Unit: Circuitry and Sensory Substitution Devices

Lesson 1: Brain and Computer Connection

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CENTER *for*
NEUROTECHNOLOGY
a National Science Foundation Engineering Research Center

LESSON OVERVIEW

Activity Time:
One 45 minute class period (+)

Lesson Plan Summary:
In this lesson, students will make connections between what they have learned about basic and complex circuits in the previous weeks to neuroscience applications (assistive devices and sensory substitution). They will compare and contrast the brain and circuitry, and brainstorm about types of senses/sensors (inputs) and types of outputs.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- **The brain**: The brain can be thought of similarly to an electric circuit, where sensory neurons receive input, the brain processes this, and motor neurons instigate a response.
- **Sensorimotor neural engineering**: Sensorimotor neural engineering is a field of study that aims to understand how to capitalize on the sensorimotor loop to design devices, treatments, and therapies to help people with neurological, sensory, and motor disorders. Neural engineering connects the nervous system and computers to restore and enhance normal human function. Sensorimotor neural engineering is focused on the loop between sensory information received by the brain, information that the central nervous system (CNS) sends out, and devices (computers, implants, prosthetics, etc.) that receive inputs and produce outputs that feed back into the CNS.

- **Sensory substitution**: Sensory substitution is when one sense is substituted with another. Usually this occurs through a non-invasive device which takes one input (which the body can no longer sense) and converts it to a different input (which the body can sense, process, and react to). This relies heavily on brain plasticity, the brain's ability to repair and enhance existing neural pathways.

Investigative Phenomenon: How does a robotic gripper hand work to translate biosignals from the human body to a simple machine?

Driving Question:

- What are similarities and differences between our brains and electric circuits, and how is that useful in neuroscience applications?

Learning Objectives:
Students will know…

- That there are similarities between electrical and biological systems including inputs (human senses and electrical sensors), processors (the nervous system and logic gates, transistors, and relays), and outputs (movement etc., and motors, LEDs etc.), as well as differences - digital vs analogue, scale and complexity, etc.
- That the purpose of sensory substitution device is to enable a person with a sensory disability to use a working sense to replace a damaged or lost sense (i.e., a retinal implant, a cochlear implant, etc.).

Students will be able to…

- Explain the principal similarities and differences between electric circuits and the brain
- Define and give examples of sensory substitution devices

Vocabulary:

- **Sensorimotor neural engineering**: the process of engineering devices to restore or augment the body's capabilities for sensation and movement
- **Sensory and motor neurons**: sensory neurons convert external stimuli from the organism's environment into internal electrical impulses, while motor neurons conduct an impulse that causes movement
- **Sensory substitution device**: a device which enables one sense to replace the use of another sense
- **Assistive device:** any device that helps someone do something that they might not otherwise be able to do well or at all

- **Neural plasticity**: the brain's ability to reorganize itself by forming new neural connections throughout life

Next Generation Science Standards:
This lesson builds toward the following Performance Expectation (PE) and its integrated three dimensions of learning. Additional dimensions are denoted with an asterisk (*).

High School Performance Expectations		
HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. (Grades 9-12).		
Science and Engineering Practices (SEPs)	**Disciplinary Core Idea(s)**	**Crosscutting Concepts (CCCs)**
Constructing Explanations and Designing Solutions *Asking Questions and Defining Problems *Developing and using models *Obtaining, evaluating, and communicating information	ETS1.A: Defining and Delimiting an Engineering Problem PS3.A: Definitions of Energy	Energy and Matter *Structure and Function *Connections to Engineering, Technology, and Applications of Science* Influence of Science, Engineering, and Technology on Society and the Natural World *Science is a Human Endeavor *Science Addresses Questions about the Natural and Material World

Common Core State Standards:
- **CCSS.ELA-Literacy.RST.11-12.1:** Cite evidence to support analysis
- **CCSS.ELA-Literacy.RST.11-12.7:** Integrate and evaluate information in diverse formats
- **CCSS.ELA-Literacy.RST.11-12.9:** Synthesize information
- **CCSS.ELA-Literacy.SL.9-10.1:** Initiate and collaborate in discussions

IGCSE Physics standards:
- **AO1-4**. Demonstrate knowledge and understanding of scientific and technological applications with their social, economic and environmental implications.

TEACHER PREPARATION

Materials

Note: In place of the pieces below, Backyard Brains now carries a kit which eliminates the need for actually building the gripper arm: https://backyardbrains.com/products/clawBundle .

Material	Description	Quantity
Arduino Uno R3	From Amazon.com or Sparkfun.com	1 per class
EMG SpikerShield	Works with Arduino to harness electrical activity of the muscles. $75 from BackyardBrains.com	1 per class
Gripper hand	$10 from www.sparkfun.com/products/13174	1 per class
Gripper servo motor, HiTech HS-422	$10 from www.sparkfun.com/products/11884	1 per class
USB portable power bank 2200 mAh	$10 from Amazon.com	1 per class
USB cable A to B	$4 from https://www.sparkfun.com/products/512	1 per class
Male header pin	$1 from https://www.sparkfun.com/products/12693	1 per class
Jumper wire M/M	$4 from https://www.sparkfun.com/products/8431	1 per class
ECG electrodes	$29 https://backyardbrains.com/products/emglargeelectrodes	3 per stdt
Supplies	Large whiteboards and whiteboard markers	1 set per lab group
Documents	Student Handouts 1.1a-d and 2.1 Teacher Resources 1.1 and 1.2	1 per stdt

Preparation

1. Build and test Gripper Hand (or purchase the assembled kit from Backyard Brains):

   a. Instructions are at: https://www.backyardbrains.com/experiments/gripperhand. Note: The assembly includes making a custom USB cable, described at https://www.backyardbrains.com/experiments/files/USB_Cable_Gripper.pdf.
   b. Connect the gripper hand to the Arduino and SpikerShield, and test its action using the EMG patches to make sure if works reliably.
2. Access the four articles that will make up Student Handouts 1.1a-d. Print copies or have students read online.
   a. **Handout 1.1a: *Blind Sight: The Next Generation of Sensory Substitution Technology***
      Dana Smith, *The Crux* (2014). Reading level: High School.
      http://blogs.discovermagazine.com/crux/2014/04/28/blind-sight-the-next-generation-of-sensory-substitution-technology/#.XLjOiJhKiUk
   b. **Handout 1.1b: *Sensory Substitution***
      Timothy Gower, *Proto* (2015). Reading level: High School.
      http://protomag.com/articles/sensory-substitution
   c. **Handout 1.1c*: Sensory Substitution: Closing the Gap between Basic Research and Widespread Practical Visual Rehabilitation***
      Shachar Maidenbaum, Sami Abboud, and Amir Amedi, *Neuroscience & Biobehavioral Reviews* (2014). Reading level: High School-College.
      https://www.sciencedirect.com/science/article/pii/S0149763413002765?via%3Dihub
   d. **Handout 1.1d: *Tactile Substitution for Vision***
      Yael Zilbershtain-Kra, Amos Arieli, and Ehud Ahissar, *Scholarpedia* (2015). Reading level: High School.
      http://www.scholarpedia.org/article/Tactile_Substitution_for_Vision

3. Photocopy exit tickets (Student Handout 1.2) so they are ready to distribute.
4. Open and test the David Eagleman VEST video clip: https://www.youtube.com/watch?v=kbKzF8gKxT4

PROCEDURE

Engage: (10 min)

1. Show students and demonstrate the gripper hand (the investigative phenomenon).
   a. Briefly brainstorm or pair-share: When/where have you seen something like this before? What makes the gripper hand work? In what situations might this be useful? Encourage students to try the gripper hand themselves, and test the effects of different muscles and actions.
   b. Initial Explanation: Have students work in lab groups on large whiteboards to sketch the gripper hand system (arm to hand) and label what they think is

happening as the hand works. There is no correct answer at this point, but push students to commit to their ideas in writing

c. Transition: What connection does the gripper hand have to what you have learned in the previous weeks?

Explore: (10 min)

2. What are similarities between electric circuits and your brain/body? Have students work together to brainstorm a list of similarities and differences, as well as questions they have. They should/might need help to come up with ideas including
    a. Similarities: senses compared to inputs (i.e., vision and light-dependent resistors), both rely on electricity to communicate, both have outputs, both are fast, etc.
    b. Differences: brains can learn/think more organically than computers at this point, circuits have sensors in only certain places instead of all over the skin, etc.
3. Why might these similarities be useful? ...we can use circuits to assist humans to replace lost senses, or even use other senses to substitute for lost senses

Explain: (15 min)

4. Tell students: We are going to be applying what you have learned about circuits to a field called "sensorimotor neural engineering" - the process of engineering devices which aim to replace or enhance damaged neural and motor capabilities. You will be designing "sensory substitution" device - a circuit designed to interface with the nervous system in order to replace one sense with input from a different sense.
5. Show VEST by David Eagleman and discuss. Possible questions are included below.
    a. Shorter Option: https://www.youtube.com/watch?v=kbKzF8gKxT4 (3:13 min)
    b. Longer Option: http://eaglemanlab.net/sensory-substitution (20 min)
    c. What are the senses involved in the VEST? What is the input of the VEST? What is used to process the information? What is the output? Explain how this is an example of a sensory substitution device. Why is a potato head a good model?
    d. What are the advantages of this device over the cochlear implant? What disadvantages can you imagine? Can you think of other sensory substitution devices that could be designed to do similar things? Can you think of other senses for which you can design a sensory substitution device?

Elaborate: (5 min)

6. Pass out one of each homework article (Student Handouts 1a-d) to lab groups (or post online). Have students decide how to jigsaw the articles (1.1c is longer).
    a. Handout 1.1a - *Blind Sight: The Next Generation of Sensory Substitution Technology*, (Smith, 2014)

   b. Handout 1.1b - *Sensory Substitution*, (Gower, 2015)
   c. Handout 1.1c - *Sensory Substitution: closing the gap between basic research and widespread practical visual rehabilitation* (Maidenbaum, Abboud, & Amedi, 2014)
   d. Handout 1.1d - *Tactile Substitution for Vision* (Zilbershtain-Kra, Arieli, & Ahissar, 2015)
7. Explain how students should interact with the article. Suggestions include
   a. Read and highlight 10-15 most important sentences. Come prepared with 3 principal points or questions to share with the class.
   b. Answer the included questionnaire based on your understanding of the article
   c. In your lab journal, summarize the principal points of the article in 5 sentences or less. Come prepared with 2 questions you have about the article.

Evaluate: (5 min)

8. Distribute the Exit Ticket (Student Handout 1.2) for students to complete, and collect these as they leave. Students should hopefully respond with answers such as….
   a. to substitute one sense for another – i.e., substitute loss of hearing with tactile
   b. input is a push switch vs pressure feeling in hand, battery is the supply of power in both, and output is a light bulb vs a visual indicator of pressure.

STUDENT ASSESSMENT

Assessment Opportunities:

- Students will be assessed on their recognition of similarities and differences between the brain and electric circuits and why those similarities might be useful informally through conversation throughout the unit
- Students will be assessed on their understanding of connections on the exit ticket
- Students can also be assessed on their understanding of the homework article
- In preparation for the engineering design project, assign a SurveyMonkey or GoogleDoc quiz on attitudes towards STEM and Engineering in preparation for the next few lessons. See Teacher Resource 1.1 and 1.2 for ideas. Note that Teacher Resource 1.1 is an adaptation of the Student Attitudes toward STEM Survey (S-STEM). Learn more here: https://miso.ncsu.edu/articles/s-stem-survey.

Student Metacognition:

- Students will have informal notes in their lab journals about their initial ideas about connections between the brain and electric circuits, which they will add to and modify based on the class share-out.

- Students will reflect on their learning when they complete the exit ticket

Scoring Guide:

- Success is all students participating throughout and having thoughtful exit ticket answers

EXTENSION ACTIVITIES

Extension Activities:

- Students could be assigned more specific articles to read about sensory substitution devices - see resources (for example, *Sensory Substitution and the human-machine interface*, by Bach-y-Rita and Kercel)
- Students could watch additional video clips that could be discussed the next day
- Students could be asked to find more articles about sensory-substitution devices of interest to them to share with the class.

Adaptations:

- A structured handout for the initial gripper-hand explanation could be provided for students who struggle to get down abstract, unformed ideas.
- For teachers with more time, the initial discussion pieces could be much more elaborate - sharing out via whiteboards for example, or many more video clips/articles could be incorporated.

TEACHER BACKGROUND & RESOURCES

Background Information:

- Review similarities and differences in Brains vs Computers from Neuroscience for Kids: https://faculty.washington.edu/chudler/bvc.html
- More about similarities and differences between brains and computers: http://scienceblogs.com/developingintelligence/2007/03/27/why-the-brain-is-not-like-a-co/

Resources:

- A gripper hand (built by the teacher beforehand with a robot gripper, Arduino shield, and specialized cables) along with EMG patches. Will be used initially by the teacher but students will want to try it as well.
- Sensory substitution video clips: VEST by David Eagleman (also a longer TED talk)
- Sensory substitution articles:

    - Alternative 1: *Sensory substitution and the human-machine interface*, Paul Bach-y-Rita and Stephen W. Kercel (*Trends in Cognitive Science* Vol 7 No. 12, Dec 2003).
    - Alternative 2: *Brain plasticity: 'visual' acuity of blind persons via the tongue*, Eliana Sampaio, Stephane Maris, Paul Bach-y-Rita (*Brain Research* 908, May 2001)
- Brain vs Computer:
    - http://theconversation.com/to-understand-the-brain-you-need-electronic-engineers-too-26104
    - http://news.mit.edu/2000/circuit-0712
- Neuroscience:
    - http://www.nobelprize.org/educational/medicine/nerve_signaling/game/nerve_signaling.html#/plot1

Student Handout 1.2: Exit Ticket

Name: ________________________________ P: ______

1. What is the purpose of sensory substitution devices?

2. State the connection between sensory substitution devices and a simple electric circuit with a battery, push switch, and light bulb.

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Survey 1
Views about Engineering

Adapted from the Student Attitudes toward STEM Survey (S-STEM)

https://miso.ncsu.edu/articles/s-stem-survey

1. Science: Fill in the circle that best describes how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
I am good at science	○	○	○	○
I would consider choosing a career that uses science.	○	○	○	○
I get good grades in science.	○	○	○	○
I am sure I could do advanced work in science.	○	○	○	○
Knowing science will help me earn a living.	○	○	○	○

2. Math: Fill in the circle that best describes how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
I am good at math.	◯	◯	◯	◯
I would consider choosing a career that uses math.	◯	◯	◯	◯
I get good grades in math.	◯	◯	◯	◯
I am sure I could do advanced work in math.	◯	◯	◯	◯
Knowing math will help me earn a living.	◯	◯	◯	◯

3. Engineering: Fill in the circle that best describes how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
I like to imagine creating new products.	○	○	○	○
If I learn engineering, then I can improve things that people use every day.	○	○	○	○
I am good at building and fixing things.	○	○	○	○
I am interested in what makes machines work.	○	○	○	○
Designing products or structures will be important for my future work.	○	○	○	○
I am curious about how electronics work.	○	○	○	○
I would like to use creativity and innovation in my future work.	○	○	○	○
Knowing how to use math and science together will allow me to invent useful things.	○	○	○	○
I believe I can be successful in engineering.	○	○	○	○

4. 21st Century: Fill in the circle that best describes how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
I am confident I can lead others to accomplish a goal.	○	○	○	○
I am confident I can encourage others to do their best.	○	○	○	○
I am confident I can produce high quality work.	○	○	○	○
I am confident I can respect the differences of my peers.	○	○	○	○
I am confident I can help my peers.	○	○	○	○
I am confident I can make changes when things do not go as planned.	○	○	○	○
I am confident I can manage my time wisely when working on my own.	○	○	○	○
I am confident that I can figure out how to start on large challenging projects.	○	○	○	○

5. Thinking about your friends and family...

	Yes	No	Not sure
Do you know any adults who work as scientists?	○	○	○
Do you know any adults who work as engineers?	○	○	○
Do you know any adults who work as mathematicians?	○	○	○
Do you think you know what engineers do for work?	○	○	○
Do you think you know what scientists do for work?	○	○	○

6. Are the following myth or reality?

	Myth	Reality
Engineers do not need strong soft skills (writing, speaking, leadership)	○	○
Engineers must love math	○	○
Engineers must be good problem solvers	○	○
Engineering involves finding solutions to the world's problems.	○	○
Engineering involves improving people's lives.	○	○
Women are not as successful in engineering as men.	○	○
An engineer and a scientist have totally different jobs.	○	○
Engineers more often work alone.	○	○
Engineers spend much of their time trying to improve existing designs rather than designing new ones.	○	○
Engineers have to spend a lot of time at their desks in front of computers.	○	○
Engineers must love science	○	○
Engineering can have an direct impact on people's lives.	○	○
Engineers work in the private sector, not the public or academia.	○	○

7. Which of the following might be job descriptions for an engineer, and which might be a job description for a scientist? Select all that apply; some titles might apply to both.

	Scientist	Engineer
aviation engineer	☐	☐
lab technician	☐	☐
astronomer	☐	☐
statistician	☐	☐
nurse	☐	☐
geologist	☐	☐
weather forecaster	☐	☐
software engineer	☐	☐
computer programmer	☐	☐
chemist	☐	☐
nuclear physicist	☐	☐
pharmacologist	☐	☐
systems analyst	☐	☐
electrical technician	☐	☐
civil engineer	☐	☐
welder	☐	☐
professor	☐	☐

8. How confident are you in your understanding of what is involved in the following tasks, and your ability to carry them out?

	Very confident	Somewhat confident	Somewhat uncertain	Very uncertain
Ask a testable question	○	○	○	○
Define a solvable problem	○	○	○	○
Identify experimental variables	○	○	○	○
Identify engineering constraints	○	○	○	○
Use observational evidence to develop a model	○	○	○	○
Model a phenomenon in multiple ways	○	○	○	○
Plan and conduct an investigation resulting in relevant data	○	○	○	○
Build and test a prototype resulting in relevant data	○	○	○	○
Analyse data using scientific and mathematical tools to develop a conclusion	○	○	○	○
Consider the limitations of resulting data	○	○	○	○
Analyse data using scientific and mathematical tools to optimise a design	○	○	○	○

Consider the limitations of resulting data	◯	◯	◯	◯
Analyse data using scientific and mathematical tools to optimise a design	◯	◯	◯	◯
Construct an explanation using gathered evidence	◯	◯	◯	◯
Develop an improved design using gathered evidence	◯	◯	◯	◯
Compare and evaluate given explanations for observable phenomena based on scientific principles	◯	◯	◯	◯
Compare and evaluate given designs for real-world problems based on scientific principles and relevant factors and constraints	◯	◯	◯	◯
Have fun doing engineering	◯	◯	◯	◯
Have fun doing science	◯	◯	◯	◯

Survey 2
The Engineering Process

1. On a scale of 1 to 5, how confident are you that you understand the engineering design process?

0 (no confidence) **5 (total confidence)**

2. On a scale of 1 to 5, how much overlap do you think there is between the engineering process and the scientific method?

0 (no overlap) **5 (complete overlap)**

3. On a scale of 1 to 5, how confident are you that you have the understanding and skills to be successful in a future engineering project, class, or summer program (whether you intend to or not)?

0 (no confidence) **5 (total confidence)**

4. Which activity would an engineer do, but not a scientist?

- ◯ record measurements
- ◯ make observations
- ◯ draw conclusions
- ◯ build prototypes
- ◯ ask questions

5. During the design process, engineers often do the following in what order?

- Identify a need
- Research a problem
- Develop possible solutions
- Construct a prototype
- Test and evaluate a design

6. An engineer notices that a transistor-operated heat lamp circuit has a flaw in its design - it turns the heat lamp on when it is still hot outside. What step should the engineer take next to improve the design?

- ◯ draw a schematic for several new circuits
- ◯ identify design constraints for heat lamp circuits
- ◯ build models of several new circuits
- ◯ gather information about heat lamp circuits

7. When finding a solution to an engineering design problem, there is/are usually

- ◯ only one possible correct solution
- ◯ a very limited number of possible correct solutions
- ◯ many possible correct solutions

8. The engineering design process is iterative. This allows engineers to

- ◯ become proficient at many different engineering software applications
- ◯ find the most optimal solution to a design problem
- ◯ incorporate both math and science concepts into a design problem

9. When following the engineering design process, the different stages can occur in what order?

- ◯ clockwise
- ◯ either clockwise or counterclockwise
- ◯ in any direction, including shortcuts
- ◯ there are no distinct stages int he engineering design process

10. Both engineers and scientists work towards a purpose using the methods at their disposal. What tools/methods do each use, and towards what purpose?

Scientist purpose and methods:

Engineer purpose and methods: