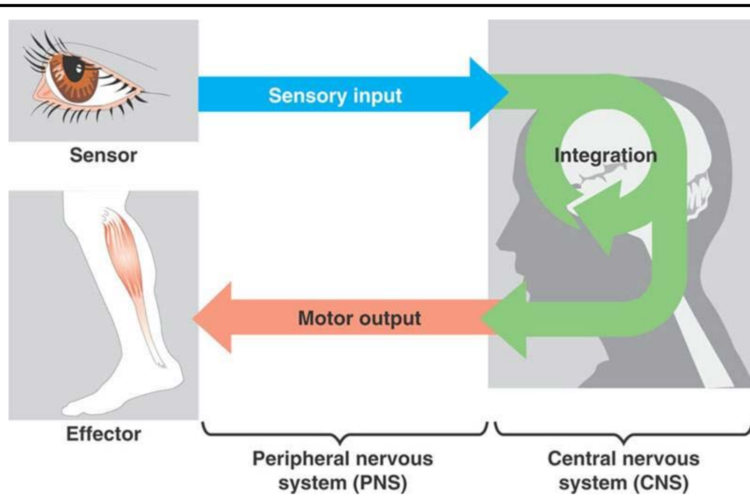
	Sight	Hearing	Touch
....what would you be able to do well or better?			
....what would be more challenging for you to do (but you could still do)?			
....what would be very hard to do?			

What assumptions are we making about what people need to function daily?

Student Handout 1.2: Nervous System Diagrams

Name:_________________________________ Date:___________________

Period:__________

A.	 By OpenStax - https://cnx.org/contents/FPtK1zmh@8.25:fEI3C8Ot@10/Preface, CC BY 4.0,
B.	 https://upload.wikimedia.org/wikipedia/commons/b/bd/Neuron.jpg
C.	

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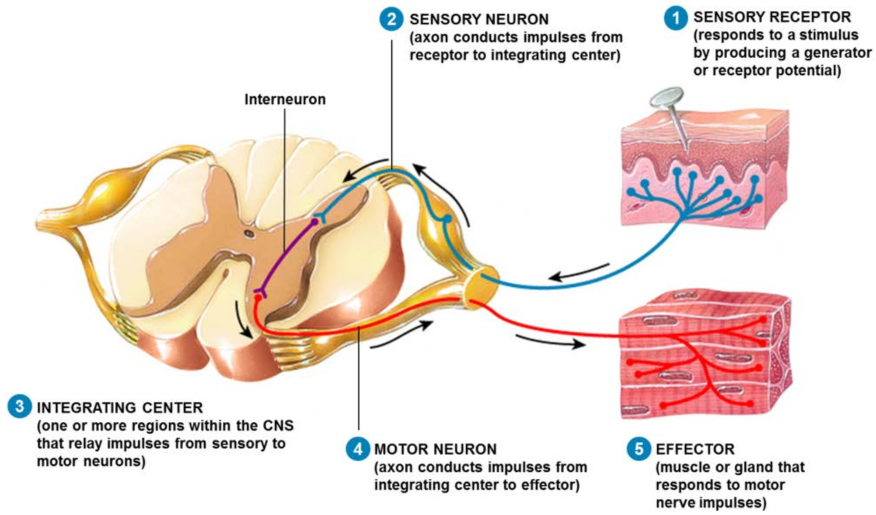
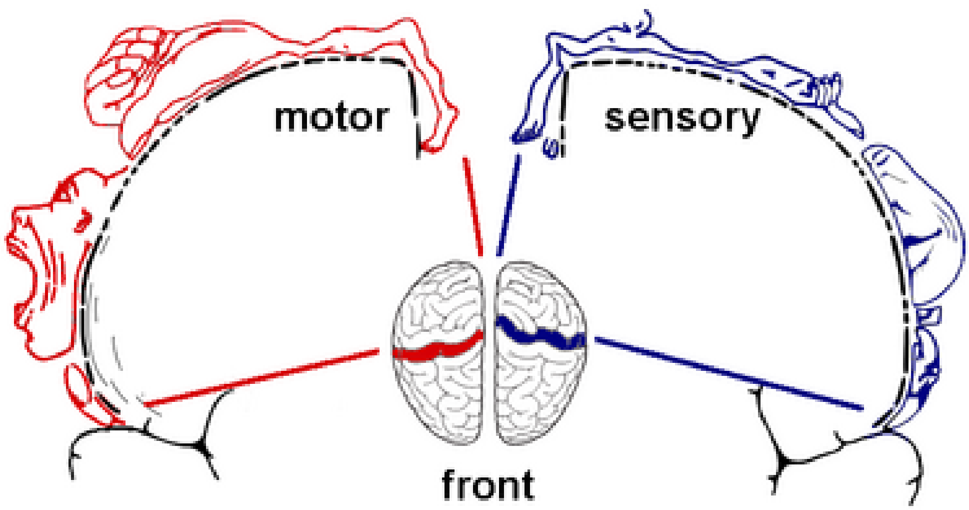
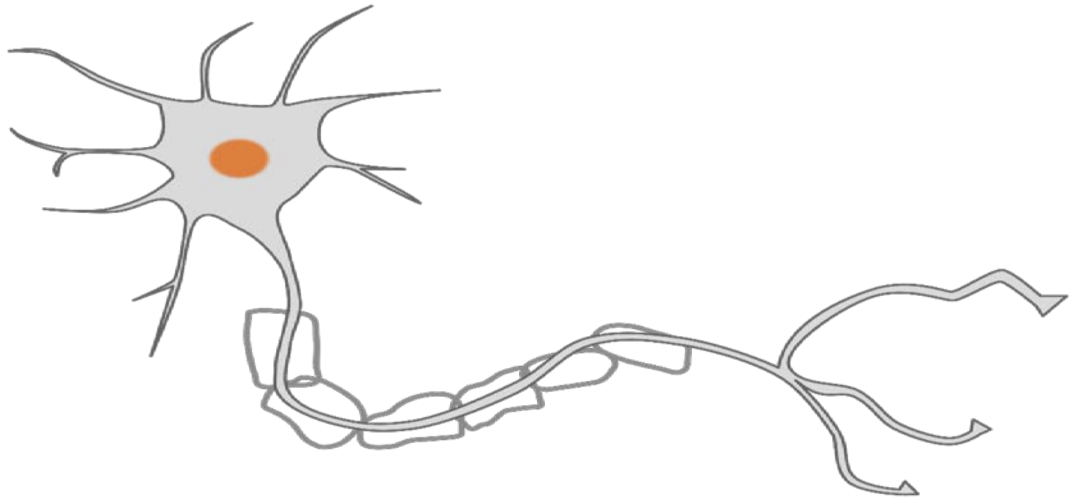
D.	 http://images.rapgenius.com/15bbff4d8aca800d8f495444dbcee8c8.1000x594x1.png
E.	 https://neuwritesd.files.wordpress.com/2013/08/homunculi.png

Main Take-Aways:

Student Handout 1.3: The Neuron

Name:___________________________________ Date:____________________

Period:___________



Part of Neuron	Why it's important	How you'll remember where it is and what it's for
Dendrites		
Cell Body		
Nucleus		
Axon		
Myelin		
Axon Terminal		

The Synapse

https://pixabay.com/en/science-neuron-synapse-biology-305773/

The **synapse** is the ___________________ between two ______________ (or between a neuron and a muscle/gland).

When the _______________________ signal that traveled through the _____________ reaches the axon terminal, _____________________________ are released. These neurotransmitters are a ___________________ signal that travels across the ______________________. Receptors for the neurotransmitters are located on the __________________________ of the next neuron (or muscle or gland)

To summarize:

- ______________ signals travel _________________ a neuron.
- ______________ signals (neurotransmitters) travel ______________ neurons.

Word Bank:	Electrical	Chemical	Space	Between	Across
	Dendrites	Axon	Synapse	Neurons	Neurotransmitters

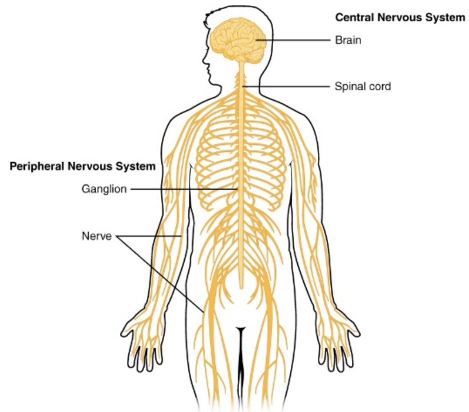
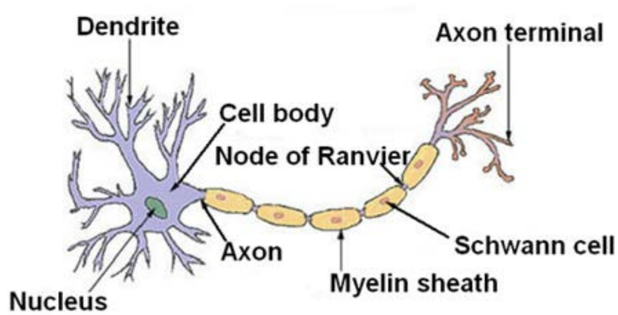
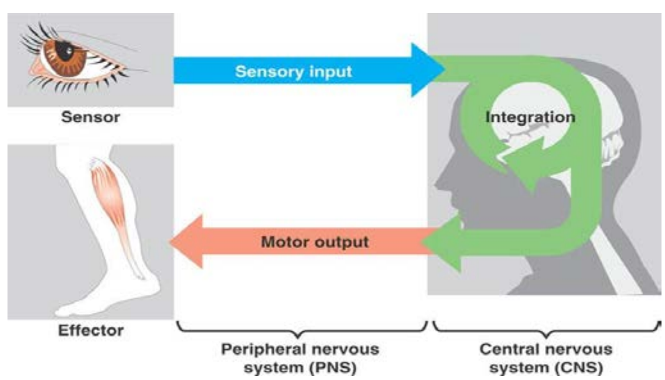
Teacher Resource 1.1: What is the problem we are trying to solve? Answer Key

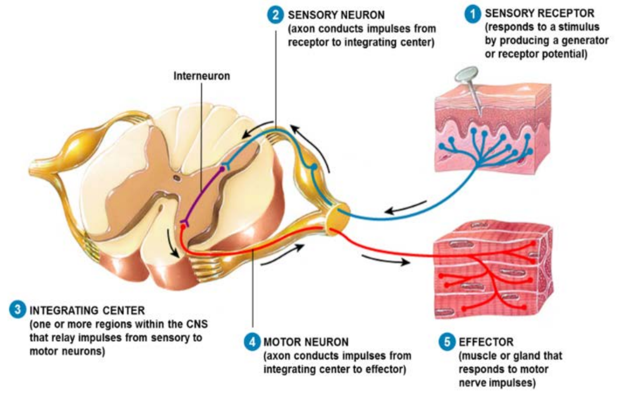
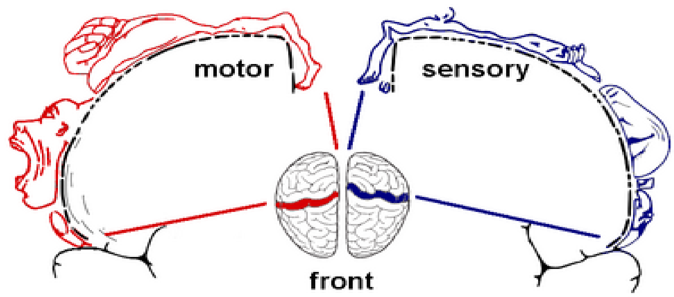
If you lost or damaged your sense of _________________....

	Sight	Hearing	Touch
....what would you be able to do well or better?	Possible answers: Listen to conversations Type your thoughts	Possible answers: Lip read what someone is saying across the room	Possible answers:
....what would be more challenging for you to do (but you could still do)?	Possible answers: Cross the street Read Cook	Possible answers: Talk on the phone Play an instrument well	Possible answers: Grip an egg or ball without cracking it or dropping it
....what would be very hard to do?	Possible answers: Drive See facial expressions Choose matching clothes	Possible answers: Hear emergency sirens behind you	Possible answers: Sense temperature Sense pain/injury

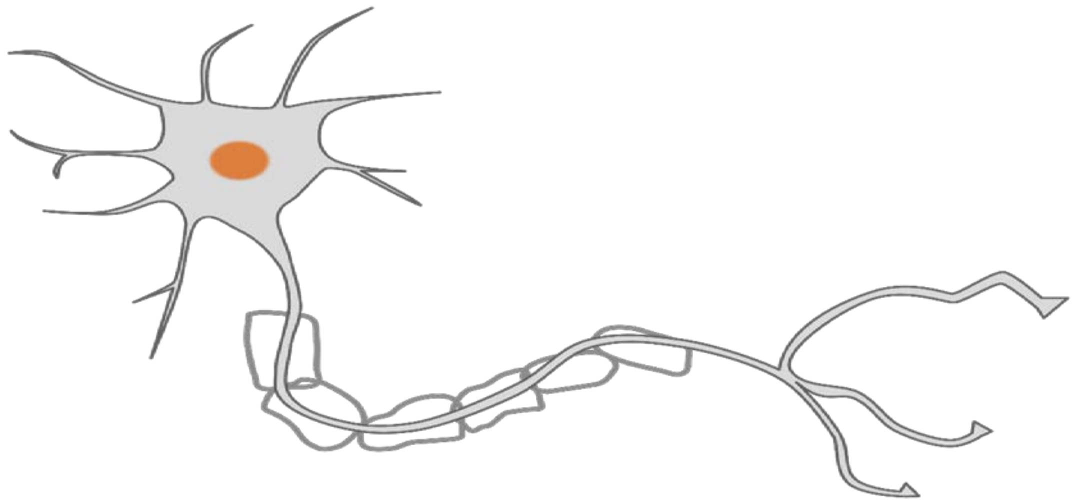
What assumptions are we making about what people need to function daily?

Teacher Resource 1.2: Nervous System Diagrams Answer Key

A. CNS is made of brain and spinal cord; PNS is made of nerves that bring information to and away from CNS	 By OpenStax - https://cnx.org/contents/FPtK1zmh@8.25:fEI3C8Ot@10/Preface, CC BY 4.0,
B. Neuron has many parts: dendrites receive chemical messages, electrical impulse travels down axon	 https://upload.wikimedia.org/wikipedia/commons/b/bd/Neuron.jpg
C. Input from senses go to the brain for processing which sends information to the muscles (motor output).	 http://www.proprofs.com/flashcards/upload/a7106439.jpg

D. Sensory receptors receive information, sending to CNS through sensory neurons which cause muscle or gland to respond based on information sent from motor neuron.	 http://images.rapgenius.com/15bbff4d8aca800d8f495444dbcee8c8.1000x594x1.png
E. Sensory and motor cortex are located adjacent to each other in brain, and neurons responsible for sensing and moving different parts of the body can be mapped out on the brain.	 https://neuwritesd.files.wordpress.com/2013/08/homunculi.png

Teacher Resource 1.3: The Neuron Answer Key



Part of Neuron	Why it's important	How you'll remember where it is and what it's for
Dendrites	Receives neurotransmitters from other neurons	Ex: hand that receives a ball
Cell Body	Contains nucleus and other cell organelles	Ex: head that contains the brain
Nucleus	Contains DNA	Ex: brain that controls what rest of body does
Axon	Where electrical signal travels	Ex: blood vessels that transports nutrients
Myelin	Insulates the axon	Ex: insulation surrounding electrical wire
Axon Terminal	Releases neurotransmitters when electric signal reaches here	Ex: shipping dock releasing boxes of goods to another company

The Synapse

https://pixabay.com/en/science-neuron-synapse-biology-305773/

The **synapse** is the space between two neurons (or between a neuron and a muscle/gland).

When the electrical signal that traveled through the axon reaches the axon terminal, neurotransmitters are released. These neurotransmitters are a chemical signal that travels across the synapse. Receptors for the neurotransmitters are located on the dendrite of the next neuron (or muscle or gland).

To summarize:

Electrical signals travel within a neuron.

Chemical signals (neurotransmitters) travel between neurons.

Lesson Two: Robot Gripper Hand
Center for Sensorimotor Neural Engineering
Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: 50+ minutes.

Lesson Plan Summary:
Students will experiment with an electromyography (EMG) controlled robot gripper hand to see that electrical signals generated by muscles can be used for electrical circuits. Students will also draw similarities between the sensory inputs and motor outputs of a nervous system with the inputs and outputs of a circuit.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:
- Electrical signals produced by our neuromuscular system can be detected; these same signals can be used for electrical circuits.
- Our nervous system involves processing input from sensory neurons, causing an output through motor neurons. Circuits can also vary their output based on input.

Essential Question:
- How are the nervous system and electrical circuits similar?

Learning Objectives:
Students will know…
- Electrical signals generated by muscles in our body can be detected using electromyogram (EMG) electrodes.
- Electricity flows through a circuit.
- The same electrical signals from our muscles can be used to control a motor in a circuit.
- Nervous system pathway includes input from sensory neurons, processing by the brain, and output through motor neurons
- Robot gripper hand device takes input from muscles, electrical signals are processed by Arduino/Muscle SpikerShield, and movement results in gripper hand based on electrical signals from Arduino/Muscle SpikerShield

Students will be able to…
- Describe through words and diagrams the similarities between the nervous system and an electrical circuit.

Vocabulary:

- **Divisions of the nervous system**: central nervous system (brain and spinal cord), peripheral nervous system (sensory/afferent neurons, motor/efferent neurons)
- **Electromyogram (EMG**)

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards (NGSS).

NGSS High School Disciplinary Core Ideas

- **MS-LS1.A**: **Structure and Function**: Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.

NGSS Cross-Cutting Concepts

- **Systems and Systems Models**
- **Structure and Function**

NGSS Science & Engineering Practices

- **SEP**: Developing and Using Models

MATERIALS

Material	Description	Quantity
Robot Gripper Hand with Arduino and Muscle SpikerShield	$189 from https://backyardbrains.com/products/clawBundle	1 for class
EMG electrodes	$29 from https://backyardbrains.com/products/emglargeelectrodes	2 per student
Student Handout 2.1: Robot Gripper Hand	Students record questions and observations	1 copy per student

TEACHER PREPARATION

1. Set-up and test the gripper hand: Connect the gripper hand to the Arduino and Muscle SpikerShield and test its action using the EMG electrodes to make sure its works reliably. Directions come with the purchased gripper hand kit. Note: You may need to calibrate the gripper hand using the two buttons on the top of the SpikerShield to adjust the threshold and whether the claw is open or closed. The following websites may be helpful:
    - https://backyardbrains.com/experiments/musclespikershield_gripperhand
    - https://backyardbrains.com/experiments/RobotHand
    - https://backyardbrains.com/products/clawbundle

2. Copy handouts as listed in the Materials section above.

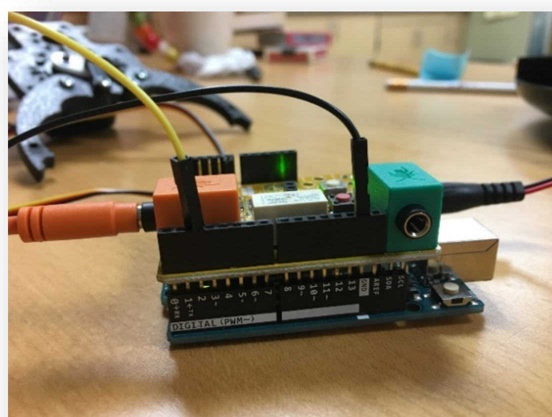
PROCEDURE

Engage: Electricity in the Nervous System (10 minutes)

1. Have students share out what they remember about the structure and function of the nervous system.

2. Pass out *Student Handout 2.1: Robot Gripper Hand* and show students the device. Ask students the question (through pair-shares or journaling): "How might something like a robotic hand that is connected to an Arduino processor be similar to our nervous system?"

Explore: EMG-Controlled Robot Gripper Hand (30 minutes)



3. Attach two electrodes per student (one on inside of upper forearm, one near inside of wrist, along the arm muscle), as pictured above. Student should hold the ground wire in other hand. Try to get robot hand to grip objects by having the student tense and relax their hand, activating the muscles in their arm.

4. Ask the following questions (think-pair-share, class discussion) and document their observations/questions on *Student Handout 2.1: Robot Gripper Hand*:
   a. What are you observing? What questions do you have?
   b. What is happening? Where's the input? What's the output? Is there any processing in between?

5. Have as many students try out the device as time will allow.

6. Have different variations/challenges: grip different objects (Styrofoam peanut, eraser, crumpled paper balls, etc.); use different muscles (forearm, bicep, leg, cheek); transfer objects from one bowl to another; use two people (one with the electrode patches on their body, the other holding and maneuvering the robot gripper hand). Have students record additional observations on the back of their student handout or in their lab notebook.

Explain: Wrap-up Discussion (5 minutes)

7. Class discussion: How does the robot hand and circuits connect to our nervous system? Emphasize: electricity, inputs, processing, and outputs.

Evaluate: Exit Ticket (5 minutes)

8. Exit ticket: How is the robot gripper hand connected to the nervous system? Use as many terms and connect as many ideas from our lesson today.

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- Class discussions can be used to check for general understanding.
- Exit ticket can help with seeing whether students made connections between robot arm, circuits, and nervous system.

Student Metacognition:

- Provide students opportunities to come up with questions, reflect on their initial ideas about what they know and understand, and write them down in their lab notebook. They can add new/changing ideas to their lab notebook.
- Students will reflect on their learning when they complete the exit ticket.

Scoring Guide:

- *Teacher Resource 2.1* provides a scoring key for *Student Handout 2.1*.
- Look for the following in the exit ticket:
    - Electricity is used for signaling human body (muscles and nerves).
    - Electricity is used to move the gripper hand.
    - Electric signal from muscles can control gripper hand.
    - Nervous system has inputs (senses) and outputs (movements).
    - Robot hand took input (electrical signal from muscles) and output was movement.

EXTENSION ACTIVITIES

Extension Activities:

- Record and study electrical signals produced on computer, tablet, or phone by plugging the muscle shield into a computer with the Backyard Brains Spike Recorder application. Students can change variables (such as length of contraction, distance between electrodes) when exploring the robot gripper arm and observe differences in electrical signals. See https://backyardbrains.com/experiments/muscleSpikerbox.

- Any battery operated circuit component (motors, buzzers) can be connected to the output pin of the Arduino Muscle SpikerShield. Students can try to manipulate different outputs with their muscle activity.

TEACHER BACKGROUND & RESOURCES

Resources:

Additional experiments that can be conducted with the Muscle SpikerShield can be found at Backyard Brains (https://backyardbrains.com/experiments/muscleSpikerShield).

Citations:

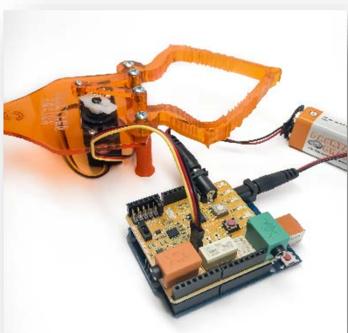
Photographs taken by Phelana Pang.
EMG Gripper Claw from Backyard Brains.

Student Handout 2.1: Robot Hand

Name:__________________________________ Date:___________________ Period:___________

Observations	Questions

The Science behind the Hand



How this connects to the Nervous System

My Ideas	Class Discussion

Photo: EMG-controlled robotic gripper hand and muscle SpikerShield from Backyard Brains.

Teacher Resource 2.1: Robot Hand Answer Key

Observations	Questions
Possible answers: • When flex, gripper hand closes • When relax, gripper hand opens • Takes practice to control • When ground cable is not held by other hand, it doesn't work. • Smaller movements result in less of a grip	

The Science behind the Hand

- Electrical signal comes from the human arm and is detected by electrodes
- Wires carry the electrical signal to Arduino
- The Arduino processes the electrical signal
- Wires carry another electrical signal to the gripper hand
- Gripper hand moves as a result

How this connects to the Nervous System

My Ideas	Class Discussion
	This models the nervous system. Input of electrical signal from human arm is like input into senses of nervous system. Wires from the electrodes are like sensory neurons taking the information to the brain. The brain processes the information, just like the Arduino processes the electrical signals generated by the human arm. Wires carrying the electrical signal for output are like motor neurons. Gripper hand movement is analogous to muscle movement.

Lesson Three: Prosthetic Fingers
Center for Sensorimotor Neural Engineering
Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: 80 minutes (over two days).

Lesson Plan Summary:
Students will create and observe a silicone model of their finger to consider constraints in engineering a prosthetic device.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:
- Models can be made and examined to consider design criteria and constraints.

Essential Question:
- What factors need to be considered when designing a prosthetic device?

Learning Objectives:
Students will know…
- Models have limitations.
- Models can be used to consider the criteria and constraints in a design process.

Students will be able to…
- Come up with similarities and differences between their prosthetic finger and their real finger.

Vocabulary:
- **Engineering design:** criteria, constraints.

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards (NGSS).

NGSS Middle School Disciplinary Core Ideas

- **MS-ETS1.A Defining and Delimiting Engineering Problems:** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specifications of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.

NGSS Cross-Cutting Concepts

- **Structure and Function**

NGSS Science & Engineering Practices

- **SEP**: Asking Questions and Defining Problems
- **CCC**: Influence of SET on Society and Natural World
- **NoS**: Science is a Human Endeavor
- **NoS**: Science Addresses Questions about the Natural and Material World

MATERIALS

Material	Description	Quantity
Student Handout 3.1: Making a Prosthetic Finger	Guides students through the process of making prosthetics and includes reflection questions	1 copy per student
Dow Corning silicone rubber curing agent	Ellsworth Adhesives Part # 3-6559 CURE ACCEL .45KG BT, https://www.ellsworth.com/	1 bottle
Silastic E curing agent and accelerator	Ellsworth Adhesives Part # RTV-4230-E KIT 4.4KG KIT, https://www.ellsworth.com/	1 bottle each (comes as a set)
Alginate powder Alja-Safe	Smooth-on, http://www.smooth-on.com/Life-Casting-Alja-/c3_1185/index.html	3lb should be plenty
100 mL Graduated cylinders	For measuring water	1 per group
10 mL Graduated cylinders or large disposable pipettes	For measuring curing agent and accelerator; very difficult to clean afterwards	2 for class (teacher use)
Small disposable cups (Dixie bathroom cups)	For mixing alginate	1+ per student
Popsicle sticks or tongue depressors	For mixing and applying alginate	1+ per student
Film canisters or other rack/apparatus	For holding molds/casts while curing	1+ slots per student
Paper towels	Should be dry for removing any silicone on hands	1+ roll per class

Scissors	For trimming silicone after curing	1+ per group
Lab bench underpads (optional)	To protect tables and for easy clean-up	1 per group
Permanent markers	For decorating prosthetic fingers	5+ colors per group

TEACHER PREPARATION

1. Try making the prosthetic finger on your own ahead of time. Use dry paper towels to remove any silicone that gets on your hands before washing with soap.
2. Pre-measure alginate into small cups so students only have to measure water.
3. Prior to Day 2: check to make sure the fingers are cured (should only take 24 hours)

PROCEDURE

Day 1

Engage: Brainstorm (10 minutes)

1. In groups, partners, or individually, brainstorm responses to the questions listed in the Brainstorm section of *Student Handout 3.1: Making a Prosthetic Finger*. Possible answers are listed in *Teacher Resource 3.1.*

Explore: Make a Prosthetic Finger (30+ minutes)

2. Use alginate and silicone to make mold and cast of finger (these will need to cure overnight).
    - Instructions are provided on Day 1 section of *Student Handout 3.1: Prosthetic Fingers.*
    - Save time for cleaning up. Students should wipe off silicone with DRY paper towels before washing their hands with soap.
    - Allow fingers to cure for 24-72 hours.

Day 2

Explain and Evaluate: Examining Prosthetic Fingers (40+ minutes)

3. After prosthetic fingers have cured overnight:
    a. Remove mold (can be discarded) and use scissors to trim excess silicone.
    b. Examine and sketch prosthetic fingers.
    c. Complete Day 2 section of *Student Handout 3.2: Prosthetic Fingers*.
        i. Discuss similarities/differences compared to actual finger in terms of structure, function.
        ii. Discuss modifications to this finger to make it an optimally functional prosthetic component.
        iii. Discuss with students whether aesthetics may be important to an end-user.

4. *Optional*: Decorate prosthetic finger with permanent markers.

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- Oral discussion of criteria, constraints, and modifications to prosthetic finger
- Written and oral reflection on limitations of prosthetic model
- Written reflections on student handout or lab notebook.

Student Metacognition:

- Provide students opportunities to come up with questions, reflect on their initial ideas about what they know and understand, and write them down in their lab notebook. They can add new/changing ideas to their lab notebook.

Scoring Guide:

- *Teacher Resource 3.1*. provides a scoring key for *Student Handout 3.1.*

EXTENSION ACTIVITIES

Extension Activities:

- Students can make a prosthetic of other body parts (for example: nose, ear, or toe). If doing nose or ear, use cotton to plug openings before making alginate mold.
- Students can research the challenges of creating prosthetic limbs and how engineers have addressed various criteria and constraints in their solutions.

TEACHER BACKGROUND & RESOURCES

Background Information:

Written by Dianne Hendricks (see citation below):

"The material used for the mold is produced from reaction of water with algiform. The alginate is a gelating polysaccharide that makes up a large part of the cell wall of giant brown seaweed, horsetail kelp, and sugar kelp. It is often used as a creamer in ice cream, a suspending agent in soft drinks, and in various medical applications such as dental impressions and capsule coatings for pharmaceuticals.

"The casting material, Silastic E RTV Silicone Rubber, contains polydimethylsiloxane (PDMSO) and an organo-platinum complex catalyst. The curing agent contains the crucial crosslinking ingredient that is activated by the catalyst to join the polymer chains in the base (casting) material. The crosslinking process attaches chains of polymer together to form a network and eventually a solid material.

"An accelerator, which consists of additional platinum catalyst, is sometimes required to cure the rubber when surfaces such as masking tape or latex inhibit the catalyst already in the base. It is used here to ensure formation of a firm, well set prosthetic."

Citations:

Prosthetics finger lab is based on an activity developed by Dr. Dianne Hendricks, Lecturer and Faculty Lead for Outreach, Department of Bioengineering, University of Washington, dgh5@uw.edu, https://bioe.uw.edu/outreach.

Photographs taken by Phelana Pang.

Student Handout 3.1: Prosthetic Fingers
Name:________________________________ Date:__________________ Period:__________

Day 1: Making a Prosthetic Finger
Brainstorm
What are different types of functions a hand can perform? If you didn't have a hand, what could you not do? Describe/diagram.

If you were to design a prosthetic hand, what considerations would you prioritize? What would it look like? What would it do?

Procedures
1. Combine 100 mL of alginate powder and 90 mL of warm water in a small Dixie cup.
2. Stir with popsicle stick.
3. Use popsicle stick to apply alginate over one whole finger. Be sure to cover all holes and apply an even layer about 1.0-1.5 cm thick.
4. Allow to dry for a few minutes, then carefully remove finger.
5. Place mold in film canister.
6. Obtain silicone mixture from your teacher (2.0 mL Cure Accelerator, 5.0 mL Curing Agent, 40 mL Silastic Rubber Base).
7. Pour silicone into mold. Allow to sit overnight.
8. Use a dry paper towel to wipe off your finger, then wash with soap and water.
9. The next day, peel off alginate mold to reveal the cast of your finger!

Day 2: Observations of Prosthetic Finger

Sketch and **label** and/or **describe** your prosthetic.

How is your prosthetic **similar** to your real finger?

How is your prosthetic **different** from your real finger?

Brainstorm some **modifications** that would make this prosthetic finger more "real." Think of both **functional** and **structural** modifications.

Teacher Resource 3.1: Prosthetic Fingers Answer Key

Day 1: Making a Prosthetic Finger Answer Key
Brainstorm
What are different types of functions a hand can perform? If you didn't have a hand, what could you not do? Describe/diagram.

Possible answers: gripping, grabbing, bending, pushing, pinching, twisting, holding, typing, writing, pointing

If you were to design a prosthetic hand, what considerations would you prioritize? What would it look like? What would it do?

Possible answers: looks like a hand, feels like a hand, has fingers, has opposable digit, has joints that can bend, has ability to revert back to its original shape (not stay bent), skin tone matches user, can be controlled easily, lasts a long time, can be taken off,

Day 2: Observations of Prosthetic Finger Answer Key
Sketch and **label** and/or **describe** your prosthetic.

Possible answers: has details of lines on skin, might be dented based on how finger was positioned while curing, bubbles can exist if the silicone was thick and quickly poured in

How is your prosthetic **similar** to your real finger?

Possible answers: details of skin and nail present, size is same

How is your prosthetic **different** from your real finger?

Possible answers: color is white, doesn't bend in the same way, flexible/malleable, has a better grip due to silicone

Brainstorm some **modifications** that would make this prosthetic finger more "real." Think of both **functional** and **structural** modifications.

Possible answers: skin tone can match person, can bend at joint

Lesson Four: Neuroprostheses and Sensory Substitution
Center for Sensorimotor Neural Engineering
Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: Two 50 minute periods.

Lesson Plan Summary:
Students will differentiate between and provide examples of assistive devices and neuroprosthetics. Students will explain the basics of sensory substitution.

STUDENT UNDERSTANDINGS
Big Idea & Enduring Understanding:

- Assistive devices help people with a disability to function successfully (for example, a magnifying glass or a wheelchair).
- Neuroprosthetics are devices that connect the external stimuli to the brain for processing (ex: cochlear implant) or that read brain signals to result in action (ex: thought controlled movement of robotic arm).
- Sensory substitution allows the replacement of an impaired or missing sense by another, and is often processed by the part of the brain that normally processes information from the impaired sense (ex: visual cortex processes information from a tactile map of the visual field sensed on the tongue).

Essential Question:

- How might a neuroprosthetic assist someone who has an impaired or missing sense?

Learning Objectives:
Students will know…

- The difference between assistive devices and neuroprosthetics. Assistive devices help a person with a certain disability. A neuroprosthetic uses a brain-computer interface to assist a person with a sensory or motor disability.
- That certain neuroprosthetics can help a person with an impaired or missing sense through sensory substitution.

Students will be able to…

- Identify and explain why certain devices are classified as assistive devices or neuroprosthetics.
- Provide examples of sensory substitution devices and explain why they are classified as neuroprosthetics.

Vocabulary:

- Assistive device
- Neuroprosthetic
- Sensory substitution

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards (NGSS).

NGSS Middle School Disciplinary Core Ideas

- **MS-LS1.A: Structure and Function:** Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.
- **MS-LS1.D**: Information Processing: Each sense receptor responds to different inputs, transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories.

NGSS Cross-Cutting Concepts

- **Structure and Function**
- **Cause and Effect**

NGSS Science & Engineering Practices

- **SEP**: Obtaining, Evaluating, and Communicating Information

MATERIALS

Material	Description	Quantity
Student Handout 4.1: Assistive Devices v. Neuroprosthetics & Sensory Substitution	Used for defining and writing examples, taking notes on video, and brainstorming ideas	1 copy per student

TEACHER PREPARATION

1. Preview the videos, read articles, and search for more current articles on assistive devices, neuroprostheses, and sensory substitution.
2. Make copies of handouts.
3. Make copies of articles or have links to articles and videos pre-loaded onto your class website.

PROCEDURE

Engage: Warm-up (10 minutes)

1. Students can journal on the following warm-up questions:
    a. What do you think an assistive device is? What might be some examples?
    b. Is it possible for devices to be directly controlled by the brain? What might be some examples?

Explore and Explain: Neuroprosthetics and Sensory Substitution (60+ minutes)

2. Use *Student Handout 4.1: Assistive Devices v. Neuroprosthetics & Sensory Substitution* to guide students in understanding the difference between assistive devices and neuroprosthetics and to gain a basic understanding of a sensory substitution device. The following can be explored through a whole class discussion, jigsaw, stations, etc. depending on the level/structure/make-up/energy of the class. Resources are included here.
    a. What are **assistive devices**? Come up with definition, reasons, and examples.
        i. https://www.nichd.nih.gov/health/topics/rehabtech/conditioninfo/Pages/device.aspx

    b. What are **neuroprosthetics**? Come up with definition, reasons, and examples. (use computer to project pictures from articles)
        i. "Neuroprosthetics: Once more, with feeling", *Nature*, May 8, 2013, http://www.nature.com/news/neuroprosthetics-once-more-with-feeling-1.12938

        ii. "Bionic Senses: How Neuroprosthetics Restore Hearing and Sight", Harvard Blog, March 16, 2013, http://sitn.hms.harvard.edu/flash/2013/issue138a/

        iii. "Neuroprosthetics", *The Scientist*, November 1, 2014, http://www.the-scientist.com/?articles.view/articleNo/41324/title/Neuroprosthetics/

        iv. "The Mind-Controlled Prosthetic Arm with a Sense of Touch from Motherboard, https://www.youtube.com/watch?v=F_brnKz_2tI&t=6s (11:28) – Please preview to determine if it is appropriate to show as there are graphic images of the patient's injury in the first 3 minutes

    c. Focus on **motor output**:
        i. Brain Controlled Wheelchair (non-invasive) from Swiss Federal Institute of Technology, https://www.youtube.com/watch?v=JyJj32MsAUo (2:18)

    ii. Brain Controlled Robot Arm (invasive) from Keck Medicine of USC, https://www.youtube.com/watch?v=lZgeb_HDb48 (4:00)

  d. Focus on **sensory substitution**:
    i. Articles on Sensory Substitution for blind people, http://blogs.discovermagazine.com/crux/2014/04/28/blind-sight-the-next-generation-of-sensory-substitution-technology/#.VeeAmdRVhBd and http://www.newyorker.com/magazine/2017/05/15/seeing-with-your-tongue

Elaborate and evaluate: TED Talk (20 minutes)

3. Watch David Eagleman TED talk, part 1.
   a. https://www.youtube.com/watch?v=4c1lqFXHvqI (to 13:58 minutes)

4. As students watch the David Eagleman video, they can take notes and write down questions onto the second page of the handout. Discuss the questions in small groups or large group (time-permitting).

5. Connect the content to the design challenge introduced in the beginning of the unit. Students can start brainstorming ideas for sensory substitution devices (use bottom of handout to list).

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- *Student Handout 4.1: Assistive Device v. Neuroprosthetic* can be used to check for definitions and examples.
- Class discussions can be used to check for general understanding.

Student Metacognition:

- Provide students opportunities to come up with questions, reflect on their initial ideas about what they know and understand, and write them down in their lab notebook. They can add new/changing ideas to their lab notebook.

Scoring Guide:

Teacher Resource 4.1 provides a scoring key for *Student Handout 4.1.*

EXTENSION ACTIVITIES

Extension Activities:

- Read more articles/watch more videos about different neuroprosthetic and sensory substitution devices. Learn more about Brain-Computer Interfaces (BCIs) to more directly understand how neuroprostheses communicate with the brain.

Adaptations:

- A shorter version of the David Eagleman VEST video and more guided questions specific to the video (instead of students taking notes) are provided on *Student Handout 4.2: Sensory Substitution Video and Questions*.
- Articles can be assigned for homework rather than read in class.

TEACHER BACKGROUND & RESOURCES

Background Information:

Review the resources provided for students and choose what is most appropriate with time constraints and student needs.

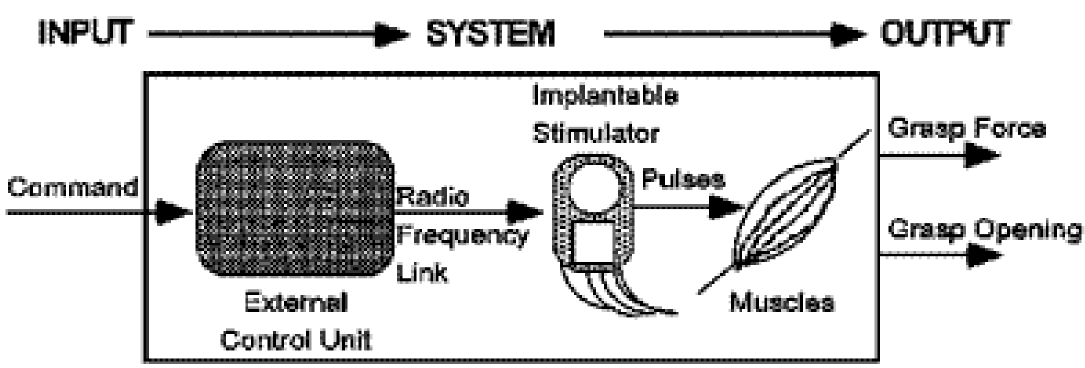
Resources:

- **"Neuroprosthetics: Testing the Limits of the Brain", The Aspen Institute**
    - https://www.youtube.com/watch?v=CWBQyIOHomM

Student Handout 4.1: Assistive Devices v. Neuroprosthetics

Name:______________________________ Date:________________ Period:_________

Definition	**Examples**
Assistive Device -	
Neuroprosthetic -	



http://www.rehab.research.va.gov/jour/00/37/1/memberg.htm

Sensory Substitution

Notes	Questions

https://pixabay.com/en/toys-mr-potato-head-fun-happy-cute-488397/

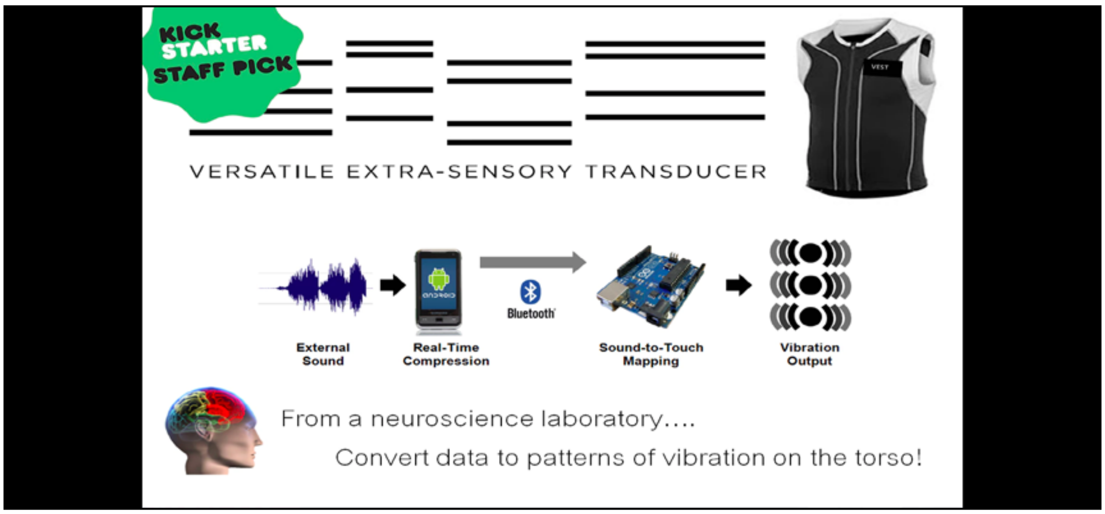
Brainstorm of Ideas for Sensory Substitution Devices

Impaired or Absent Sense	Substituting/ Replacement Sense	Description of Device

Student Handout 4.2: Sensory Substitution Video and Questions
Name:____________________________ Date:_______________ Period:________

The VEST by David Eagleman and Scott Novich
Watch this video: https://www.youtube.com/watch?v=kbKzF8gKxT4 (3:13 minutes)

Background information: David Eagleman is a neuroscientist at Stanford. Scott Novich is his graduate student. Together they are working on VEST (Versatile Extra-Sensory Transducer).



Citation: From Kickstarter.org

Questions to answer in your lab notebook as you watch the video:

1. What are the senses involved in the VEST?

2. What is the input of the VEST? What is used to process the information? What is the output?

3. Explain how this is an example of a sensory substitution device.

4. What are the advantages of this device over the cochlear implant?

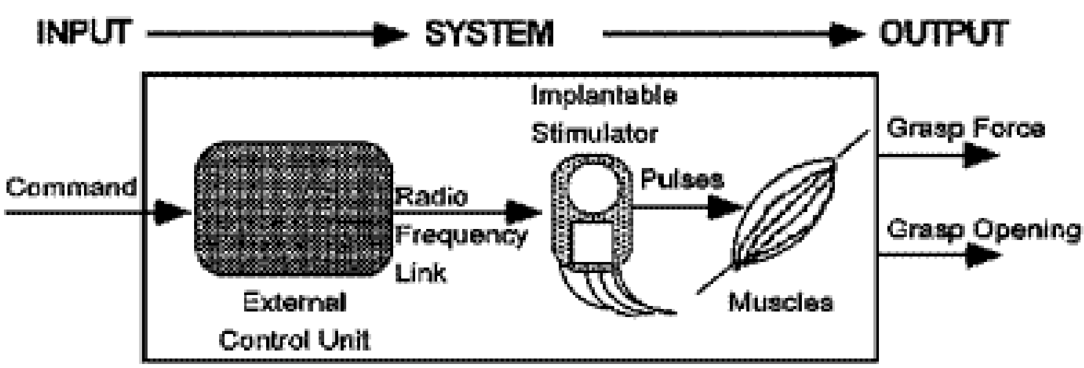
5. What disadvantages can you imagine for this device?

6. Can you think of other sensory substitution devices that could be designed to do similar things?

7. Can you think of other senses for which you can design a sensory substitution device?

Teacher Resource 4.1: Assistive Devices v. Neuroprosthetics Answer Key

Definition	**Examples**
Assistive Device - “Rehabilitative and assistive technology refers to tools, equipment, or products that can help a person with a disability to function successfully at school, home, work, and in the community.” from https://www.nichd.nih.gov/health/topics/rehabtech/Pages/default.aspx	● Wheelchairs ● Walkers ● Orthoprosthetics ● Hearing aids ● Glasses ● Computers ● Pencil Grippers ● Ramps ● Automatic doors
Neuroprosthetic - “Neuroprostheses are devices that use electrodes to interface with the nervous system and aim to restore function that has been lost due to spinal cord injury (SCI). Neuroprostheses can restore some motor, sensory, and autonomic functions by stimulating various parts of the nervous system including muscles, nerves, spinal cord, or the brain” from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3758523/	● Cochlear implants ● Retinal implant ● Neuroprosthetic arm



http://www.rehab.research.va.gov/jour/00/37/1/memberg.htm

Sensory Substitution

Notes	Questions
From TED Talk: - Umwelt - reality created from what each organism can sense - We don’t miss what we can’t sense - Technology can expand our umwelt (therefore expanding what we experience as a human) - Brain figures out how to use electrochemical signals, extracting patterns, assigning meaning - Brain doesn’t know where it gets the data from; whatever information comes in, it figures out what to do with it - Potato Head analogy - each of our senses is a peripheral plug and play device. Examples: heat pits in snakes, magnetite in birds, sensors for electrical fields, air compression in bats - Sensory substitution - feeding info to brain via unusual sensory channels, and brain figures out what to do with it - Examples: sonic glasses, electrotactile grid on forehead or tongue - From Eagleman lab, VEST provides perception of sound through vibratory motors on chest and back via processing by tablet which maps sounds	

https://pixabay.com/en/toys-mr-potato-head-fun-happy-cute-488397/

Brainstorm of Ideas for Sensory Substitution Devices

Impaired or Absent Sense	Substituting/ Replacement Sense	Description of Device
Touch	Light	Light goes off if there’s pressure on a part of body that can’t sense touch
Sight	Sound	Different sounds made based on how close or big something is

Lesson Five: End-Users and Ethics

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: 50 minutes.

Lesson Plan Summary:
In this lesson, students will discuss the ethics of neuroengineering. Students will consider and examine the perspectives of various stakeholders and end-users. Students will review the difference between assistive devices and neuroprosthetics. Students will brainstorm ideas for sensory substitution device with end-users and ethics in mind.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- When designing a neuroprosthetic, the needs of the end-user must be considered and addressed.

Essential Question:

- How are the needs/desires of the end-user considered in designing a neuroprosthetic?

Learning Objectives:

Students will know…

- Persons with impaired/missing abilities may have different needs/wants than what is assumed by a person who is able.

Students will be able to…

- Come up with questions to ask an end-user about what their needs and concerns are when designing a neuroprosthesis.

Vocabulary:

- End-user
- **Engineering design:** criteria, constraints

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards (NGSS).

NGSS Middle School Disciplinary Core Ideas

- **MS-ETS1.A Defining and Delimiting Engineering Problems:** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specifications of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.

NGSS Cross-Cutting Concepts

- **Structure and Function**
- **Cause and Effect**

NGSS Science & Engineering Practices

- **SEP**: Asking Questions and Defining Problems
- **CCC**: Influence of SET on Society and Natural World
- **NoS**: Science is a Human Endeavor
- **NoS**: Science Addresses Questions about the Natural and Material World
    - o Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
    - o Science knowledge indicates what can happen in natural systems -- not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.
    - o Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.

MATERIALS

Material	Description	Quantity
Student Handout 5.1: Stella Young's TED Talk	Students reflect on what "normal" is, write assumptions and questions for end-user	1 copy per student
Student Handout 4.1 from Lesson 4	To review idea of sensory substitution and brainstorm device	

TEACHER PREPARATION

1. Preview TED talk and review questions on handout.

2. If you are able to access it through a public or academic library, read the article “Engineering the Brain: Ethical Issues and the Introduction of Neural Devices” by Klein, Brown, Sample, Truitt, and Goering in the *Hastings Center Report*, November-December 2015.

PROCEDURE

Engage: What Do End-Users Really Want? (10 minutes)

1. Journal or Group Discussion: If someone got in an accident which resulted in paralysis in the lower part of their body (below the waist), what do you think are the functions this person would want restored? How might this person prioritize the functions for which assistive devices or technologies can be developed?
    a. Automatic answer for many students is restoring the ability to walk. However, studies show that restoring basic functions which allow for independence like relieving the bladder, controlling bowels, managing chronic pain and muscle spasticity, and restoring sexual function are most important to people who have experienced a spinal cord injury.

2. Journal or Group Discussion: What do end-users really want? What questions would you ask them? Are there assumptions being made about what end-users want? What do they need? Whose values are we considering? Use the questions on *Student Handout 5.1: Stella Young’s TED Talk* to prompt students to think and write.

Explore: Neuroethics (25 minutes)

3. Show Stella Young’s TED Talk. Synopsis: “Stella Young is a comedian and journalist who happens to go about her day in a wheelchair — a fact that doesn't, she'd like to make clear, automatically turn her into a noble inspiration to all humanity. In this very funny talk, Young breaks down society's habit of turning disabled people into "inspiration porn.” **Maturity Note:** In this video, Stella Young clearly explains the use of the word “porn” as objectifying disabled people for the benefit of nondisabled people. At 7:40 minutes, she uses the word “bullshit.”
    a. Stella Young TED Talk: https://www.ted.com/talks/stella_young_i_m_not_your_inspiration_thank_you_very_much?language=en (9:40 minutes)

4. Discuss assumptions one might make about someone with an impaired sense. Come up with questions to interview an end-user. If an end-user is known (for example, a deaf person in the community), send questions for them to respond and share with class.

Evaluate/Apply: Sensory Substitution Devices (10 minutes)

5. Review the differences between assistive devices and neuroprosthetics using *Student Handout 4.1* from Lesson 4.

6. Discuss the concept of sensory substitution and the TED talk.

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- Assess students on the questions that they might ask an end-user.

Student Metacognition:

- Students reflect on their assumptions of others' needs. Ask students to think about how their thinking has changed before and after this lesson.

Scoring Guide:

- *Teacher Resource 5.1* provides a scoring guide for *Student Handout 5.1.*

EXTENSION ACTIVITIES

Extension Activities:

- If possible, find a person in your community who has an impaired sense or other disability to be a guest speaker (in person, virtually via Skype, or through an email interview). Have students come up with questions to ask this person so they are more informed about the human behind the device they intend to design.

- Watch the movie *FIXED: The Science/Fiction of Human Enhancement* to offer students a broader view of dis/ability and human enhancement.
  - http://www.fixedthemovie.com/

- Finish watching the rest of the David Eagleman TED Talk which focuses on the enhancement of senses.

- https://www.ted.com/talks/david_eagleman_can_we_create_new_senses_for_humans/discussion?lan

TEACHER BACKGROUND & RESOURCES

Background Information:

An end-user is a person who uses a particular product. It is important for students to not just engineer a solution to a problem, but to learn more about who is using the product and what they might want from that product (and if they want the product at all).

Resources:

- CSNE Website's K-12 Online Resources on Neuroethics and Philosophy, including a series of Case Studies in Neuroethics developed for classroom use, http://csne-erc.org/education-resources-teachers/neuroethics-philosophy
- CSNE's *Neural Engineering and Ethical Implications* curriculum unit for grades 6-12, http://csne-erc.org/education-k-12-lesson-plans/neural-engineering-and-ethical-implications
- Academic articles on neuroethics:
  - Specker Sullivan et al., (2017). Keeping Disability in Mind: A Case Study in "Implantable Brain-Computer Interface Research," *Sci Eng Ethics,* pp. 1-26. This article has a great list of interview questions in the appendix for both engineers and end-users.
  - Klein, Brown, Sample, Truitt, and Goering. (November-December 2015). "Engineering the Brain: Ethical Issues and the Introduction of Neural Devices." *Hastings Center Report*.
  - Gilbert, Goddard, Viana, Carter & Horne. (2017). "I Miss Being Me: Phenomenological Effects of Deep Brain Stimulation." *AJOB Neuroscience, 8*(2), pp. 96-109.

Citations:

Frederic Gilbert, Eliza Goddard, John Noel M. Viaña, Adrian Carter & Malcolm Horne. (2017). "I Miss Being Me: Phenomenological Effects of Deep Brain Stimulation". *AJOB Neuroscience, 8*(2), pp. 96-109.

Laura Specker Sullivan, Eran Klein, Tim Brown, Matthew Sample, Michelle Pham, Paul Tubig, Raney Folland, Anjali Truitt & Sara Goering. (2017). "Keeping Disability in Mind: A Case Study in Implantable Brain–Computer Interface Research." *Science and Engineering Ethics,* pp. 1–26.

Student Handout 5.1: Stella Young's TED Talk

Name:__________________________________ Date:___________________

Period:___________

Before watching the video, answer the following questions. Don't worry about right or wrong answers. Be honest and answer to the best of your ability.

1. What does it mean to be *normal*?

2. What role does our society/culture play with regards to persons with disabilities?

3. What are some examples of how persons with disabilities use technology?

4. What do you think the role of technology *should* be regarding persons with disabilities?

5. Do you know anyone with a disability? If so, what type(s) of disability?

After the video:

When considering the person for whom you are designing a sensory substitution device, what assumptions might you be making? What questions would you want to ask that individual or group of individuals?

Assumptions	Questions

Teacher Resource 5.1: Stella Young's TED Talk Answer Key

What does it mean to be *normal*?
Possible answers (there's no right answer here, but try to get students to think about how their version of "normal" is influenced by their upbringing/culture/societal pressure): look and act like everyone else, an average person, however you are born, not missing any part of your body, whatever you're mostly surrounded by

What role does our society/culture play with regards to persons with disabilities?
Possible answers (again, there's no right answer here): making things more accessible to persons with disabilities (braille, sounds at crosswalks, wheelchair ramps, flashing lights with fire alarms); society is not accepting of a lot of persons with disabilities and many look down about persons with disabilities as if they are lacking

What are some examples of how persons with disabilities use technology?
Possible answers: dictation applications, motorized wheelchairs, automated insulin pumps and blood sugar monitors.

What do you think the role of technology *should* be regarding persons with disabilities?
Answers can vary. To consider: with advancing technology, at what point does the technology become a part of the person's identity? For example, does a prosthetic limb a part of the person if it has sensors and can make adjustments without the person's conscious control?
Do you know anyone with a disability? If so, what type(s) of disability?
Answers will vary.
After the video:
When considering the person for whom you are designing a sensory substitution device, what assumptions might you be making? What questions would you want to ask that individual or group of individuals?

Assumptions	Questions
Possible Answers: ● Person wants to restore their impaired or missing function. ● A person will feel depressed if they don't regain what they used to have.	Possible Questions: ● What are the most important aspects you want restored? ● Does it matter what it looks like, or do you want it to just be functional? ● Would you rather learn a new way to deal with your impaired sense or would you rather restore your sense as much as possible?

Lesson Six: Circuits

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: Four+ 50 minute periods.

Lesson Plan Summary:

In this lesson, students will learn about the basic components of a circuit. Students will design circuits using Snap Circuits kits, online animations, and classroom materials and draw corresponding circuit diagrams. Students will begin exploring control of output using various inputs (photoresistors, whistle chip, motor) in a circuit. This lesson will provide the circuitry fundamentals needed for students to design their sensory substitution device.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- Circuits must be carefully designed and components properly arranged in order for it to function properly.
- A variety of inputs can go into a circuit. Depending on the resistance that results from the various inputs, outputs can be controlled.

Essential Question:

- What factors need to be considered when designing a functional circuit?

Learning Objectives:

Students will know…

- **The parts of a circuit:** circuits have a power source, current runs through wires and components, currents can cause output (motors, lights, etc).
- Circuits have various components that must be arranged in certain orientations to work.
- Parallel circuits involve components placed in separate loops of the same circuit; components placed in parallel will have the same voltage going across.
- Series circuits involve components placed in line. The same current flows through all components.
- Sensors vary the amount of resistance and therefore current/voltage in a circuit. This differing level of current/voltage can result in different outputs such as whether motors or lights are on or off.

Students will be able to…

- Follow a circuit diagram to build a functioning circuit.
- Differentiate between a circuit in parallel and a circuit in series.
- Create circuit diagrams for circuits in series and in parallel.
- Explain how a circuit works based on the components present.

Vocabulary:

- **Parts of a circuit**: circuit, electricity, battery/power, electrons, current, switch, open/closed, conductor, insulator, load, positive/negative terminals
- **Circuits**: circuit, battery/power, current, switch, open/closed, positive/negative terminals, resistor, LED, motor, diode
- **Parallel, series**

Standards Alignment: This lesson addresses the following Next Generation Science Standards

NGSS Cross-Cutting Concepts

- Systems and System Models
- Structure and Function
- Cause and Effect

NGSS Science & Engineering Practices

- Developing and Using Models

MATERIALS

Material	Description	Quantity
Student Handout 6.1: Exploring Circuits	Animations 1 to 6	1 copy per student
Student Handout 6.2: Snap Circuit Components	Students write down what the simplest components do	1 copy per student
Computers/laptops	For circuits animations	1 per student/pair
Elenco Electronics Snap Circuit 300 Kits	$45.99 from https://www.amazon.com/Snap-Circuits-SC-300-Electronics-Discovery/dp/B0000683A4	1 per group/pair
Document camera	For projecting Snap Circuit projects as students explain them to the class	1 for the class

TEACHER PREPARATION

1. Copy handouts as listed in the materials section above.

2. Find an appropriate article or video to teach about the basics of circuits. See Resources section.

3. Preview and go through the online interactive circuit activity.

4. Look over the Snap Circuit kits. You can pick out some projects in the project guide that comes with the kits that are appropriate to your students' level of understanding and engagement, or allow them to pick the ones that are interesting to them.

PROCEDURE

Engage: Robot Gripper Hand Circuitry (10 minutes)

1. Through discussion or journaling, review students' understanding of the circuit involved in the Robot Gripper Hand from Lesson 2. What were some requirements for the gripper hand to function? Tell students we will be learning more about circuits to gain a clearer understanding.

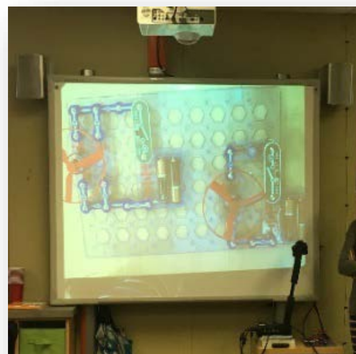
Explore and Explain: Introduction to Circuits (~90 minutes)

2. Introduction to circuits and terms.
    a. Find a video or reading which introduces circuits (see Resources section). Define terms, discuss definitions with small group, watch video again, and discuss drawings/examples with small group. Then draw simple circuit diagram with small group. (20+ min)

    b. Students can explore the online animations of circuits on the website from PCCL (Physics and Chemistry by Clear Learning). They can complete activities 1 through 6. Record observations and draw circuit diagrams on *Student Handout 6.1: Exploring Circuits.* (20+ min)
        i. http://www.physics-chemistry-interactive-flash-animation.com/electricity_interactive.htm

3. Snap Circuits Part 1 (50 min)
    a. Assess and group students based on experience with circuits (students with similar experience can work together, or you can pair a more experienced student with a novice).
    b. Choose a starting project from the Snap Circuit manual based on experience and interest
    c. Teacher circulates and asks students to explain circuits and components.
    d. Students use project instructions and background information on components in front of each manual.
    e. Students identify and describe function of different components on *Student Handout 6.2: Snap Circuit Components.*

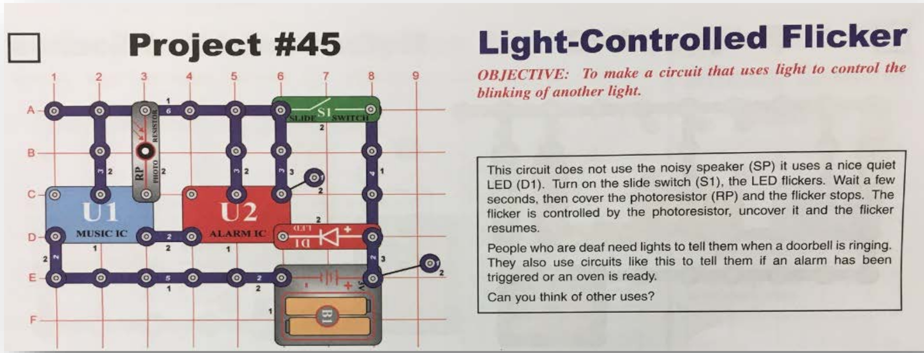
Evaluate:



4. Snap Circuit, Part 2 (50+ minutes)
    a. Each pair picks a project number from the manual to set up and draw a corresponding circuit diagram.
    b. Students prepare a presentation for their circuit to be projected on the document camera. Suggested information to present include:
        i. Explain what the circuit does
        ii. What are important components and what do they do?
        iii. How are components connected? Are they in series? In parallel?
        iv. Circuit Diagram
        v. Possible Questions
        vi. Possible Modifications

Explore, Explain and Evaluate:

5. Snap Circuits Part 3 (50 min)
    a. Have groups go through projects # 45 Light-Controlled Flicker, #61 Light-Controlled Sounds, #71 Light-Controlled Lamp, and #72 Voice-Controlled Lamp in the project manual that comes with the Snap Circuit kits.
    b. Check in with each group before allowing them to move on to the next project.



Project #45

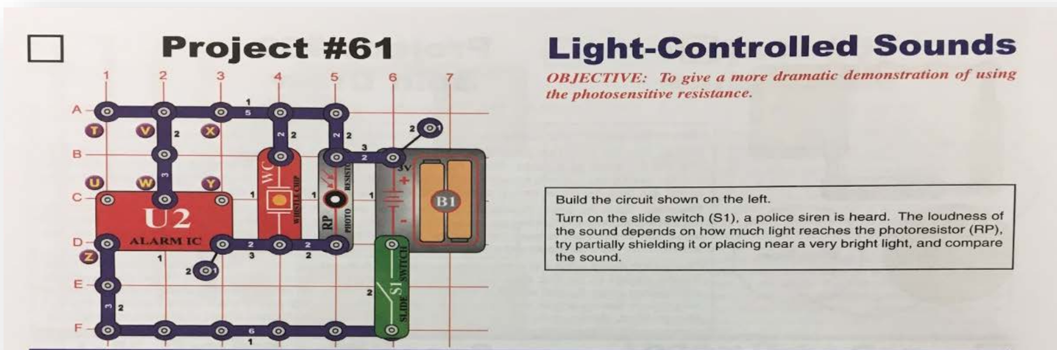
Light-Controlled Flicker

OBJECTIVE: To make a circuit that uses light to control the blinking of another light.

This circuit does not use the noisy speaker (SP) it uses a nice quiet LED (D1). Turn on the slide switch (S1), the LED flickers. Wait a few seconds, then cover the photoresistor (RP) and the flicker stops. The flicker is controlled by the photoresistor, uncover it and the flicker resumes.

People who are deaf need lights to tell them when a doorbell is ringing. They also use circuits like this to tell them if an alarm has been triggered or an oven is ready.

Can you think of other uses?



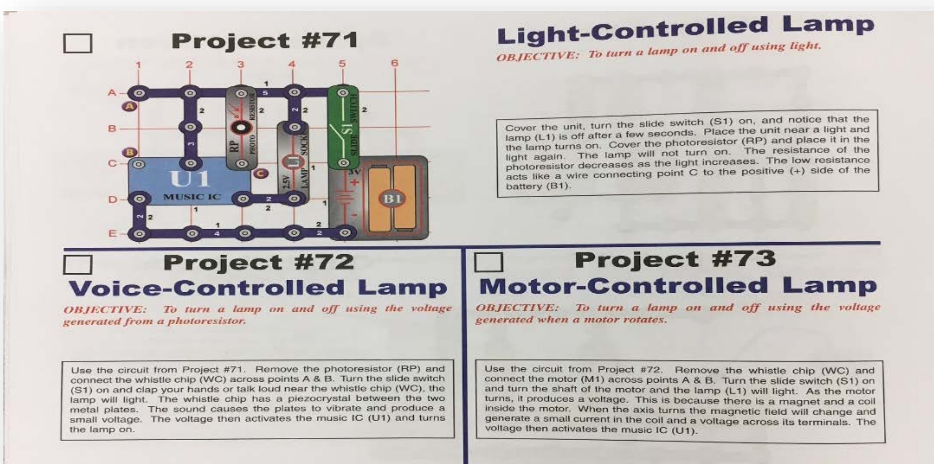
Project #61

Light-Controlled Sounds

OBJECTIVE: To give a more dramatic demonstration of using the photosensitive resistance.

Build the circuit shown on the left.

Turn on the slide switch (S1), a police siren is heard. The loudness of the sound depends on how much light reaches the photoresistor (RP), try partially shielding it or placing near a very bright light, and compare the sound.



Project #71

Light-Controlled Lamp

OBJECTIVE: To turn a lamp on and off using light.

Cover the unit, turn the slide switch (S1) on, and notice that the lamp (L1) is off after a few seconds. Place the unit near a light and the lamp turns on. Cover the photoresistor (RP) and place it in the light again. The lamp will not turn on. The resistance of the photoresistor decreases as the light increases. The low resistance acts like a wire connecting point C to the positive (+) side of the battery (B1).

Project #72

Voice-Controlled Lamp

OBJECTIVE: To turn a lamp on and off using the voltage generated from a photoresistor.

Use the circuit from Project #71. Remove the photoresistor (RP) and connect the whistle chip (WC) across points A & B. Turn the slide switch (S1) on and clap your hands or talk loud near the whistle chip (WC), the lamp will light. The whistle chip has a piezocrystal between the two metal plates. The sound causes the plates to vibrate and produce a small voltage. The voltage then activates the music IC (U1) and turns the lamp on.

Project #73

Motor-Controlled Lamp

OBJECTIVE: To turn a lamp on and off using the voltage generated when a motor rotates.

Use the circuit from Project #72. Remove the whistle chip (WC) and connect the motor (M1) across points A & B. Turn the slide switch (S1) on and turn the shaft of the motor and the lamp (L1) will light. As the motor turns, it produces a voltage. This is because there is a magnet and a coil inside the motor. When the axis turns the magnetic field will change and generate a small current in the coil and a voltage across its terminals. The voltage then activates the music IC (U1).

Credit: Images are photographs of Elenco Electronics Snap Circuit project guide.

6. As a class, discuss:
    a. Inputs and outputs: Does it make sense to use a photoresistor as an input control if output is LED for a sensory substitution device? Why or why not?
        i. It doesn't make sense for the input and output to be the same if the purpose is to replace a sense. For example, the purpose of using a photoresistor, which senses light, is to help a person who is visually impaired. This person would not be able to detect the LED output.

    b. The importance of a resistor when using an LED.
        i. LEDs by themselves do not have enough resistance compared to motors and lamps. Too much current would result in damage to the LED. For a more detailed explanation: http://led.linear1.org/why-do-i-need-a-resistor-with-an-led/).

    c. The importance of the difference in voltage needed to power different outputs.
        i. A light bulb requires more power than an LED, and a motor requires even more power.

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- The online animations are self-guided, and students cannot move forward until they set up circuits correctly. Teachers can collect the notes and diagrams recorded onto the handout for formal assessment.
- Teacher should circulate while students are building circuits to ask questions, give feedback, and answer questions.
- Presentation of Snap Circuit project: Students explain their understanding of the role of each component, how their circuit is put together, any trouble shooting, etc.

Student Metacognition:

- Provide students opportunities to come up with questions, reflect on their initial ideas about what they know and understand, and write them down in their lab notebook. They can add new/changing ideas to their lab notebook.

Scoring Guide:

Teacher Resource 6.1 and *6.2* provided scoring guides for the *Student Handouts*.

EXTENSION ACTIVITIES

Extension Activities:

- Students can do other animations on the online activity and present their findings to the class.
- Students can go further in the Snap Circuits projects depending on their level of understanding. The project manual offers many possibilities.

Adaptations:

- Kinesthetic adaptation: Act out a circuit, assigning different roles (battery, switch, output, wires) to different students. Tennis or ping pong balls can be used to simulate electrons.
- It is important to know the level of complexity of the Snap Circuit projects. Go through several of them with your students in mind to know what might be good starting points.
- For classes that already have experience with circuits, less time can be spent on the Snap Circuits.

TEACHER BACKGROUND & RESOURCES

Resources:

For introductory lessons and activities on electric circuits, see the resources below.

- PBS lessons on Electric Circuits
  - https://kcts9.pbslearningmedia.org/resource/phy03.sci.phys.mfe.lp_electric/electric-circuits/
- Bill Nye Video on Electricity
  - https://www.youtube.com/watch?v=ywHcssUjXD0
- Put a Spark in It! - Electricity unit from TeachEngineering
  - https://www.teachengineering.org/curricularunits/view/cub_electricity_curricularunit
- Sparkfun information and videos
  - https://learn.sparkfun.com/tutorials/series-and-parallel-circuits

Citations:

Snap Circuit kits are an educational product of Elenco Electronics.

Photograph by Phelana Pang.

Student Handout 6.1: Exploring Circuits

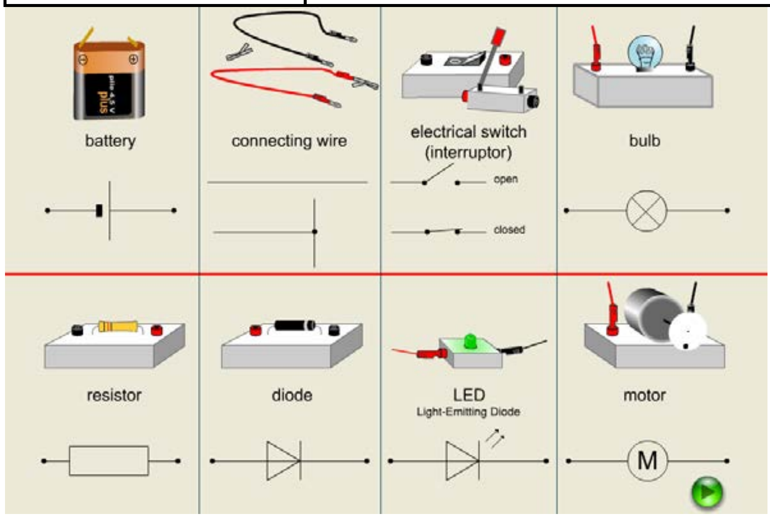
Name:________________________________ Date:__________________ Period:__________

Go to the website: http://www.physics-chemistry-interactive-flash-animation.com/electricity_interactive.htm

Go through the Basic Circuits animations (1-6) and write/draw your observations.

Animation	**Observation/Notes/Diagrams**
1 - Simple Circuit	
2 - Parallel or Series Circuit	Series Parallel
3 - Short Circuit Activity	

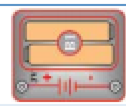
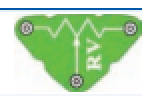
4 - Short Circuit - Why it's dangerous	
5 - Circuit Diagram (see below for symbols)	
6 - Conductors v.Insulators	Conductors Insulators



Student Handout 6.2: Snap Circuit Components

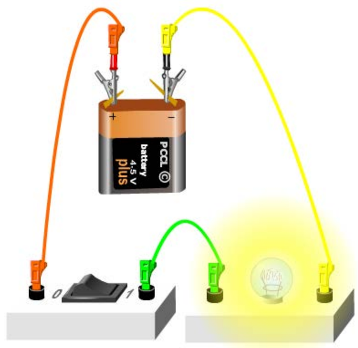
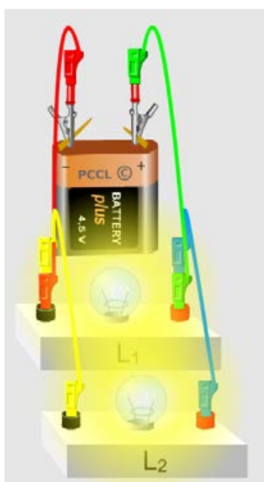
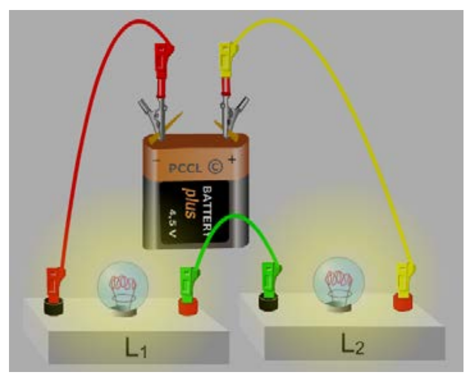
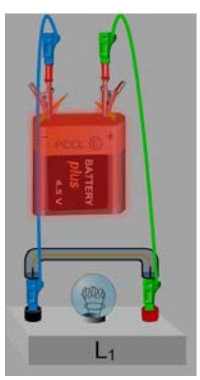
Name:___________________________________ Date:____________________ Period:___________

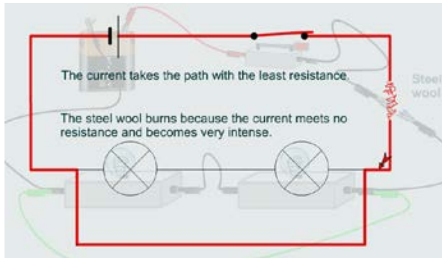
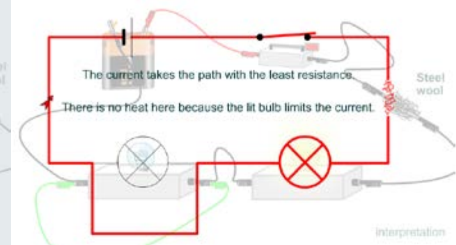
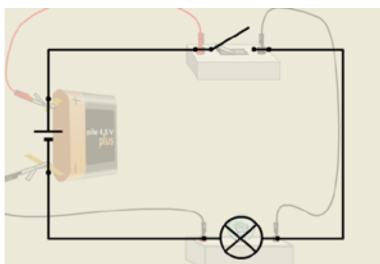
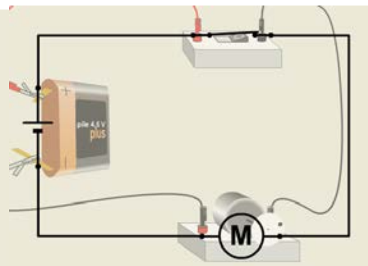
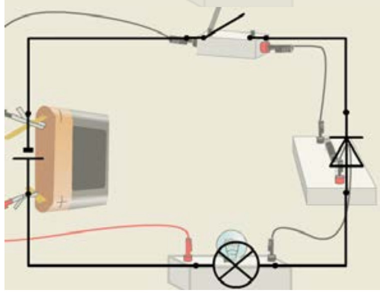
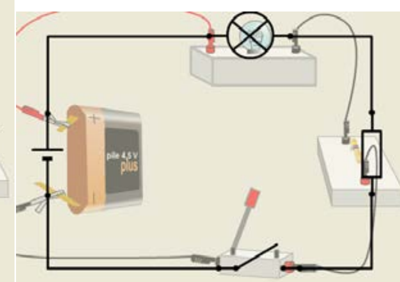
What does each do?

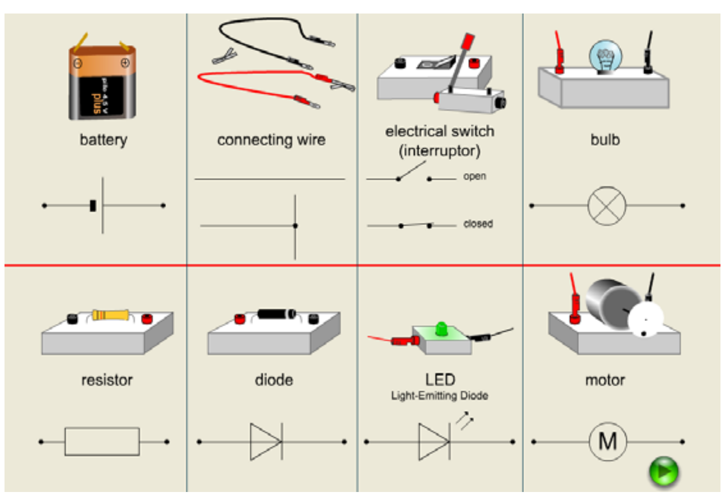
Component			Notes
(B1)	Battery Holder - uses 2 1.5V type AA (not included)		
(S1)	Slide Switch		
(S2)	Press Switch		
(RP)	Photoresistor		
(R1)	100Ω Resistor		
(RV)	Adjustable Resistor		
(L1)	2.5V Lamp Socket 3.2V Bulb (3.2V, 0.2A) Type 14 or similar		
(D1)	Red Light Emitting Diode (LED)		
(M1)	Motor Fan		

Teacher Resource 6.1: Exploring Circuits Answer Key

Go to the website: http://www.physics-chemistry-interactive-flash-animation.com/electricity_interactive.htm
Go through the Basic Circuits animations (1-6) and write/draw your observations.

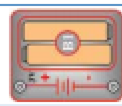
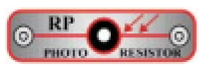
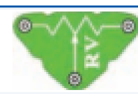
Animation	**Observation/Notes/Diagrams**
1 - Simple Circuit	
2 - Parallel or Series Circuit	  Lamps are brighter in a parallel circuit. Lamps are dimmer in series.
3 - Short Circuit Activity	 When the shunt is added to bypass the lamp, the lamp does not light up and the battery flashes red.

4 - Short Circuit - Why it's dangerous	When a wire is used to bypass the two lamps, the steel wool burns up because the current is too intense. When only bypassing one lamp, the current encounters some resistance and does not burn up the steel wool. Short circuits can cause fire! 
5 - Circuit Diagram (see below for symbols)	
6 - Conductors v. Insulators	Conductors: alloy, copper, salt water, graphite, aluminum Insulators: water, glass, wood, plastic



Teacher Resource 6.2: Snap Circuit Components Answer Key

What does each do?

Component			Notes
B1	Battery Holder - uses 2 1.5V type AA (not included)		Provides power to circuit; total of 3V with 2 batteries
S1	Slide Switch		Control whether circuit is open or closed. Slide switch allows continuous on/off. Press switch results in open circuit unless held down continuously.
S2	Press Switch		
RP	Photoresistor		Resistance varies with amount of light. If light level is high, then resistance is low, increasing current flow. If light is low, then resistance is high.
R1	100Ω Resistor		Resistors reduce current flow.
RV	Adjustable Resistor		The slider allows for variable resistance, working as a potentiometer.
L1	2.5V Lamp Socket 3.2V Bulb (3.2V, 0.2A) Type 14 or similar		Possible load to put into circuit - lights up when circuit is closed.
D1	Red Light Emitting Diode (LED)		Possible load to put into circuit. As a diode, direction is important. Requires resistor.
M1	Motor Fan		Possible load to put into circuit. Often requires more power than a lamp.

Lesson Seven: Introduction to Breadboards

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: 50 minutes.

Lesson Plan Summary:
In this lesson, students will explore how breadboards work and create simple circuits.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- Breadboards are used to prototype circuits.

Essential Question:

- How can breadboards be used to create circuits?

Learning Objectives:

Students will know…

- Breadboards are made of rows of metal clips. Components can be inserted into certain positions in the breadboard to create a circuit.

Students will be able to…

- Use breadboards and create circuits.

Vocabulary:

- **Circuits**: circuit, battery/power, current, switch, open/closed, positive/negative terminals, resistor, LED, motor, diode.

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards (NGSS).

NGSS Cross-Cutting Concepts

- **Systems and System Models**
- **Cause and Effect**

NGSS Science & Engineering Practices

- **SEP:** Developing and Using Models

MATERIALS

Material	Description	Quantity
Student Handout 7.1: Introduction to Breadboards	Students label the parts of the breadboard and identify components	1 copy per student
Breadboards	Item #64, $5.00 from https://www.adafruit.com/product/64	1 per group/pair
AA battery packs	Item #12900, $1.50 from https://www.sparkfun.com/products/12900	1+ per student/pair
AA batteries		2+ per student/pair
LEDs	Item# 12062, $2.95 for 20 pack from https://www.sparkfun.com/products/12062	1+ per group/pair
330 ohm resistors	Item #11507, $0.95 for 20 pack from https://www.sparkfun.com/products/11507	1+ per group/pair
Push buttons	Item #9190, $0.50 from https://www.sparkfun.com/products/9190	1 per group/pair
Potentiometers	Item #9806, $0.95 from https://www.sparkfun.com/products/9806	1 per group/pair
Vibration motors	Item #8449, $4 from https://www.sparkfun.com/products/8449	1 per group/pair
Buzzers	$4.49 from https://www.amazon.com/Electric-Buzzer-DC-Physics-Circuits/dp/B0083LWHDQ	1 per group/pair

TEACHER PREPARATION

1. Teacher should go through *Student Handout 7.1* and create each circuit (can save the circuits as samples or take pictures as needed).

2. Preview the Introduction to Breadboard video by Science Buddies and see how much of it you want to show (entire video is 12:20 minutes, but you can show just up to 6:04).
    a. https://www.youtube.com/watch?v=6WReFkfrUIk

PROCEDURE

Engage: Circuit Review (5 minutes)

1. Review circuit concepts from lesson 6. Have students quickly recap the components they've used and how circuits need to be wired.

Explore and Explain: Introduction to Breadboards (35 minutes)

2. Introduce breadboards and how they are arranged.

3. Show the Introduction to Breadboard video by Science Buddies.
    a. https://www.youtube.com/watch?v=6WReFkfrUIk (up to 6:04).

4. Design the following circuits on a breadboard:
    a. Circuit 1: Battery, LED, resistor
    b. Circuit 2: circuit 1 + switch
    c. Circuit 3: circuit 2 with motor or multiple LEDs

Evaluate: Reflection (10 minutes)

5. Students can explain their understanding in their lab notebook using the reflection prompts at the bottom of the page of the handout.

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- As students go through the exercises, check for understanding. Ask students to explain why components were placed in certain orientations.
- Check the responses to the reflection questions at the bottom of the handout.

Student Metacognition:

- Provide students opportunities to come up with questions, reflect on their initial ideas about what they know and understand, and write them down in their lab notebook. They can add new/changing ideas to their lab notebook.

Scoring Guide:

- *Teacher Resource 7.1* provides a scoring guide for *Student Handout 7.1*.

EXTENSION ACTIVITIES

Extension Activities:

- Students can use breadboards to create circuits in parallel and circuits in series with multiple LEDs, resistors, buttons, etc.
- Students can draw circuit diagrams for the circuits they design.

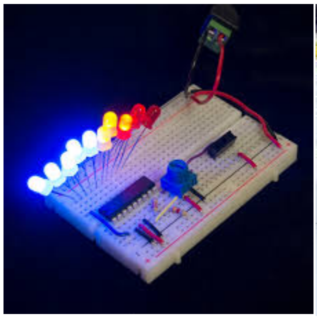
TEACHER BACKGROUND & RESOURCES

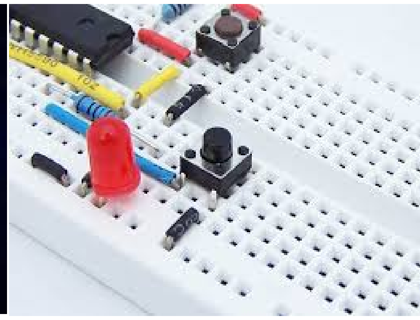
Background Information:

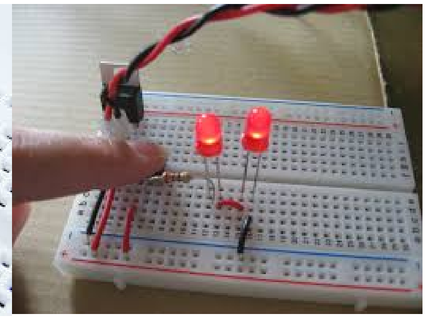
Breadboards allow for prototyping of circuits. It allows for “plug and play” of components without soldering. This is great for students to experiment with and gain understanding of the way circuits need to be designed in order for them to work.

Student Handout 7.1: Introduction to Breadboards

Name:_________________________________ Date:__________________ Period:__________

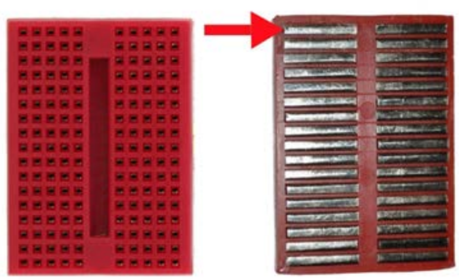




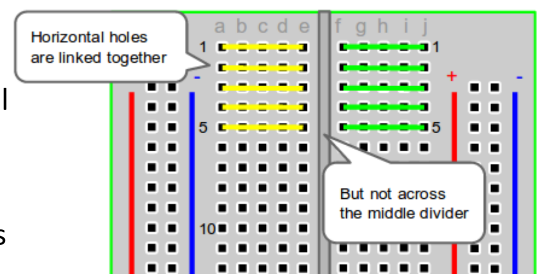


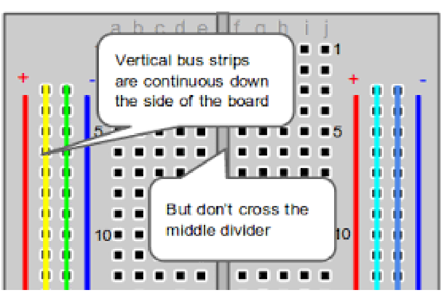
What is a breadboard?

A breadboard is a device that allows you to build basic to intricate circuits. Here is how it works…



If we open up a breadboard and look inside, this is what you will find (left). Metal rows, which means every row is connected. Each column is not!

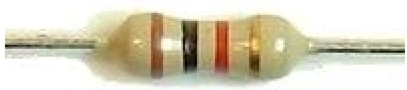




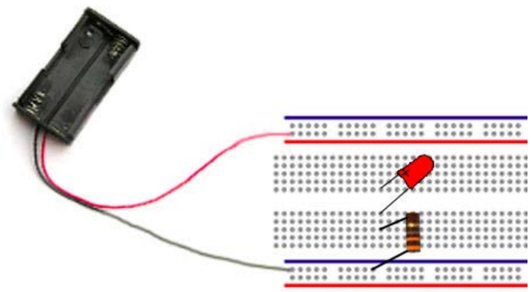
The two columns along the side are for powering the board. You will notice a (+) on one side and a (-) on the other. When connecting a battery pack, the red wire goes to (+) and the black wire goes to (-).

Connect any wire from the power columns to the board to power your circuit. You can watch this detailed how-to video for more explanation. The first six minutes are best! How to Use a Breadboard from Science Buddies TV: https://www.youtube.com/watch?v=6WReFkfrUIk.

You will often need a resistor to make sure your circuit works**.** A resistor is a component that reduces the voltage traveling through the circuit. This is important because different pieces need different amounts of power even when they are in the same circuit! If you don't use a resistor, you can damage components, like burn out an LED, or your circuit simply just won't work! It can be hard to determine what resistor to use for your circuit. Each resistor reduces electricity by a certain amount. The best method is to do some research and find out what is best based on your project.



Do this: On the diagram to the right,



1. Label the battery pack, (+) column, LED, resistor, and (-) column.

2. Is the circuit open or closed? How do you know?

3. What might you add to the circuit to make it work? Draw it in and label.

TASK 1:

Let's try using it! You will need: two AA batteries, a battery holder, 1 LED, 330 ohm (Ω) resistor, and jumper wires

<u>Step 1:</u> Power your bread board by connecting the red wire to the **positive column** and the black wire to the **negative column**.

<u>Step 2:</u> Place your LED in the breadboard. Be sure to place the two leads into different **rows.**

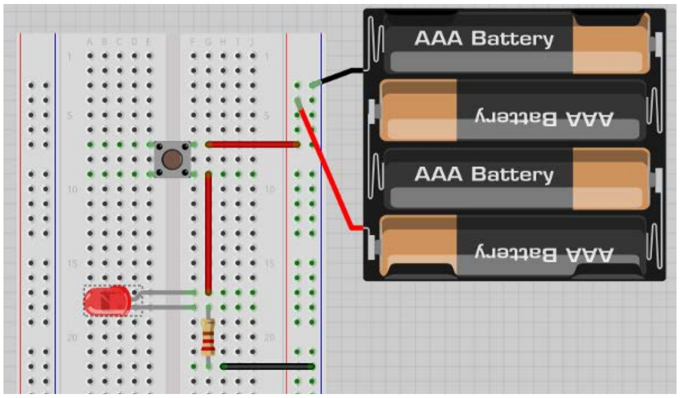
<u>Step 3:</u> Use a red wire to connect the **positive column** to the **positive lead** (the longer one!) of your LED.

<u>Step 4:</u> Connect one end of the resistor on the same row as the **negative lead** (the shorter one!) of your LED, and the other end in a different row (NOT the same row as the positive lead of the LED).

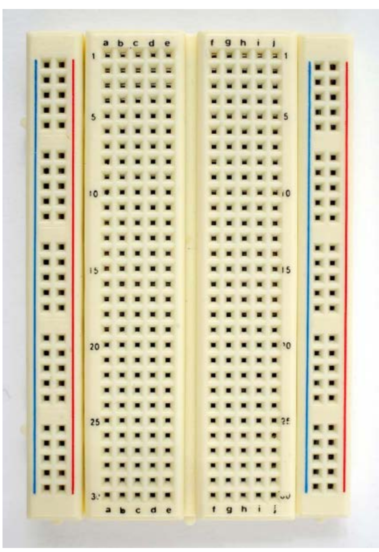
<u>Step 5:</u> Use a black wire to connect the resistor to the **negative column** of your bread board.

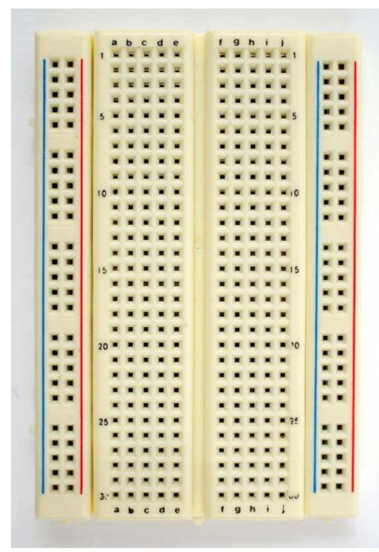
Congratulations! Your light should be on, you have successfully used a breadboard to complete a circuit!

TASK 2: Try building the circuit diagrammed below! Gather your supplies (LED, resistor, push button, battery pack - it's okay to use two batteries only), then build the circuit.



TASK 3: Instead of an LED, can you attach a motor to your circuit so that the button turns the motor on and off (a motor requires more current than an LED)? Or can you connect multiple LEDS to your breadboard (try in parallel and in series)? Draw your breadboard set-up(s) below and label.





TASK 4: Instead of a button, can you connect a potentiometer to your circuit? A potentiometer acts like a dimmer switch, changing the brightness of your light!

Here is a helpful guide: Dimmer Switch Step by Step Guide, available at: http://www.instructables.com/id/How-to-control-the-brightness-of-a-LED/

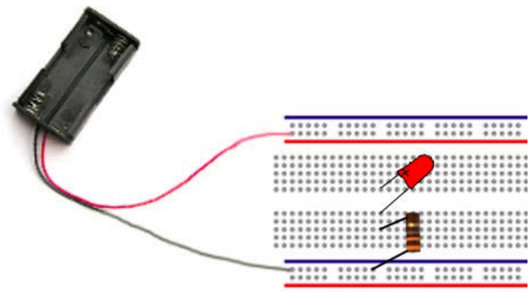
Reflection

1. How does a breadboard work? Explain its layout and how its construction makes it a helpful tool.

2. Explain the role of each of the following components:

Battery	
Wires	
Push Button	
LED	
Resistor	
Potentiometer	

Teacher Resource 7.1: Introduction to Breadboards Answer Key



Do this: On the diagram to the right,

1. label the battery pack, (+) column, LED, resistor, and (-) column.
2. Is the circuit open or closed? How do you know?

Open - no wire to connect LED to battery

3. What might you add to the circuit to make it work? Draw it in and label.

Insert one end of a wire anywhere along column of red wire from battery pack, and insert the other end of the wire in the same row as the positive end of the LED.

Reflection

1. How does a breadboard work? Explain its layout and how its construction makes it a helpful tool.

The breadboard is made of metal clips that are connected by rows. Components can be used to connect different rows. The columns on either side of the breadboard are not connected to the rows and can be used for battery and ground. This allows for testing circuits and different components without having to solder them in a permanent circuit.

2. Explain the role of each of the following components:

Battery	Source of voltage
Wires	Connects components
Push Button	Switch that closes circuit
LED	Light emitting diode - lights up in closed circuit, requires resistor
Resistor	Reduces current flowing through circuit
Potentiometer	Varies the amount of resistance flowing through a circuit

Lesson Eight: Introduction to Arduinos
Center for Sensorimotor Neural Engineering
Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: Three+ 50 minute periods.

Lesson Plan Summary:
In this lesson, students will be introduced to the parts of an Arduino, basic Arduino code, upload standard sketches, and set up the correlating breadboard circuits.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- Arduinos are small processors (microcontrollers) that can be programmed to sense and control objects.

Essential Question:

- How can Arduinos be set up and programmed to control output based on input received?

Learning Objectives:

Students will know…

- Arduinos can be programmed to produce desired outputs like blinking LEDs.
- Arduino codes are open-source; they are available online and can be edited as needed.
- Arduinos can be connected to breadboards to create more complex circuits.

Students will be able to…

- Upload sample codes onto the Arduino device and produce desired outputs.
- Read codes to understand their purpose (ex: make an LED blink on for 1 second, off for 1 second) and modify these codes to change their purpose (ex: blink at a faster rate).
- Create conditional statements (if, then, else) to vary output based on input.
- Build circuits which integrate the breadboard and the Arduino and upload programs which correspond to the components and their desired action on the breadboard.

Vocabulary:

- **Sketch**: a program for the Arduino which performs a certain function; a unit of code that is uploaded to and run on an Arduino board.

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards (NGSS)

NGSS Cross-Cutting Concepts

- Systems and System Models
- Structure and Function
- Cause and Effect

NGSS Science & Engineering Practices

- Developing and Using Models

MATERIALS

Material	Description	Quantity
Student Handout 8.1: Introduction to Arduinos	Students label the parts of the Arduino and parts of simple codes.	1 copy per student
Arduinos	$19.95 from https://www.amazon.com/Arduino-Uno-R3-Microcontroller-A000066/dp/B008GRTSV6	1 per group/pair
Breadboards	Item #64, $5.00 from https://www.adafruit.com/product/64	1 per group/pair
LEDs	Item #12062, $2.95 for 20 pack from https://www.sparkfun.com/products/12062	1+ per group/pair
330 ohm resistors	Item #11507, $0.95 for 20 pack from https://www.sparkfun.com/products/11507	1+ per group/pair
Push buttons	Item #9190, $0.50 from https://www.sparkfun.com/products/9190	1 per group/pair
Potentiometers	Item #9806, $0.95 from https://www.sparkfun.com/products/9806	1 per group/pair
Vibration motors	Item #8449, $4 from https://www.sparkfun.com/products/8449	1 per group/pair
Buzzers	$4.49 from https://www.amazon.com/Electric-Buzzer-DC-Physics-Circuits/dp/B0083LWHDQ	1 per group/pair
Motors	Item #11696, $1.95 from	1 per

	https://www.sparkfun.com/products/11696	group/pair
Tilt sensors	$2 from https://www.sparkfun.com/products/10289	1 per group/pair
Pressure sensors	$7 from https://www.sparkfun.com/products/9375	1 per group/pair
Photoresistors	$1.50 from https://www.sparkfun.com/products/9088	1 per group/pair
Temperature sensor	$1.50 from https://www.sparkfun.com/products/10988	1 per group/pair
Flex sensor	$8 from https://www.sparkfun.com/products/10264	1 per group/pair (or 2-3 per class)
Proximity sensor	$13.95 from https://www.sparkfun.com/products/12728	1 per group/pair (or 2-3 per class)

TEACHER PREPARATION

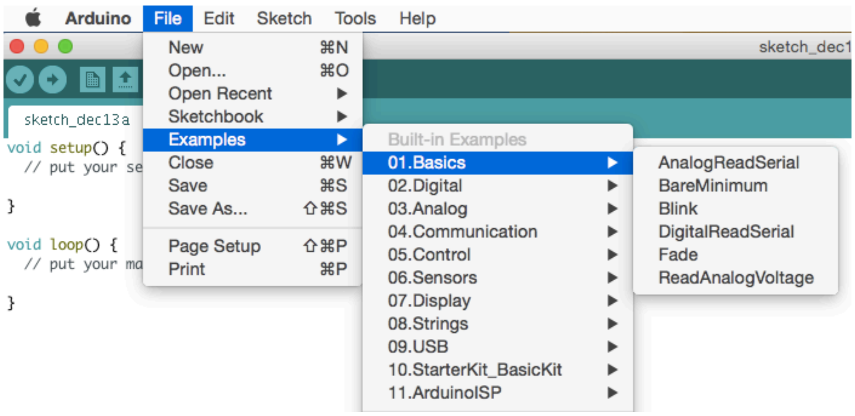
1. Copy handouts as listed in the Materials section above.
2. If you are not familiar with using Arduinos, try them out yourself. Look up tutorials on YouTube and try sample sketches. See the resources section for some online tutorials.

PROCEDURE

Part 1 (60 min)

1. Examine the Arduino and label its parts (page 1 of *Student Handout 8.1*).

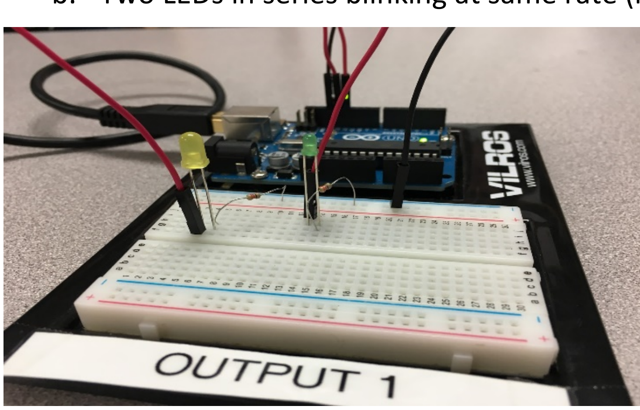
2. Examine the basic Arduino code "Blink" and identify parts of the code (page 1 of *Student Handout 8.1).* Main parts to point out:
    a. Comments following "//" describe what the code does
    b. Code is written between { and }
    c. Void Setup command assigns pins
    d. Void Loop command allows action(s) to repeat
    e. Parts that can be modified easily: output pin, time interval

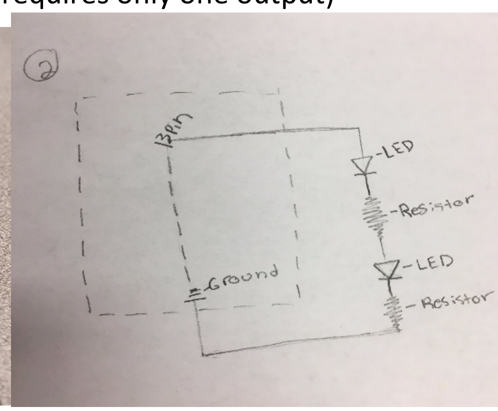


3. Upload Blink code and build associated circuit.

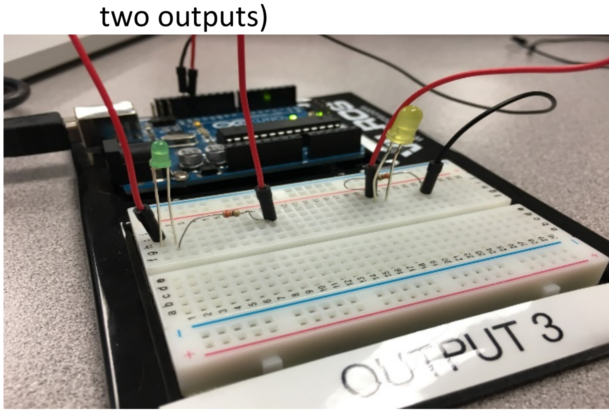
Part 2 (70 min)

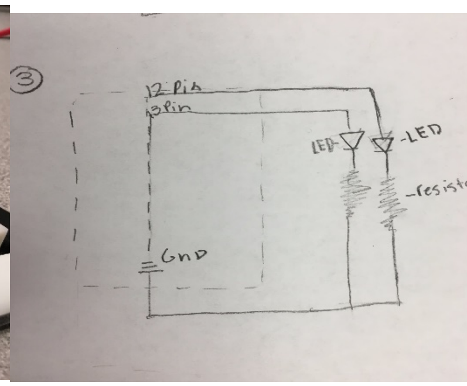
4. Modify the Blink code to do the following:
   a. LED blinks on/off for 0.5 sec, then on/off for 1 sec, then repeat
   b. Two LEDs in series blinking at same rate (requires only one output)





   c. Two LEDs in parallel blinking alternately (one is on while other is off - requires two outputs)





   d. Replace LED with vibration motor (will not work with resistor)

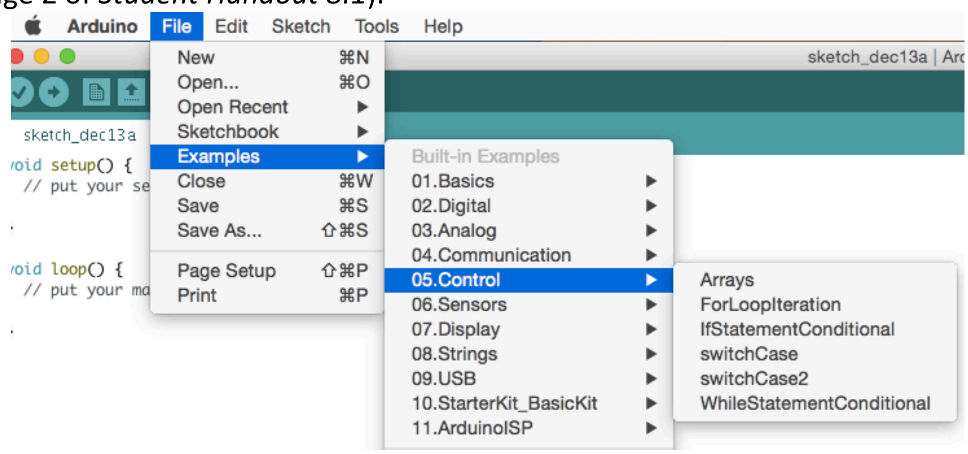
5. For each variation, do the following:
    a. Edit the code
    b. Edit the comments
    c. Save the files (to be uploaded and turned in) following format provided (example: "PP Blink Half Full Sec" to include student initials and description of code)
    d. Draw a circuit diagram

Part 3 (40 min)

6. Review control of output with students presenting code, breadboard, and circuit diagrams for the modifications they worked on previously:
    a. LED blinks on/off for 0.5 sec, then on/off for 1 sec, then repeat
    b. Two LEDs in series blinking at same rate (requires only one output)
    c. Two LEDs in parallel blinking alternately (one is one while other is off - requires two outputs)
    d. Replace LED with vibration motor (will not work with resistor)

Part 4 (30 min)

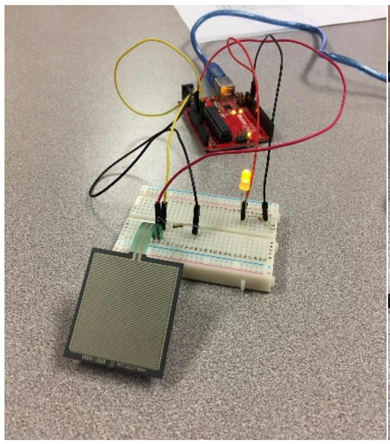
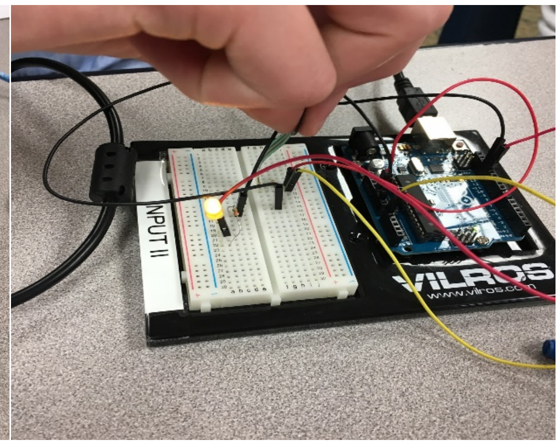
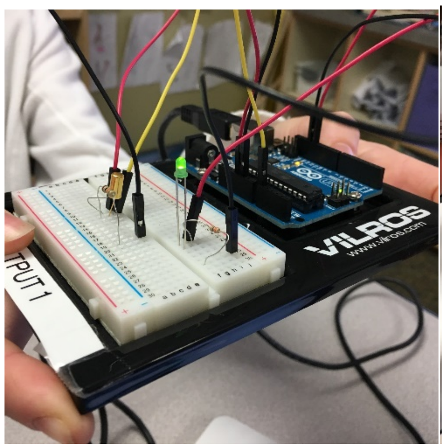
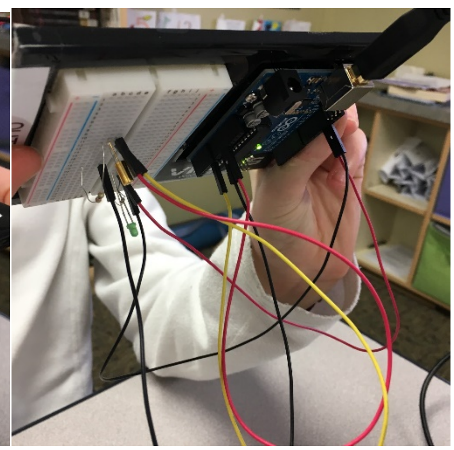
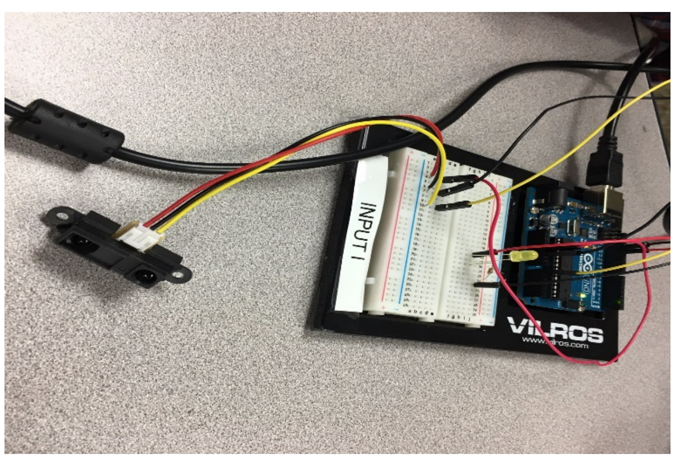
7. Examine the basic Arduino code "IfStatementConditional" and identify parts of the code (page 2 of *Student Handout 8.1*).



    a. Comments following "//" describe what the code does
    b. Code is written between { and }
    c. Constants: output, analog input, threshold
    d. Void Setup command assigns pins
    e. If, then, else command
    f. Parts that can be modified easily: threshold value

Part 5 (60 min)

8. Modify the "IfStatementConditional" code and/or breadboard to do the following:
    a. Change the threshold value
    b. Change the input: force sensor, tilt sensor, proximity sensor (use 10 ohm resistor with each sensor)
    c. Control multiple LEDs

Force Sensor	 
Tilt Sensor	 
Proximity Sensor	

9. For each variation, do the following:
    a. Edit the code
    b. Edit the comments
    c. Save the files (to be uploaded and turned in) following format provided (example: "PP Blink Half Full Sec" to include student initials and description of code)

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- As students work with their Arduinos, ask them to explain to you what each component or each part of the code does.
- Check students' comments on the code they modify. This helps to see whether they understand the purpose of each line of code.

Student Metacognition:

- Ask students to think about where they can seek answers/help without asking the teacher.
- As students troubleshoot their circuits and code, they can reflect on the strategies they used to solve their problems. They can write a reflection about this in their lab notebooks at the end of each day.

EXTENSION ACTIVITIES

Extension Activities:

- Students can use more components or try sketches beyond the ones that are outlined in this lesson.
- Students who are more familiar with the Arduino can create tutorials for others.
- Students can try different circuits, such as wiring an RGB LED and using the Arduino code to control its color. The Vilros Ultimate Starter Kit Guide or the SparkFun Inventor's Kit Guide provides some helpful tutorials.
    - https://cdn.sparkfun.com/datasheets/Kits/SFE03-0012-SIK.Guide-300dpi-01.pdf

TEACHER BACKGROUND & RESOURCES

Background Information:

General Arduino troubleshooting note: if board and port are set correctly but code won't upload to the board, go to Tools > Board > Board Manager to check for updates on board packages. Update and restart the Arduino IDE.

Teacher Resource 8.1 - Sample sketches for varying outputs

Resources:

- Arduino Board Anatomy:
  - https://www.arduino.cc/en/Guide/BoardAnatomy
  - http://arduinoarts.com/wp-content/uploads/2011/08/Arduino-callouts1.jpg
- Arduino Tutorials:
  - https://www.arduino.cc/en/Tutorial/HomePage
  - http://www.ladyada.net/learn/arduino/
  - http://forefront.io/a/beginners-guide-to-arduino/
- Videos by Jeremy Blum:
  - https://www.youtube.com/watch?v=fCxzA9_kg6s

Arduino Codes:

- *Teacher Resource 8.1: Sample Sketches for Varying Outputs*
- Force Sensor Resistor Arduino Code:
  - https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr
- Analog Input Varying Length of LED Blink:
  - https://www.arduino.cc/en/Tutorial/AnalogInput
- Analog Input/Output Dimming LED:
  - https://www.arduino.cc/en/Tutorial/AnalogInOutSerial
- Boolean Operators (and, or, not):
  - https://www.arduino.cc/en/Reference/Boolean
- Flex Sensor Tutorial (SparkFun):
  - https://learn.sparkfun.com/tutorials/flex-sensor-hookup-guide

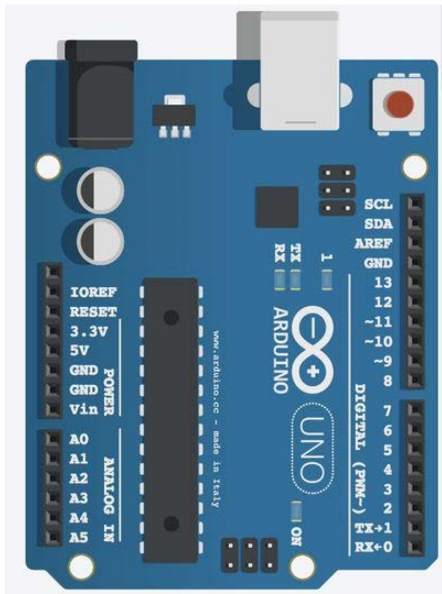
Citation:

Photographs by Phelana Pang.

Student Handout 8.1: Introduction to Arduinos

Name:_________________________________ Date:__________________ Period:__________

Label the parts in the diagram below.



https://cdn.instructables.com/F6R/IPAP/HQF9H5IO/F6RIPAPHQF9H5IO.MEDIUM.jpg

Label the parts in the basic Arduino sketch below.

```
/*
  Blink
  Turns on an LED on for one second, then off for one second, repeatedly.

  Most Arduinos have an on-board LED you can control. On the Uno and
  Leonardo, it is attached to digital pin 13. If you're unsure what
  pin the on-board LED is connected to on your Arduino model, check
  the documentation at http://www.arduino.cc

  This example code is in the public domain.

  modified 8 May 2014
  by Scott Fitzgerald
 */


// the setup function runs once when you press reset or power the board
void setup() {
  // initialize digital pin 13 as an output.
  pinMode(13, OUTPUT);
}

// the loop function runs over and over again forever
void loop() {
  digitalWrite(13, HIGH);   // turn the LED on (HIGH is the voltage level)
  delay(1000);              // wait for a second
  digitalWrite(13, LOW);    // turn the LED off by making the voltage LOW
  delay(1000);              // wait for a second
}
```

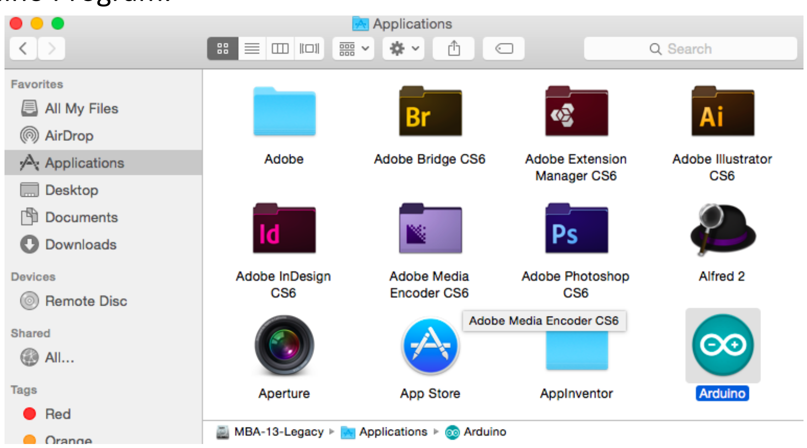
What can you conclude about what the following code does?

```
/*
 Conditionals - If statement

 This example demonstrates the use of if() statements.
 It reads the state of a potentiometer (an analog input) and turns on an LED
 only if the potentiometer goes above a certain threshold level.

 The circuit:
 * potentiometer connected to analog pin 0.
 Center pin of the potentiometer goes to the analog pin.
 side pins of the potentiometer go to +5V and ground
 * LED connected from digital pin 13 to ground

 * Note: On most Arduino boards, there is already an LED on the board
 connected to pin 13, so you don't need any extra components for this example.

 created 17 Jan 2009
 modified 9 Apr 2012
 by Tom Igoe

This example code is in the public domain.
http://www.arduino.cc/en/Tutorial/IfStatement

 */

// These constants won't change:
const int analogPin = A0;    // pin that the sensor is attached to
const int ledPin = 13;       // pin that the LED is attached to
const int threshold = 400;   // an arbitrary threshold level that's in the range of the analog input

void setup() {
  // initialize the LED pin as an output:
```

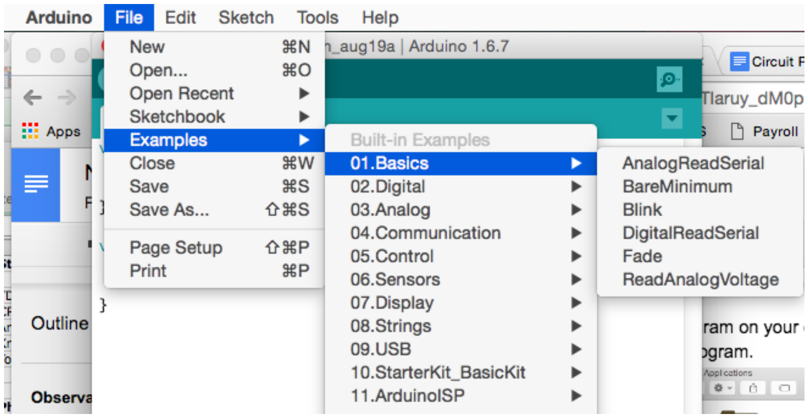
```
  pinMode(ledPin, OUTPUT);

}

void loop() {
  // read the value of the potentiometer:
  int analogValue = analogRead(analogPin);

  // if the analog value is high enough, turn on the LED:
  if (analogValue > threshold) {
    digitalWrite(ledPin, HIGH);
  } else {
    digitalWrite(ledPin, LOW);
  }

}
```

How to use the Arduino program on your computer

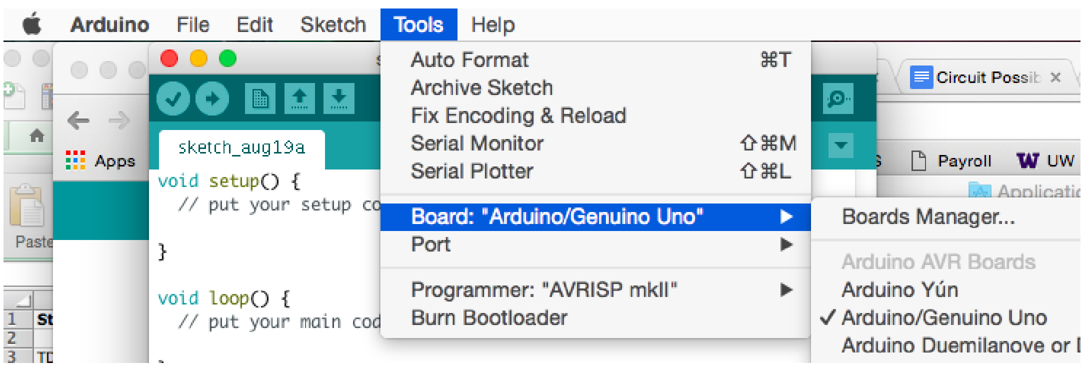
1. Open the Arduino Program.



2. Open up an existing sketch.

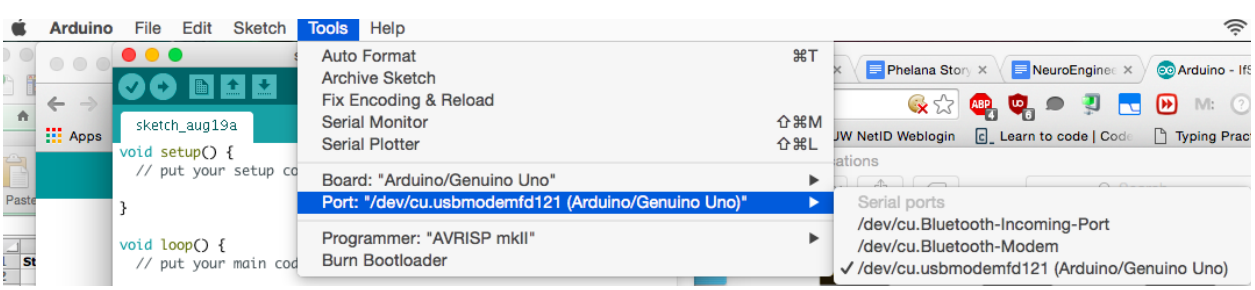


3. Select the correct Arduino Device. We are using the Arduino Uno.



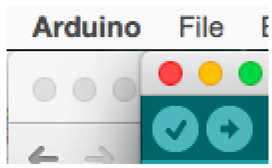
4. Plug in the USB cord to the Arduino and to your computer.

5. Make sure the correct port is connected.



6. Verify your code by clicking on the check button. A message will occur at the bottom of the window to show whether there are any errors in the code.

7. If your code is good to go, you can upload your code by clicking on the right arrow button.



8. Save your code by renaming it if you modified it.

Teacher Resource 1.1: Sample Arduino Sketches

The following can be used to change the LED output based on an input which acts like a switch (on or off based on whether the input is below or above a certain threshold).

```
/*
 Conditionals - If statement
 This example demonstrates the use of if() statements.
 It reads the state of a potentiometer (an analog input) and turns on an LED
 only if the potentiometer goes above a certain threshold level

 The circuit:
 * potentiometer connected to analog pin 0.
 Center pin of the potentiometer goes to the analog pin.
 side pins of the potentiometer go to +5V and ground
 * LED connected from digital pin 13 to ground

 created 17 Jan 2009
 by Tom Igoe
 modified 12 Aug 2016
 by Phelana Pang, with the help of Lefteris Kampianakis
 */

// These constants won't change:
const int analogPin = A0;    // pin that the sensor is attached to
const int ledPin = 13;       // pin that the green LED is attached to
const int redPin = 12;       // pin that the red LED is attached to
const int threshold = 500;   // threshold value

//this function will run first
void setup() {
  // initialize the LED pin as an output:
  pinMode(ledPin, OUTPUT);
  pinMode(redPin, OUTPUT);
}

//then this function will run all the time looping
void loop() {
  // read the value of the potentiometer:
  int analogValue = analogRead(analogPin);

  // if the analog value is high enough, turn on the LED:
  if (analogValue > threshold) {
    digitalWrite(ledPin, HIGH);
  } else {
    digitalWrite(ledPin, LOW);
  }
  if (analogValue < threshold) {
    digitalWrite(redPin, HIGH);
  } else {
```

```
    digitalWrite(redPin, LOW);
  }
}
```

The following has 3 LEDs as output, and the output depends on whether the input is detected in a low, medium, or high range:

```
/*
 Conditionals - If statement
 This example demonstrates the use of if() statements.
 It reads the state of a potentiometer (an analog input) and turns on a certain color LED
 depending on the range in which the potentiometer reads.
The potentiometer can be substituted with different input sensors (pressure sensor, proximity sensor,
photoresistor).

 The circuit:
 * potentiometer connected to analog pin 0.
 Center pin of the potentiometer goes to the analog pin.
 side pins of the potentiometer go to +5V and ground
 * LED connected from digital pin 13 to ground

 created 17 Jan 2009
 by Tom Igoe
 modified 12 Aug 2016
 by Phelana Pang, with the help of Lefteris Kampianakis
 */


// These constants won't change:
const int analogPin = A0;    // pin that the pressure sensor is attached to
const int redPin = 13;       // pin that the red LED is attached to
const int yedPin = 12;       // pin that the yellow LED is attached to
const int gedPin = 11;       // pin that the green LED is attached to
const int threshold1 = 200;   // low threshold level that's in the range of the analog input
const int threshold2 = 400;   // med threshold level that's in the range of the analog input

//this function will run first
void setup() {
  // initialize the LED pin as an output:
  pinMode(redPin, OUTPUT);
  pinMode(yedPin, OUTPUT);
  pinMode(gedPin, OUTPUT);
}
```

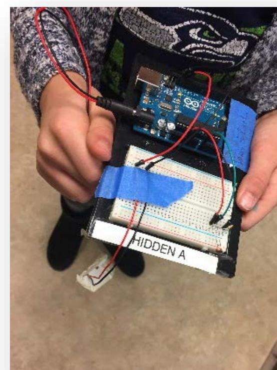
```
//then this function will run all the time looping
void loop() {
  // read the value of the pressure sensor:
  int analogValue = analogRead(analogPin);

  // depending on how hard pressure sensor is pressed, green, yellow, or red LED will turn on:
  if (analogValue < threshold1) {
    digitalWrite(redPin, HIGH); // if pressure is low, red LED is on
    digitalWrite(yedPin, LOW); // if pressure is low, yellow LED is off
    digitalWrite(gedPin, LOW); // if pressure is low, green LED is off
  }
  else if (analogValue >= threshold1 && analogValue <= threshold2) {
    digitalWrite(redPin, LOW); // if pressure is medium, red LED is off
    digitalWrite(yedPin, HIGH); // if pressure is medium, yellow LED is on
    digitalWrite(gedPin, LOW); // if pressure is medium, green LED is off

  } else if (analogValue > threshold2) {
    digitalWrite(redPin, LOW); // if pressure is high, red LED is off
    digitalWrite(yedPin, LOW); // if pressure is high, yellow LED is off
    digitalWrite(gedPin, HIGH); // if pressure is high, green LED is on
  }

  }
```

Lesson Nine: Designing a Sensory Substitution Device
Center for Sensorimotor Neural Engineering
Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: Three+ 50 minute periods.

Lesson Plan Summary:
In this lesson, students will discuss engineering practices, identify criteria and constraints in a project, recognize that the steps involved in designing a solution is not necessarily linear and that optimizing a solution requires rounds of testing, feedback, and modification. Students will design and program their sensory substitution devices.



STUDENT UNDERSTANDINGS
Big Idea & Enduring Understanding:

- Engineering is a non-linear, iterative process which involves coming up with a design to solve a problem, considering the criteria and constraints, asking questions, testing the design, modifying the design, and seeking feedback to help with optimizing the design.

Essential Question:

- How can a model of a sensory substitution device be designed and tested to meet the needs of the end-user?

Learning Objectives:
Students will know…

- Criteria and constraints for a design project must be identified, with special attention to the person (end-user)'s needs.
- Designs can be improved through iterative testing and modifications, and through the incorporation of feedback from peers.

Students will be able to…

- List criteria and constraints for their design project.
- Document the engineering process in their design notebook.
- Test and modify their design to create a functional model.
- Seek and incorporate feedback into their design.

Vocabulary:

- **Criteria**: requirements of the design (ex: serving a certain function, size).
- **Constraint**: limitations for the design (ex: budget, materials, time).
- **End-User**: the person the product is designed for (patient, doctor).

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards (NGSS) Disciplinary Core Ideas (DCIs):

NGSS Disciplinary Core Ideas

- **MS-ETS1.A Defining and Delimiting Engineering Problems:** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specifications of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.
- **MS-ETS1.B Developing Possible Solutions:** There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of the problem.
- **MS-ETS1.C Optimizing the Design Solution:** Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.

NGSS Cross-Cutting Concepts

- **Systems and System Models**
- **Cause and Effect**
- **Influence of SET on Society and Natural World**

NGSS Science & Engineering Practices

- **SEP:** Asking Questions and Defining Problems
- **SEP:** Constructing Explanations and Designing Solutions
- **SEP:** Developing and Using Models
- **SEP:** Engaging in Argument from Evidence
- **NoS:** Science is a Human Endeavor
- **NoS:** Science Addresses Questions about the Natural and Material World

MATERIALS

Material	Description	Quantity
Student Handout 9.1: Engineering Design Sketchpad	Notebook used for students to document their design process	1 copy per student
Student Handout 9.2: Making it Real (optional)	An optional extension activity	1 copy per student
Teacher Resource 9.1: Engineering Design Process Cards	To be laminated and cut as a puzzle to discuss design process	1 set per group
All Arduino, breadboard, and circuit component materials from *Lesson 8*		1 of each per group/pair
Teacher Resource 8.1: Sample Arduino Sketches from *Lesson 8*	If needed, make available for students electronically so they can cut and paste the code, and then modify it	

TEACHER PREPARATION

1. Make copies of *Student Handout 9.1: Engineering Design* Sketchpad for each student.

2. Copy, laminate (optional), and cut the *Engineering Design Process Card*s to make one set per group.

3. If needed, make *Teacher Resource 8.1: Sample Arduino Sketches* available for students electronically (can be posted on class website or shared through email or Google Doc) so that students can cut, paste, and modify the code.

4. Assign students to design teams of 3 or 4 students per team. You can assign roles which rotate between team members each day to facilitate engagement. Roles might include:
    - Electrical engineer (in charge of circuit and components)
    - Computer scientist (in charge of Arduino program)
    - End-user (ensures design meets criteria)
    - Project manager (supervises process and manages time and materials).

PROCEDURE

Engage: Engineering Design Process (20 minutes)

1. Pass out *Student Handout 9.1: Engineering Design Sketchpad.*

2. Discuss engineering practices through a group brainstorm using some of the following questions to elicit students' ideas. Have students record their ideas on the first page of the Sketchpad.
   - What does an engineer do?
   - Who does the engineer serve (who are stakeholders)?
   - What aspects of design have to be considered?

3. Pass out *Engineering Design Process Cards* to each group, and have students try to put them in order. Take away message: There is not necessarily a set order…engineering design is an iterative, interconnected process!

4. You can also show the video The Engineering Design Process: A Taco Party from PBS (3:37 minutes). The video doesn't emphasize that steps can take place "out of order" so you may have to discuss that with your class.
   - https://kcts9.pbslearningmedia.org/resource/tacoparty/tacoparty/

5. Students can write down the steps of the design process and draw a web of their interconnectedness in their Sketchpad.

Explore, Explain, & Elaborate: Design, Prototype, Test, and Share (120+ minutes)

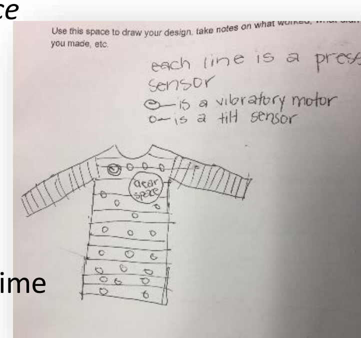
6. Allow students to look over the layout of the Sketchpad and tell students this is where they will document their thinking process and design work.

7. Introduce students to the materials they have available to them to design their device: inputs (sensors: light, temperature, pressure, tilt, distance, flex, push button) and outputs (motors, LEDs, buzzers). You will have a lot of small components so it is important to be organized.

8. Students will work in their teams to design their sensory substitution device. Each student is accountable for documenting their teamwork in the design Sketchpad. Work through the Sketchpad at the pace that is appropriate for your students. Remind students to consider the end-user:
   - Would an LED output help someone who is visually impaired? Why or why not?

- Is there a reason why two inputs would be helpful? For example, when would it be helpful to have two pressure sensors instead of one? Or when might it be helpful to have a pressure sensor and a temperature sensor?
- Is it helpful to have a switch? Why or why not?

9. Brainstorm pathways… “If… then.” See *Teacher Resource 9.2* for examples of circuit possibilities.

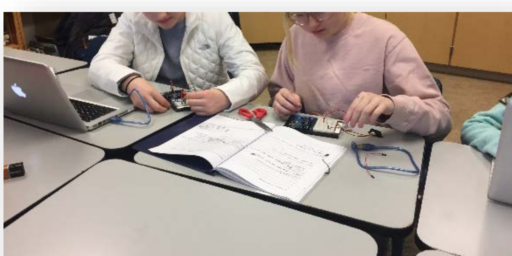


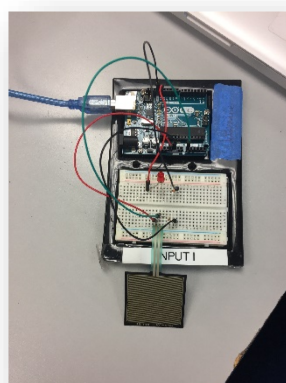
10. Be sure that students draw a diagram of their chosen circuit in their Sketchpads. Stress the importance of documenting their design process.

11. Once students have completed their design work, it is time to build their prototypes. They can grab their Arduinos, breadboards, and other components needed to construct their input and output circuits

12. Allow ample time for students to program and construct their circuits based on their designs. As they work, encourage students to independently solve problems and to use appropriate resources—including peers with expertise—to seek help when needed, rather than always coming to the teacher for help.

13. It is important to allow plenty of time for students to test, modify, and evaluate their model sensory substitution devices. The testing phase of the engineering design process is imperative, but it often gets skipped in classroom instruction due to time constraints.





14. Ask each student group to show their device to another pair/group of students so that they can collect peer feedback and modify their designs. Encourage students to document feedback and modifications in the design Sketchpad.

15. As students work through the design process, they may become frustrated. Here are some resources to help you set the tone for supporting your students.
    - Managing Student Frustration During Engineering Design Projects
        - http://stemteachingtools.org/brief/36
    - How to Focus Students' Engineering Design Projects on Science Learning
        - http://stemteachingtools.org/brief/45

16. In *Lesson 10*, students will prepare a poster or slideshow as a way to present their design to others.

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- Each teacher will need to decide if they will focus assessment on the design process, documentation of the design process, and/or the designed product. See the Scoring Guide section below. Addition criteria may be added depending on each teacher's preferences.
- The design Sketchpad should reflect students' growing understanding and problem-solving skills. The teacher may develop a scoring key to assign points for the thoroughness of documentation within the Sketchpad.

Student Metacognition:

- Students can continuously reflect as they troubleshoot their design. Guide students to asking themselves questions such as: What are you trying to make happen? What components are needed? What needs to happen first? Would drawing a circuit diagram help with your understanding?
- Students can reflect on the design process on the last page of their Sketchpad.

Scoring Guide:

- A rubric can be created to see if students can (1) independently solve problems, (2) use appropriate resources to seek help when needed, (3) document changes made to the model and the resulting output, and (4) addressed the needs of the end-user and criteria of the design challenge. See sample below:

Criteria	4	3	2	1
Statement of problem and consideration of end-user	Design challenge is clear with extensive list of criteria and constraints that are driven by the needs and wants of the end-user	Design challenge is stated, with list of criteria and constraints that are driven by the needs of the end-user	Design challenge is somewhat unclear, many criteria and constraints are missing, or the criteria do not completely match the needs of the end-user	Design challenge is not stated or is incorrect, and no criteria or constraints are listed
Documentation of modifications and resulting output	All modifications are noted with details of effects of changes made	Most modifications included with explanation of result of modification	Some modifications included with inconsistent explanation of results	No modifications indicated, and no explanations are provided
Critical thinking and problem solving	Consistently attempts to solve problems independently or with group and uses appropriate resources to seek help	Often attempts to solve problems independently or with group and uses resources to seek help	Solves problems with teacher guidance or relies often on classmates, uses resources with guidance	Seeks help from teacher immediately before troubleshooting on own, does not use resources

EXTENSION ACTIVITIES

Extension Activities:

- Students who have a working prototype on their first attempt should be challenged to make a more advanced model of their device. They can add more components, program more intricate parameters/instructions, or identify and document additional applications for their device.
- Students can further explore other relevant topics in designing their sensory substitution device. Use the optional *Student Handout 9.2: Making it Real* to guide their research.

TEACHER BACKGROUND & RESOURCES

Resources:

- To support students in developing their Arduino sketches and designing their circuits, refer to *Teacher Resource 8.1: Sample Sketches for Varying Outputs* and *Teacher Resource 9.2: Circuit Possibilities.* These other Arduino code resources are also helpful:
  - Force Sensor Resistor Arduino Code:
    - https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr
  - Analog Input Varying Length of LED Blink:
    - https://www.arduino.cc/en/Tutorial/AnalogInput
  - Analog Input/Output Dimming LED:
    - https://www.arduino.cc/en/Tutorial/AnalogInOutSerial
  - Boolean Operators (and, or, not):
    - https://www.arduino.cc/en/Reference/Boolean
  - Flex Sensor Tutorial (Sparkfun):
    - https://learn.sparkfun.com/tutorials/flex-sensor-hookup-guide

- Teaching engineering design in the science classroom can be daunting if this is your first time. The resources from STEM Teaching Tools offer helpful tips on making engineering design meaningful, authentic, and equitable in the science classroom.
  - Failing Forward: Managing Student Frustration During Engineering Design Projects
    - http://stemteachingtools.org/brief/36
  - How to Focus Students' Engineering Design Projects on Science Learning
    - http://stemteachingtools.org/brief/45
  - Learning STEM through Design: Students Benefit from Expanding What Counts as "Engineering"
    - http://stemteachingtools.org/brief/7
  - How Can Students' Everyday Experiences Support Science Learning through Engineering Design?
    - http://stemteachingtools.org/brief/39

Citations:

Photographs by Kristen Bergsman.

Student Handout 9.1: Engineering Design Sketchpad

Name:_________________________________ Date:__________________ Period:__________

Brainstorm

What is engineering? What do engineers do?

Diagram of Engineering Practices

Designing a Sensory Substitution Device - Making a Plan

Big Ideas - Dreams/Things I wish could exist

____

____

____

____

Flip your big ideas into possible design challenges.
How might we…..

____

____

____

____

What are the end goals? What will I work to produce?

- ____
- ____
- ____
- ____

How will I know if it's successful? What measures and indicators will inform me of success of design?

- ____

☐ ____

☐ ____

☐ ____

What constraints will I need to manage?

☐ ____

☐ ____

☐ ____

☐ ____

Define your end-users. Who will you be building this design for?
Who will be your primary users?

____

Who might be other end-users?

____

____

____

What do you already know/understand in starting your design?

☐ ______________________________________ ☐ ______________________________________

☐ ______________________________________ ☐ ______________________________________

☐ ____

□ ____

What else do you need to know/understand to start your design? How might you acquire this knowledge?

□ ______________________________________ □ _____________________________________

□ ______________________________________ □ _____________________________________

□ ____

Design Sketchpad

Write out as many "If… then..." statements for your sensory substitution device as possible.

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Sketch out your basic ideas for what how you might connect different parts of the circuit for your sensory substitution device.

Basic Components:

- ❑ Sensory/Input
- ❑ Motor/Output
- ❑ Power supply

Which types of Arduino sketches might you use to copy and paste portions of the code?

Initial Design

Use this space to draw your design, take notes on what worked, what didn't work, what changes you made, etc.

Sketchpad 2

Expand your “If… then...” statements for your sensory substitution device to include the use of logic gates (AND, OR, NOT). For example, you can write statements such as “If not…. and… then….” or “If…. or….. then….” or “If…. then…. and ….”

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Sketch out more ideas for what how you might connect different parts of the circuit for your sensory substitution device to include at least one logic gate.

Basic Components:

- ❏ Sensory/Input
- ❏ Motor/Output
- ❏ Power supply

Additional Component(s):

- ❏ Switch
- ❏ Additional sensor
- ❏ Additional output
- ❏ AND gate
- ❏ OR gate
- ❏ NOT gate

Which types of sketches might you use to copy and paste portions of the code?

Modified Design

Use this space to draw your design, take notes on what worked, what didn’t work, what changes you made, etc.

Review your design plan. What else do you need to consider and incorporate?

Prototyping & Testing: Design Notebook

Use this page to document the things you tried, what worked, what didn't work, what you modified, and the feedback you received.

Design Reflection

What are you most proud of in designing your sensory substitution device?

What was one of the biggest challenges you encountered? Why was it challenging? How did you feel initially?

How did you overcome your challenges? What resources did you seek to help you through your challenges?

How did you and your teammate(s) work together? What interactions were you proud of? What interactions would you like to improve?

What tips would you give to a student who will be learning the same things you did to design your sensory substitution device?

Student Handout 9.2: Making it Real

Name:________________________________ Date:__________________ Period:__________

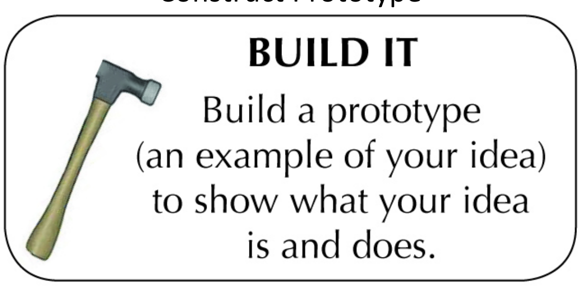
Pick one or two of the following areas to explore further for your sensory substitution device.

- What are the requirements of testing this device on users before making it available for public use?
- What materials should be used to build/encase the device?
- What aesthetic considerations should you take into account so that someone wants to use it?
- How can you scale down/up the device so it is more convenient for the user?
- What is the budget for making a complete prototype?
- How fast can a single device be produced?
- What safety concerns might be involved in using this device?
- Do any devices like this already exist? If so, how is yours alike or different?
- If you were to patent your design, what steps do you need to take?
- Who would you market the device to? Who would be selling this device?
- What's the history of the development of devices like yours?
- If you needed a battery to power your device, what type of battery is best? How long would your battery last before you needed to change it?
- Anything else you can think of?

Find a creative way to present your sensory substitution device, along with your one or two "Making It Real" ideas.

Teacher Resource 9 .1: Engineering Design Process Cards

Print and cut the following cards (one set per pair/group). Have students come up with an order for these cards. Discuss afterwards about the non-linearity of the engineering design process. Steps in engineering design process acquired from [Tch Teaching Channel].

Identify Need or Problem 	Research Criteria/Constraints 
Brainstorm Possible Solutions 	Select Best Solution 
Construct Prototype 	Test 
Present Results 	 Redesign

Teacher Resource 9.2: Circuit Possibilities

Light Sensor

If it is bright, then the resistance in the LDR (light dependent resistor) will decrease, which will decrease the total circuit resistance, which increases the current, which will turn the motor/bell/buzzer on.

If it is dark, then the resistance in the LDR will increase, which will increase the total circuit resistance, which decreases the current, which will prevent the motor/bell/buzzer from being turned on.

With NOT gate: If it is dark, then the resistance in the LDR will increase, which will decrease the total circuit resistance. The NOT gate inverts the low input to a high output, which increases the current, which will turn the motor/bell/buzzer on.

With AND gate: If it is bright AND the switch is closed, then the current will flow into both inputs of the AND gate, and current will flow through the output as well, turning on the motor/bell/buzzer.

Examples: If you want to turn "off" the ability to sense light like closing your eyes.

With OR gate: If it is bright through one LDR OR if it is bright through the other LDR, then one of these inputs will have current, the current will flow into the OR gate, and current will flow through the output, turning on the motor/bell/buzzer.

Pressure Sensor

If pressure is high, then the resistance in the sensor will decrease, which will decrease the total circuit resistance, which increases the current, which will turn on the motor/bell/buzzer/light.

The harder you press, the more current.
Example: For prosthetic arm, if pushed too hard, turn on light or move arm away. If push hard and it's hot, then move arm away.
If you pushed just one pressure sensor, only one LED comes on. If both pushed, then different motor or buzzing sound comes on.

With NOT gate: If pressure is low, then resistance will be high, then NOT gate will invert and produce high output current, and motor will run.
(helps move closer to desired object or location until pressure is sensed)

Tilt Sensor

Tilt sensor with low power on prothestic leg will relay information to muscle that moves the leg. Give voltage to leg (with switch).

If tilt sensor is tilted, then no current is flowing into NOT gate, which produces output current to relay. If there's current through relay AND switch on muscle is closed, then current will be delivered to the muscle to activate movement.

For Arduino

If light sensor 1 receives light over certain threshold, then vibration motor 1 turns on.
If light sensor 2 receives light over certain threshold, then vibration motor 2 turns on.

If pressure sensor 1 AND pressure sensor 2 are pushed passed certain threshold, then LED turn on.

If pressure sensor is over certain threshold, then LED 1 turns on.
If pressure sensor is over even higher threshold, then LED 1 and 2 turn on.

Lesson Ten: Presenting and Evaluating the Design
Center for Sensorimotor Neural Engineering
Lesson Plan Author: Phelana Pang

LESSON OVERVIEW

Activity Time: Four 50 minute periods.

Lesson Plan Summary:
In this lesson, students will create a poster to showcase their sensory substitution device design. Students will use Pugh Charts to evaluate the models created by different teams.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- Scientists and engineers communicate their research publicly in order to share their new discoveries and understandings, and to receive constructive criticism and questions about their work. In this way, professionals can build off the work of each other and effectively collaborate on larger projects.

Essential Question:

- How do scientists and engineers share their discoveries and designs with the wider scientific and engineering communities?

Learning Objectives:
Students will know…

- The purpose and use of a Pugh Chart in assessing an engineering design and prototype.
- How a scientific poster session runs and why they are important.

Students will be able to…

- Speak knowledgeably to different groups of people curious about their engineering designs.
- Evaluate a variety of sensory substitution models based on relevant and (weighted) criteria and constraints .

Vocabulary:

- Pugh Chart

Standards Alignment: This lesson addresses the following middle school Next Generation Science Standards Disciplinary Core Ideas (DCIs):

NGSS Middle School Disciplinary Core Ideas

- **MS-ETS1.A Defining and Delimiting Engineering Problems:** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specifications of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.
- **MS-ETS1.B Developing Possible Solutions:** There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of the problem.
- **MS-ETS1.C Optimizing the Design Solution:** Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.

NGSS Cross-Cutting Concepts

- **Systems and System Models**
- **Structure and Function**
- **Influence of SET on Society and Natural World**

NGSS Science & Engineering Practices

- **SEP:** Asking Questions and Defining Problems
- **SEP:** Constructing Explanations and Designing Solutions
- **SEP:** Developing and Using Models
- **SEP:** Engaging in Argument from Evidence
- **SEP:** Obtaining, Evaluating, and Communicating Information
- **NoS:** Science is a Human Endeavor
- **NoS:** Science Addresses Questions about the Natural and Material World

MATERIALS

Material	Description	Quantity
Posterboards or butcher paper		1 per group
Markers		1 set per group
Rulers		2 per group
Optional: Glue or Tape	To paste on typed text for the poster	1 per group
Student Handout 10.1: Presenting Your Sensory Substitution Device—Presentation Guidelines		1 per student
Student Handout 10.2: Pugh Charts		1 per student
Student Handout 10.3: Presentation Simplified—Your Sensory Substitution Device (Optional)		1 per student (optional)
Student Handout 10.4: Sensory Substitution Device Pugh Chart		1 per student

TEACHER PREPARATION

1. Gather materials for each group to make their poster.

2. Copy handouts as listed in the materials section above.

3. Depending on the level of your students, prepare a template for a rough draft of a poster, or have samples of other types of posters that students can view and evaluate for effectiveness.

4. If you would like a real visual for the Sample Pugh Chart activity, bring three different pairs of shoes (or be ready to ask students to volunteer theirs).

5. For the actual day of presentations, invite other members of the community (teachers, administrators, staff, mentors, parents/guardians) to come observe, ask questions, and give feedback. Alternatively, showcase this engineering design project as part of a Science Fair or Engineering Exhibition event.

PROCEDURE

Engage: Scientific Communication (20 minutes)

1. Ask students: How do scientists and engineers communicate what they've designed and learned to the greater community?
    - (articles/publications, videos, research talks and poster sessions at scientific conferences, informal conversations)

2. Introduce the poster session using *Student Handout 10.1: Presenting Your Sensory Substitution Device—Presentation Guidelines.*

Explore, Explain, Elaborate: Posters (80+ minutes)

3. Students work on the creating their poster. If needed, assign roles such as:
    - End-user: in charge of explaining the purpose and criteria of the project
    - Electrical engineer: in charge of drawing and explaining circuit diagram
    - Computer scientist: in charge of showcasing and explaining the Arduino code
    - Neuroethicist: in charge of explaining the ethical considerations involved
    - Business consultant: in charge of explaining the budgetary constraints and marketing the advantages of their design

Explore, Explain, Elaborate: Pugh Chart (50 minutes)

4. Introduce the idea of Pugh Charts as tools engineers use to evaluate designs based on criteria of different weights. Use *Student Handout 10.2: Pugh Charts* to guide your class through an example about choosing which shoes to buy.

5. As a class, brainstorm criteria that can be used to evaluate the design of the sensory substitution device.

6. In their groups, allow students to choose the criteria that they would like to use on *Student Handout 10.4: Sensory Substitution Device Pugh Chart* (it can be all or just some of the ones that are brainstormed). Groups will then assign weights to each criteria (it may be helpful to pick the same maximum weight). It is encouraged that the groups come up with the weights independent of other groups. This helps with the conversation about how different groups might value one criterion more, therefore potentially resulting in choosing a different "best" design.

Explain, Evaluate: Presentations and Evaluations (50 minutes)

7. Have all students to set up their poster in their groups, and divide each group into two (A and B). (5 min)

8. All the students who are A's will stand by their poster while all the B's will circulate and fill out the Pugh Chart created the day before. Depending on the number of groups, you will have to set up time limits (2 minutes per group) or limit the number of presentations each person visits (only visiting 4 groups instead of all 8, giving each group 4 minutes to present). Students should be rotating through the groups on the teacher's clock so that there are always B students visiting A presentations. (20 min)

9. B students will stand at their poster and the A's will rotate through the presentations and fill out the Pugh Chart. (20 min)

10. Reflect as a class or for homework on what is the best design. If groups have different ideas about what is "best," you can have a class discussion on the merits of each design and how different criteria and weights may have played a role.

11. Possible homework assignment: Based on how different designs scored on the Pugh Chart, is it possible to optimize a design in the class? How might different aspects of different designs be combined to make a new design which might score even higher on all the criteria?

STUDENT ASSESSMENT

Assessment Opportunities: Student knowledge, skills, and concepts for this lesson will be assessed in a number of ways.

- Poster
- Oral presentation
- Effective creation and use of Pugh Chart
- Reflection on how the design can be optimized

Student Metacognition:

- At the bottom of the class Pugh Chart, there is space for students to think about whether they are surprised by what is considered as the best design. This will help students think about the criteria they chose and the weights they used.

Scoring Guide:

- *Teacher Resource 10.1* provides a scoring key for *Student Handout 10.2: Pugh Charts.*

EXTENSION ACTIVITIES

Extension Activities:

- With more time, students can actually design a new sensory substitution device using aspects of various designs they learned from visiting other groups.

Adaptations:

- If there is not enough time to do a formal poster session, you can do a simplified presentation of the designs using *Student Handout 10.3: Presentation Simplified—Your Sensory Substitution Device.*
- Students can make a slideshow presentation or video instead of a poster.

TEACHER BACKGROUND & RESOURCES

Background Information:

Pugh Charts are used in the engineering world, but can really be used in a wide variety of contexts. They are a form of a decision matrix (see Resources section below for more information). Weights are done a little differently in this activity. In many Pugh Charts, scores range from -3 to +3, and each score is multiplied by its corresponding weight. This lesson simplifies the weighting by removing the multiplication step and simply setting a maximum score.

Resources:

Some Information about Poster Sessions:

- https://www.nature.com/scitable/nated/topicpage/poster-presentations-13907939
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1876493/
- http://guides.nyu.edu/posters
- https://nau.edu/undergraduate-research/poster-presentation-tips

Background about Pugh Charts:

- Decision Matrix: What it is and How to use it
    - http://www.businessnewsdaily.com/6146-decision-matrix.html
- Science Buddies: Choose the Best Solution
    - https://www.sciencebuddies.org/engineering-design-process/best-solution.shtml#keyinfo
- Jose E. Lugo, University of Notre Dame, Design + Engineering
    - https://sites.nd.edu/jlugo/2012/09/24/pugh-method-how-to-decide-between-different-designs/

Student Handout 10.1: Presenting your Sensory Substitution Device—Presentation Guidelines

Name:_________________________________ Date:__________________ Period:__________

In this class, your group will be designing a poster/video/slide show of your design. Your presentation must include large headings, bullet points, and the following sections:

- Design problem: What is name of device and how does it substitute a sense? Who is the user?
- Criteria and Constraints: What requirements did the design need to fulfill and what limitations were there?
- Methods: How did you build your model?
    - Diagrams: What components did you use in your model and how were they connected in a circuit? What was/were the input(s), how was the information processed, and what was/were the output(s)?
        - Circuit Diagram of electronic components
        - Arduino Program - describe the major elements of your program which processes the input to result in an output
- Imagining the actual device: How does the user wear the device? When is it used? Does it have a switch? What materials would make this device even more usable?
- Modifications: What changes did you make and how did they improve your model?
- Ethics: How did you consider ethics in this design?
- Future work: With more time and resources, how might you further improve your design and why?
- Further information: If you completed any of the extension research from the Making It Real handout, you can include that in your presentation

Your poster can (doesn't have to!) have the following layout:

<table>
<tr><td colspan="3" align="center">Name of your SSD
Your names</td></tr>
<tr>
<td>Introduction
- what need does your SSD seek to address?
- how does your SSD address this need?
- ?</td>
<td align="center">Draw your final SSD circuit

Explain in words how your circuit functions. Be specific but brief.</td>
<td>Conclusion
- what are some of the more important changes you made as you worked, and why?
- what would be your next steps or improvements now?</td>
</tr>
</table>

Student Handout 10.2: Pugh Charts

Name:_________________________________ Date:__________________ Period:__________

Pugh Charts are used to help engineers decide which design solution is “best.” “Best” may have different definitions based on what is values different people place on certain criteria. Let’s look at the following example.

You’re choosing between 3 pairs of shoes, and you can only buy one.

1. What are some **criteria** you might consider in choosing the one pair you buy? List them in the first column in the chart below.
2. What value or **weight** do you place on each criterion? For the most important criterion, give a weight of 3. Less important criteria can be given a weight less than 3 (1 for not very important at all, 2 for somewhat important). Two or more criteria can have the same weight (they are of equal importance).
3. Look at each of the three shoes. Give each shoe a **score** for each criteria based on the maximum weight allowed. *For example, one of your criteria is comfort and you gave it a weight of 3. When you try the shoe on, it’s not comfortable at all. You would give it a score of 1 out of 3 for comfort. If you need a shoe for playing basketball and give that a weight of 3, you might give a dress shoe a 1 out of 3 for matching its function.*
4. After going through all the criteria for each shoe, add up the **total** for each shoe. The shoe with the highest total score is the best choice.

Criteria	**Weight**	**Design 1**	**Design 2**	**Design 3**
Total				

5. Compare your “best” with another person’s or group’s. Why might you have different results? How might this be advantageous or disadvantageous when designing a solution to a problem?

Student Handout 10.3: Presentation Simplified—
Your Sensory Substitution Device

Name:________________________________ Date:__________________ Period:__________

What is the name of your device? ____

Who is the user of your device? ____

How will your device help your user? ____

____

Describe/draw your final sensory substitution device here (or print, tape in, and label a picture).

Student Handout 10.4: Sensory Substitution Device Pugh Chart

Name:________________________________ Date:__________________ Period:__________

Criteria	Weight	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8
Total									

Reflect: Based on the total score, which design was the "best"? Are you surprised by this? Why or why not?

Teacher Resource 10.1: Pugh Charts Answer Key

Pugh Charts are used to help engineers decide which design solution is "best." "Best" may have different definitions based on what is values different people place on certain criteria. Let's look at the following example.

You're choosing between 3 pairs of shoes, and you can only buy one.

1. What are some **criteria** you might consider in choosing the one pair you buy? List them in the first column in the chart below.
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3. Look at each of the three shoes. Give each shoe a **score** for each criteria based on the maximum weight allowed. *For example, one of your criteria is comfort and you gave it a weight of 3. When you try the shoe on, it's very comfortable. You would give it a score of 3 out of 3 for comfort. If you need a shoe for playing basketball and give that a weight of 3, you might give a dress shoe a 1 out of 3 for matching its function.*
4. After going through all the criteria for each shoe, add up the **total** for each shoe. The shoe with the highest total score is the best choice.

Answers can vary. Below is just an example of how one chart can be filled out.

Criteria	**Weight**	**Design 1**	**Design 2**	**Design 3**
Functionality	3	3	1	2
Affordability	1	1	0	1
Durability	2	2	2	1
Aesthetics	2	1	1	2
Comfort	2	1	1	1
Total		**8 - best**	5	7

5. Compare your "best" with another person's or group's. Why might you have different results? How might this be advantageous or disadvantageous when designing a solution to a problem?

- Advantage - seeing multiple perspectives; can combine “best” features from different designs and create a new design that incorporates these features; is more realistic representation
- Disadvantage - hard to decide which solution is the one to invest in because everyone’s values are different; have to have longer discussions with other groups about values