The Synapse: An Engineering Design Challenge

A Curriculum Unit for High School

Chemistry and AP Chemistry Classes

CENTER FOR
SENSORIMOTOR NEURAL
ENGINEERING

Research Experience for Teachers (RET) Program

Draft for Piloting, September 2015

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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 seven week 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 Center for Sensorimotor Neural Engineering (CSNE) develops innovative modes of human-computer interaction by connecting brains with technology. We study signals from the brain, use that information to cause an action—such as moving a prosthetic hand or computer cursor—and provide useful information back to the brain. Our research is aimed at significantly improving the quality of life for people with spinal cord injury, stroke, Parkinson's disease, and other disabilities. By designing closed-loop, bi-directional brain-computer interfaces, we hope to help restore mobility as well as sensory and motor functions.

CENTER FOR SENSORIMOTOR NEURAL ENGINEERING

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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Unit Description

In this unit, students will design, construct and test a device that optimizes the transfer of electrical current from one electrode to another. The engineering design challenge is placed within the context of sensorimotor neural engineering.

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:

- **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 human nervous system with brains 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.
- **Neurons:** Neurons (nerve cells) transmit information through the nervous system by using electrical signals within neurons and chemical signals (neurotransmitters) between neurons.
- **Action Potential:** The nervous systems' communication method is via action potentials, which are electrochemical changes that originate in neurons, are prorogated down their axons, and elicit a corresponding response in the adjacent neurons.
- **Synaptic Activity:** Chemicals called neurotransmitters pass from one neuron to another neuron within the synapse, the tiny gap between neurons. These neurotransmitters are released as part of an action potential that propagates down a neuron's axon.
- **Chemical & Electrical Signal Transmission**: Chemical and electrical functions are critical to the transmission of information between neurons.
- **Neuroethics:** By examining the ethical implications of neural engineering devices—such as Brain-Computer Interfaces—we can make connections between our scientific understanding of the sensorimotor neural system and applications to the real world.

Essential Questions:

- How does an understanding of the structure and function of neurons and synaptic communication provide opportunities for neural engineers to design devices that leverage these processes in order to help people?
- How is a message from the brain sent to other parts of the body? What role does chemistry have in this process?
- What is a synapse?
- How does chemistry affect synaptic action?
- Does increasing synapse potential/efficiency help with the design of neural engineering devices?
- How do scientists share and evaluate information?

Knowledge and Skills (Outcomes):

Students will know…

- An understanding of chemistry is paramount to understanding the function of the synapse, including ion interaction, metal properties, elemental trends, and electrochemistry.
- The part that the synapse plays in sending messages from the brain to other parts of the body, including what happens when brain or spinal injury has occurred.
- A Brain-Computer Interface connects a technological device to the brain through electrodes.
- Complex neuroethical issues are at play when studying synaptic function, brain function, and neural engineering devices.

Students will be able to…

- Use a volt meter.
- Design, simulate, and optimize a model of a synapse.
- Design an experiment to test a variable related to synaptic function.
- Use safety protocols in the chemistry lab.
- Work collaboratively to solve a complex problem.
- Evaluate strengths and weaknesses of an engineering design/model.
- Communicate scientific information.
- Read a scientific journal article and identify evidence that supports a statement.
- Engage in a philosophical debate, using evidence from a journal article to validate and support their claims and opinions.

Knowledge and Skills (Prerequisite):

Note: It is highly recommended that prior to teaching this unit, instructors deliver the unit *Introduction to Neural Engineering & Ethical Implications* from the 2015 Research Experience for Teachers program at the Center for Sensorimotor Neural Engineering. This unit provides an introduction to a broad range of neural engineering topics, including the human nervous system, electrophysiology, history of neural engineering, medical devices, and ethical implications of these emerging technologies.

Helpful prerequisite knowledge includes:

- Basic understanding and familiarity with the engineering design process.
- Basic understanding of the human nervous system.
- Basic understanding of chemistry concepts related to ions, metals, periodic trends, and electrochemistry.

Helpful prerequisite skills include:

- Basic familiarity with experimental design of controlled experiments.

Key Vocabulary:

- Action potential
- Axon
- Concentration
- Conduction
- Dendrite
- Depolarization
- Diffusion
- Ions
- Neuron
- Neurotransmitters
- Resting potential
- Polarization
- Sensorimotor neural engineering
- Synapse

Alignment to National Learning Standards

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

Next Generation Science Standards: Performance Expectations

Next Generation Science Standards: High School (Grades 9-12)

	1: Introduction to Neural Engineering	2: The Synapse & Action Potential	3: Designing a Synapse	4: Neuroethics & BCIs
Engineering Design				
HS-ETS1-2 Engineering Design: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.				
HS-ETS1-3 Engineering Design: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.				
HS-ETS1-4 Engineering Design: Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.				

Physical Sciences				
HS-PS1-3: Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.				
HS-PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.				
HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.				
Life Sciences				
HS-LS1-2 Structure and Function: Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.				

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: Introduction to Neural Engineering	2: The Synapse & Action Potential	3: Designing a Synapse	4: Neuroethics & BCIs
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.				
Stability and Change: For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.				

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: Introduction to Neural Engineering	2: The Synapse & Action Potential	3: Designing a Synapse	4: Neuroethics & BCIs
Developing and using models.				
Planning and carrying out investigations.				
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.

Common Core State Standards—Literacy in History/Social Studies, Science, & Technical Subjects: High School (Grades 9-12)

	1: Introduction to Neural Engineering	2: The Synapse & Action Potential	3: Designing a Synapse	4: Neuroethics & BCIs
SL.11-12.5: Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.				
RH.9-10.4: Determine the meaning of words and phrases as they are used in a text, including vocabulary describing political, social, or economic aspects of history/social science.				
RST.9-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-12 texts and topics.				
RST.11-12.1: Cite specific textual evidence to support analysis of science texts.				
RST.9-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-12 texts and topics.				
RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.				
WHST.9-12.5: Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.				
WHST.9-12.7: Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.				
WHST.9-10.8: Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.				

WHST.9-12.9: Draw evidence from informational texts to support analysis, reflection, and research.				
WHST.11-12.2: Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.				
WHST.11-12.8: Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.				

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science, and Technical Subjects*. Washington, DC: Common Core State Standards Initiative.

Common Core State Standards—Mathematics: High School (Grades 9-12)

	1: Introduction to Neural Engineering	2: The Synapse & Action Potential	3: Designing a Synapse	4: Neuroethics & BCIs
HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.				
HSN.Q.A.2: Define appropriate quantities for the purpose of descriptive modeling.				
HSN.Q.A.3: Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.				

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common Core State Standards for Mathematics.* Washington, DC: Common Core State Standards Initiative.

Lesson One: Introduction to Neural Engineering

Center for Sensorimotor Neural Engineering

Lesson Plan Authors: Paul Zimmer, South Kitsap High School
and Denise Thompson, Orting High School

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary: In this lesson, students will observe neural signals using a SpikerShield, Arduino, and LEDs. They will then construct a visual model of a reflex arc that identifies all of the structures and their functions.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- **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 human nervous system with brains 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.
- **Neurons:** Neurons (nerve cells) transmit information through the nervous system by using electrical signals within neurons and chemical signals (neurotransmitters) between neurons.

Essential Question:

- How does an understanding of the structure and function of neurons and synaptic communication provide opportunities for neural engineers to design devices that leverage these processes in order to help people?

Learning Objectives:

Students will know…

- The relationship between a mechanical system and biological system.

Students will be able to…

- Make the connection of the importance of chemistry for the development of sensorimotor neural engineering device and technologies.

Vocabulary:
- Neuron
- Sensorimotor neural engineering
- Synapse

Standards Alignment: This lesson addresses the following high school Next Generation Science Standards (NGSS) and Common Core State Standards (CCSS).

NGSS Disciplinary Core Ideas (DCIs)
- **HS-PS2-6:** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- **HS-LS1-2 Structure and Function:** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

NGSS Crosscutting Concepts
- Structure and Function

NGSS Science & Engineering Practices
- Developing and using models.
- Planning and carrying out investigations.
- Using mathematics and computational thinking.
- Obtaining, evaluating, and communicating information.

Common Core State Standards in English Language Arts
- **RST.11-12.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- **WHST.11-12.2:** Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

Common Core State Standards in Mathematics
- **HSN.Q.A.1:** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

- **HSN.Q.A.2:** Define appropriate quantities for the purpose of descriptive modeling.
- **HSN.Q.A.3:** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

MATERIALS

Note: As written, this activity is designed so that students work in six groups during this lesson. Adjust the number of groups depending on your class size and budget.

Material	Description	Quantity
Media center	Classroom computer with internet access and projector	1
Computer	Each computer needs to be pre-loaded with the Arduino software	1/group
Arduino Uno R3	Ordered from Amazon.com or Sparkfun.com	1/group
EMG SpikerShield	Component that works with an Arduino to harness the electrical activity of muscles. Available from BackyardBrains.com for approximately $75 at www.backyardbrains.com/products/EMGSpikerShield	1/group
Gripper hand	Available for approximately $10 from www.sparkfun.com/products/13174	1/group
Gripper servo motor	Available for approximately $10 from www.sparkfun.com/products/11884	1/group
USB portable power bank 2200 mAh	Available for approximately $10 from http://comingsoon.radioshack.com/radioshack-2200mah-portable-power-bank-blue/2302015.html	1/group
USB cable	Available for approximately $4 from www.sparkfun.com/products/512	1/group
Male headers	Available for approximately $1 from www.sparkfun.com/products/12693.	1, to be shared by all groups

	Comes with 40 headers.	
Jumper wire kit	Available for approximately $7 from Amazon.com or www.sparkfun.com/products/8431	3 +/- as needed, to be shared by all groups
10k resistor	Available for approximately $10 from www.sparkfun.com/products/11508. Comes as a pack of 20.	1, to be shared by all groups
Wire cutters, electrical tape, soldering iron	To be used when assembling a custom USB cable. Teacher may do this prep or students may do it. Requires soldering.	1/group or 1 for teacher to use
Student Handout 1.1	*Science Poster Template*	1/group
Poster materials	Poster paper, markers, etc.	1 set per group

TEACHER PREPARATION

Preparation:

1. Go to https://backyardbrains.com/products/diyMuscleSpikerShield and watch the introductory videos and read about the EMG spiker shield and Arduino microcontroller. If you don't have very much experience using microcontrollers such as Arduinos, the Arduino starter page at https://www.arduino.cc/en/Guide/HomePage is also very useful.

2. Download Arduino software from https://www.arduino.cc/en/Guide/HomePage in order to download and modify the sketch for the SpikerShield and preload sketches.

3. Determine if you want to provide the background information from the "Controlling a Gripper Hand" experiment instructions to students, or if you will cover this information during a class discussion (https://www.backyardbrains.com/experiments/gripperhand).

4. For the gripper hand activity, determine how much assembly you want to do ahead of time, and how much you want students to do themselves. Review the instructions here https://www.backyardbrains.com/experiments/gripperhand. The assembly includes making a custom USB cable (described here https://www.backyardbrains.com/experiments/files/USB_Cable_Gripper.pdf). This step requires wire cutters, electrical tape, and a soldering iron. Determine if you will have students do the soldering or if you will prepare the cables ahead of time.

5. Copy ***Student Handout 1-1:*** *Science Poster Template*, one per group.

6. Organize materials needed.

7. Divide students into groups. As written, this activity is designed so that students work in six groups during this lesson. Adjust the number of groups depending on your class size and budget.

PROCEDURE

Engage: (10 minutes)

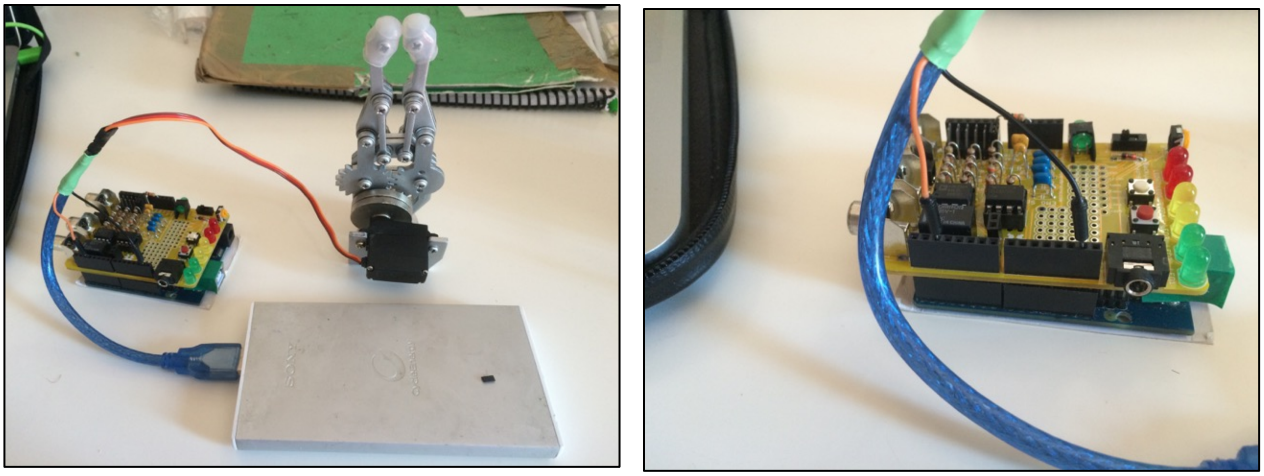
1. Introduce students to the SpikerShield by showing them the background information and visuals from https://backyardbrains.com/experiments/emgspikershield.

2. Be sure to make a clear connection between the role of electrical signals in the nerves and the electrical signal that is lighting up the LEDs.

3. Open the "LED highgain" sketch from the https://backyardbrains.com/experiments/emgspikershield website and show students what parameters that they can change (MAX and multiplier) and how to compile and upload a sketch.

Explore: (20 minutes)

4. Allow students to experiment with the SpikerShield and Arduino. They can alter the muscle used, how far the leads are placed from each other, with and without electro-conducting gel, altering parameters in the sketch, where to place the ground, etc.



Set-up of the gripper hand, showing the custom cable fabricated to power the gripper hand from an external battery pack (normally used to charge cell phones). The orange wire from the custom cable plugs into pin 3 (digital out 2) on the Ardunio. The ground wire from the custom cable plugs into the ground pin on the Arduino. The 3-pin header plugs on the custom cable plugs into the wires coming off the gripper hand cable. The USB cable plugs into an external battery pack (normally used to charge cell phones).
Photo: Courtesy of Timothy Marzullo of Backyard Brains.

Explain: (5 minutes)

5. Explain to students that the SpikerShield measures the difference in voltage between the red and black leads, converts it into a value that the Arduino can understand in binary, and reports that value to the Arduino. The Arduino inputs the value from the SpikerShield, and computes how many LEDs to light up. By altering the MAX setting, students change the value that represents lighting up all 6 LEDs. If the MAX setting is too low, all 6 LEDs remain lit. If the MAX setting is too high, all 6 LEDs may never light. Essentially, the apparatus converts a neural signal into an observable signal—the lit LEDs.

Elaborate: (10 minutes)

6. Distribute copies of ***Student Handout 1-1:*** *The Science Poster Template*, one per group.

7. Challenge students to work within their groups to start drawing the BIG idea of their science poster. They should sketch a big picture that shows their visual model of the interface between the brain, the EMG signal in their arm, and the gripper.

Evaluate: (5 minutes)

8. As their Exit Ticket, each students needs to respond on a post-it note to the following question: “Explain what you think is going on with this device and how it interacts with the human nervous system.”

9. Tell students to stick their sticky notes on their poster. This provides the teacher with an opportunity to assess students’ thinking about the nervous system, electrical activity, EMG signals, the sensory-motor loop, and brain-machine interfaces.

STUDENT ASSESSMENT

Assessment Opportunities:

Student Metacognition:

Scoring Guide:

EXTENSION ACTIVITIES

Extension Activities:

Adaptations:

TEACHER BACKGROUND & RESOURCES

Background Information:

Resources:

Citations:

TITLE OF PROJECT

Authors

Introduction

Background information of project and what is the main focus of project, what is the question you are trying to answer.

6-8 sentences

Methods

Explain the main equipment, variables, controls used in the project. Include diagram.

Synapse lab design.

Do not include a full procedure.

BIG IDEA -illustration

Brain/Arm/Spiker shield Demo

6-7 sentences explaining illustrations

Neuron illustration

Synapse illustration

Results

Main results from the experiment. What actually happened during the investigation?

Include graphs.

Illustrations.

6-7 sentences .

Discussion

Explain the results as they pertain to the problem. How can this experiment help sensorimotor neural engineers?

5-6 sentences.

Conclusion

Did you solve the question? If yes, how can we make the process better? If no, then what did not work and what can be done to further investigate?

4-5 sentences.

References / Resources

Lesson Two: The Synapse/Action Potential

Center for Sensorimotor Neural Engineering
Lesson Plan Authors: Paul Zimmer, South Kitsap High School
and Denise Thompson, Orting High School

(This lesson plan is a direct adaptation of "Action Potential" from the 2014 Research Experience for Teachers Curriculum Unit, *Introduction to Neural Engineering: Neuroprosthetics & Brain-Computer Interfaces*. The lesson plan was written by Claudia Lemus, Science Teacher at TAF Academy).

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary: In this lesson, students will learn how the generation of action potentials by neurons includes the diffusion and transport of certain molecules across the membrane in order to create the electrochemical change that drives the signal down the axon. They will learn how the synapse uses neurotransmitters to communicate information from one neuron to the next.

STUDENT UNDERSTANDINGS

Big Ideas & Enduring Understandings:

- **Neurons:** Neurons (nerve cells) transmit information through the nervous system by using electrical signals within neurons and chemical signals (neurotransmitters) between neurons.
- **Action Potential:** The nervous system's communication method is via action potentials, which are electrochemical changes that originate in neurons, are propagated down their axons, and elicit a corresponding response in the adjacent neurons.
- **Synaptic Activity:** Chemicals called neurotransmitters pass from one neuron to another neuron within the synapse, the tiny gap between neurons. These neurotransmitters are released as part of an action potential that propagates down a neuron's axon.

Essential Questions:

- What does communication look like in neurons (chemically what happens to support the electrical message of a neuron)?
- What occurs at the synapse to communicate with another neuron (chemically what happens to support the electrical message of a synapse)?

Learning Objectives:

Students will know…

- The mechanism by which molecules diffuse across a membrane and the role of the concentration gradient in that mechanism.
- That the neuron uses the different concentration gradients of Na^+ and K^+ and channels within the membrane in order to elicit an action potential based on the reversing of the membrane charge.
- That the Na^+/K^+ pump actively restores the ion concentrations needed for the cell to go back to its resting potential.
- That an action potential signal is propagated down the length of an axon.
- The synapse is a space between neurons that a message is transferred by neurotransmitters.

Students will be able to…

- Analyze a model of an action potential being propagated down a neuron and identify the various mechanisms at play. These include diffusion and active transport of ions by membrane proteins.
- Understand how the synapse transfers information to another neuron.

Vocabulary:

- Action potential
- Axon
- Channel protein
- Concentration
- Concentration gradient
- Diffusion
- Na^+/K^+ pump
- Protein pump
- Resting potential
- Semi-permeable
- Dendrite
- Depolarization
- Neurotransmitters
- Polarization
- Postsynaptic
- Presynaptic
- Synaptic cleft

Standards Alignment: This lesson addresses the following high school Next Generation Science Standards (NGSS) and Common Core State Standards (CCSS).

NGSS Disciplinary Core Ideas (DCIs)

- **MS-LS1-3 Structure, Function, and Information Processing:** Conduct an investigation to provide evidence that living things are made of cells, either one cell or many different numbers and types of cells.

- **HS-LS1-2 Structure and Function:** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

Cross-Cutting Concepts:

- Systems and systems models

Science & Engineering Practices:

Common Core State Standards in English Language Arts:

Common Core State Standards in Mathematics:

MATERIALS

Note: The lesson is designed for a class of 28 students, divided up into two groups. Ultimately, you will need two groups for this activity. Adjust the group sizes and roles according to your own classroom context.

Material	Description	Quantity
Piece of string or yarn	Cut each piece to 15 feet long	2 per group
Small beads	Need two different colors. Use plastic pony beads or something similar	34 of one color; 26 of another color **per** group
Toilet paper tubes, paper towel tubes, or mailing tubes	Cut into small cylinders	6 small cylinders per group
Dominoes		56 per group
Blindfolds		2 per group
Index cards	Add tape on the back or a loop of string, to use as labels	1 per student
Skittles	Candy	2 bags

Cups	Plastic or paper	8 cups
Computer lab or laptops	For accessing websites and the action potential interactive animation	1 student or pair
Science notebooks		1 per student
Science posters	From *Lesson One*	1 per group
Student Handout 2.1	*Action Potential Race Analysis Chart*	1 per student
Optional Extension: ***Student Handout 2.2***	Optional extension activity. *Action Potential Interactive Animation*	1 per student
Optional Extension: ***Teacher Resource 2.2***	*Action Potential Interactive Animation Teacher Key*	1

TEACHER PREPARATION

1. Make copies of ***Student Handouts 2.1*** and ***2.2***, one of each per student.

2. Arrange for students to be able to use computers/laptops for the ***Explore*** section of the lesson.

3. Review the instructions below for action potential race set-up. First, watch this video for a demonstration of the set up and the student roles: https://www.youtube.com/watch?v=eLgsrE_JQ-4&feature=youtu.be

For each team:

- Lay the two pieces of string on a long set of tables (or on the floor if tables are not available), parallel to each other and about 2 feet apart.
- Place the two Na^+ channels (tubes) on opposite sides of the strings, toward one end, perpendicular to the string.
- Place 5 beads of one color on the inside part of the string, close to the Na^+ channel, and 12 beads of that same color in the same manner for the Na^+ channel across the way.

- Place the two K^+ channels (tubes) about two feet further down from the Na^+ channels, in the same manner.
- Place 8 beads of the other color on the inside part of the string, close to the K^+ channel, and 5 beads of that same color in the same manner for the K^+ channel across the way.
- Arrange two sets of upright 28 domino tiles, running parallel in a row following the channels, so that the line can cause a domino effect.
- Place the two Na^+/K^+ pumps (tubes) at the other end of the domino tile rows, on either side of the strings, lying perpendicular to the strings.
- **Special Note:** Connect two neurons so each team must race through two neurons. At the beginning and at the end of the first neuron put two cups for each group. One cup will have 15 skittles the other will none. When the team starts they must take the skittle from one cup and put them into the next cup to start the message.

Engage (5 min)

1. Entry task: Have students answer these two questions in their science notebooks, then do a share-out with the class.
    - What do you think happens in a neuron?
    - What do you know about the synapse?

2. Show video of an over of the synapse and how it fits into the nervous system.

    Nerve Synapse Video
    GABAY Medical Library, 3:15 minutes
    https://www.youtube.com/watch?v=rF0EMT8TR2M

Explore (30 min)

3. Using a computer lab or laptops, give students the following URLs (webpages from Neuroscience for Kids). Challenge them to explore and find out in more detail about what is happening in a neuron, synapse, and action potential. They should take notes and draw diagrams in their science notebooks to capture what they discover.

    https://faculty.washington.edu/chudler/introb.html#tn
    https://faculty.washington.edu/chudler/cells.html
    https://faculty.washington.edu/chudler/synapse.html
    https://faculty.washington.edu/chudler/son.html
    https://faculty.washington.edu/chudler/java/em.html
    https://faculty.washington.edu/chudler/ap.html

4. When finished, have the students continue working on the Big Idea drawing on their science poster (as introduced in ***Student Handout 1.1*** from *Lesson One*), adding magnified views of the neuron and synapse. Then, challenge students to re-write their explanations of the previous day's activity to include accurate terminology of the sensory motor system.

Elaborate (15 min) Action Potential Race

5. This game is designed so that the class is divided up into two teams. The teams are challenged to be the first to finish propagating their action potential down the length of their axon. The roles assigned are flexible. These instructions are written for a class of 24 students (two teams of 12). You can adjust the roles accordingly to fit the number of students in your class (or have more than 2 teams competing at a time).

6. Assemble the following materials.

Materials (per team) and what they represent:

- 34 beads of one color = Na^+
- 26 beads of another color = K^+
- 56 domino tiles (divided up into two sets of 28) = to simulate action potential being propagated down the axon
- 2 blindfolds = to simulate Na^+/K^+ pump not being able to work without ATP
- 2 Finish signs/flags = to signal the finish for the team
- 2 large pieces of string/yarn (about 15 feet in length each) = to signal the axon membrane
- 6 paper tubes = 2 for Na^+ channels, 2 for K^+ channels, 2 for Na^+/K^+ pumps

7. Assign the following roles to students in the team:

Student Roles in Each Team

- 2 students to be Na^+ channels
- 2 students to be K^+ channels
- 2 students to be domino "knockers"
- 2 students to be Na^+/K^+ pumps
- 2 students to be ATP molecules
- 2 students to be finish signalers

8. Before beginning, go over the roles of the students and the reason for the various configurations. Students should identify the higher concentration of Na^+ outside the cell and the higher concentration of K^+ inside the cell.

9. Explain how the simulation will work:

- Na^+ channel will open first, and will allow diffusion of Na^+ following its concentration gradient.
  - Beads from outside cell will go through paper tube into axon.
- K^+ channel will open next, and will allow diffusion of K^+ following its concentration gradient.
  - Beads from inside cell will go through paper tube out of axon.
- K^+ channel person will tap the domino knocker, who will in turn knock down the dominoes, and the "signal" will be propagated down the axon.
- At the same time, the ATP person will remove the blindfold from the Na^+/K^+ pump person, allowing him/her to do their job.
  - They will need to retrieve Na^+ and K^+ ions from earlier in the axon and "pump" them (through their tube) in the proper direction in order to restore the original levels (following 3 Na^+ : 2 K^+ ratio).
- When the last domino falls, the finish signalers will raise their hand to signal that their team finished. (**** This would be at the end of the second neuron for each team.)***

Evaluate (5 minutes): Analysis Charts

10. Hand out copies of ***Student Handout 2.1: Action Potential Race Analysis Chart***. Have students fill out the chart on the ***Student Handout***. Responses to these will be evaluated for understanding.

STUDENT ASSESSMENT

Assessment Opportunities

The following is a list of assessment opportunities related to this lesson:

- Responses to the entry task, recorded in students' science notebooks during the *Engage* section of the lesson.
- Notes and diagrams recorded in students' science notebooks during *Explore* section of the lesson.
- Responses on ***Student Handout 2.1:*** *Action Potential Race Analysis Chart.*

Student Metacognition

EXTENSION ACTIVITIES

Have students individually (or in pairs) use the following link to learn about how diffusion plays a role in allowing neurons to transmit action potentials. Have students answer the questions on ***Student Handout 2.2:*** *Action Potential Interactive Animation* as they watch and interact with the site. **Teacher Resources 2.2** provides an answer key to the handout.

> **Action Potential Interactive Animation**
> Harvard University
> http://outreach.mcb.harvard.edu/animations/actionpotential_short.swf

TEACHER BACKGROUND & RESOURCES

Background Information

Nerve signals travel from neuron to neuron by way of action potentials. Each neuron generates an action potential in an all or none form (either it fires or it does not). Once an action potential is generated, the cell uses the mechanism of passive and active transport through the membrane in order to propagate the signal down the axon. Because there is already a difference in ion and charge concentration between the inside and the outside of the cell, the action potential is generated and propagated when this electrochemical gradient is reversed. At rest, an axon is more negatively charged inside and more positively charged outside. Factors that contribute to this difference include a higher Na^+ concentration outside of the cell, and a higher concentration of negatively charged proteins within the cell. Potassium ions (K^+) are more highly concentrated inside the cell.

When the action potential begins, sodium channels open, and allow the passive diffusion of Na^+ into the cell. This reverses the charge from inside the cell and outside the cell, making the inside the cell more positively charged. Potassium (K^+) channels open next, and sodium channels close. This leads to the passive diffusion of K^+ out of the cell, and repolarizes the cell so that the inside of the axon is more negative once again. Lastly, sodium potassium pumps use active transport in order to transport Na^+ back out of the cell and K^+ back into the cell, in order to bring the cell back to its resting potential.

This process continues down the axon until it reaches the axon terminal.

Resources

Engagement activity is based on the Young Scientist Program – Diffusion and Membrane Permeability Teaching Kit (http://ysp.wustl.edu/).

The action potential race was inspired by Pom Pom Potential activity by the Genetics Science Learning Center (http://gslc.genetics.utah.edu/).

Citations

Photograph credit: Claudia Lemus and Renee Poitras setting up the action potential race. Eric Chudler, 2014. Center for Sensorimotor Neural Engineering.

Illustration credit: Biological neuron schema. Nicolas Rougier, Wikimedia Commons, 2007.

Genetics Science Learning Center. (2014, August 5). *Print-and-Go Index: Pom Pom Potential*. Teach.Genetics. Retrieved August 5, 2014 from http://teach.genetics.utah.edu/content/.

Lemus, Claudia. (2014) Lesson Five: Action Potential. In *Introduction to Neural Engineering: Neuroprosthetics & Brain-Comptuer Interfaces*, a curriculum produced by the Research Experience for Teachers Program. Center for Sensorimotor Neural Engineering.

The Young Scientist Program. (2014). *Diffusion and Membrane Permeability Teaching Kit.* Washington University Medical School. Retrieved August 5, 2014 from http://ysp.wustl.edu/TeachingKitsCurriculum.php#Diffusion.

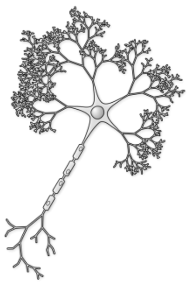
Student Handout 2.1 Action Potential Race Analysis Chart

Name:________________________________ Date:____________ Period:__________

Step	What does this model?
1. Skittles being moved to from one cup to another	
2. Na^+/K^+ pumps, put on your blindfolds	
3. Na^+ channels move beads into axon	
4. K^+ channels move beads out of axon	
7. The domino rows are knocked down	
9. The ATP molecule removes the blindfold from the Na^+/K^+ pump	
10. Na^+/K^+ pump retrieves beads from earlier in the axon and pumps 3 Na^+ out for every 2 K^+ in	
13. When the last domino has fallen, the finish signalers raise their hands	

Student Handout 2.2 Action Potential Interactive Animation

Name:_______________________________ Date:____________ Period:__________



First, go to:
http://outreach.mcb.harvard.edu/animations/actionpotential_short.swf

Next, read through the online tutorial and view the accompanying diagrams and simulations in order to familiarize yourself with action potentials.

Then, answer the following questions.

1. What is an axon?

2. At rest, an axon is shown to have a different charge between the cell interior and the cell exterior. Which of these two parts is normally negative and which is normally positive?

3. What happens to this charge difference between interior and exterior when an electrical current (action potential) travels down the axon?

4. What are ions?

5. What two ions do neurons use in order to create their membrane polarity?

6. What is the purpose of the channels found within the membrane of an axon?

7. When following their concentration gradient, do Na^+ ions diffuse into or out of the cell? Where was the higher Na^+ concentration to begin with then?

8. When following their concentration gradient, do K^+ ions diffuse into or out of the cell? Where was the higher K^+ concentration to begin with then?

9. What does the pump do? What does it require in order to do this?

10. Follow the directions for the exercise and place the appropriate ions where they belong.

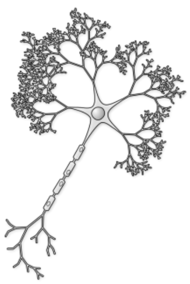
11. What is DEPOLARIZATION? What channel needs to open in order to make this happen?

12. What is REPOLARIZATION? What channel needs to open in order to make this happen?

13. After repolarization, what membrane protein restores the original concentrations of sodium and potassium?

14. How does this action potential in one axon relate to a person's brain directing a foot to move?

Teacher Resource 2.2 Action Potential Interactive Animation Teacher Key



First, go to: http://outreach.mcb.harvard.edu/animations/actionpotential_short.swf

Next, read through the online tutorial and view the accompanying diagrams and simulations in order to familiarize yourself with action potentials.

Then, answer the following questions:

1. What is an axon?
   An extension from a neuron through which an electrochemical signal is sent.

2. At rest, an axon is shown to have a different charge between the cell interior and the cell exterior. Which of these two parts is normally negative and which is normally positive?
   Cell interior is negative and cell exterior is normally positive.

3. What happens to this charge difference between interior and exterior when an electrical current (action potential) travels down the axon?
   The charges between interior and exterior switch.

4. What are ions?
   Atoms with a charge.

5. What two ions do neurons use in order to create their membrane polarity?
   Sodium (Na^+) and potassium (K^+).

6. What is the purpose of the channels found within the membrane of an axon?
   To allow ions to diffuse according to their concentration gradient in order for the charges to be reversed.

7. When following their concentration gradient, do Na^+ ions diffuse into or out of the cell? Where was the higher Na^+ concentration to begin with then?
   Na^+ ions diffuse into the cell because they start out more highly concentrated outside of the cell.

8. When following their concentration gradient, do K^+ ions diffuse into or out of the cell? Where was the higher K^+ concentration to begin with then?
   K^+ ions diffuse out of the cell because they start out more highly concentrated inside the cell.

9. What does the pump do? What does it require in order to do this?
   The pump restores the original concentrations of Na^+ ions outside the cell and K^+ ions inside the cell. It requires energy (ATP) to do this.

10. Follow the directions for the exercise and place the appropriate ions where they belong.

11. What is DEPOLARIZATION? What channel needs to open in order to make this happen?
    Depolarization is the reversal of the charges (between inside and outside of the cell). Na^+ channels need to open in order to make this happen.

12. What is REPOLARIZATION? What channel needs to open in order to make this happen?
    Repolarization is the reverting back to the original charges between inside and outside of the cell, with the cell interior being negative again and the cell exterior being positive again. K^+ channels need to open in order to make this happen.

13. After repolarization, what membrane protein restores the original concentrations of sodium and potassium?
    The pump is the protein that restores the original concentrations of sodium and potassium.

14. How does this action potential in one axon relate to a person's brain directing a foot to move?
    In order to move a foot, a person's brain has to send a signal down to the neurons whose axons extend into the foot in order to make the foot move. This signal is basically a series of action potentials that travel down the length of the person's body via the neurons and their axons.

Lesson Three: Designing a Synapse with the Neuron in Mind

Center for Sensorimotor Neural Engineering
Lesson Plan Authors: Paul Zimmer, South Kitsap High School
and Denise Thompson, Orting High School

LESSON OVERVIEW

Activity Time: Two 50 minute class periods.

Lesson Plan Summary: In this engineering design challenge, students will work with a set of provided lab materials to design, build, and optimize a circuit in order to meet the criteria of obtaining a certain voltage. The circuit will model the role of K^+ and Na^+ ions in the transmission of signals down the axon of a neuron and the role of chemical signals (neurotransmitters) in the synapse between neurons. Students will develop an understanding of the applications of foundational chemistry knowledge to the design and development of neural engineering devices.

STUDENT UNDERSTANDINGS

Big Ideas & Enduring Understandings:

- **Neurons:** Neurons (nerve cells) transmit information through the nervous system by using electrical signals within neurons and chemical signals (neurotransmitters) between neurons.
- **Synaptic Activity:** Chemicals called neurotransmitters pass from one neuron to another neuron within the synapse, the tiny gap between neurons. These neurotransmitters are released as part of an action potential that propagates down a neuron's axon.
- **Chemical & Electrical Signal Transmission**: Chemical and electrical functions are critical to the transmission of information between neurons.

Essential Questions:

- How does the experiment relate to sensorimotor neural engineering?
- What does the synapse do to send information from one neuron to another neuron?
- What chemistry is involved with the neuron?

Learning Objectives:

Students will know…

- The steps involved in experimental design and implementation.
- That K^+ and Na^+ flow into or out of the neuron to help transfer a signal down a neuron.
- Neurotransmitters help with transmitting information across a synapse.
- The role that the neuron and synapse play in sensorimotor neural engineering devices.

Students will be able to…

- Design a chemical experiment that will measure a given voltage in a solution of various concentrations, various electrodes, with electrodes at various distances. They will determine what gives the optimum voltage. This will relate to the optimum voltage for an action potential to relay information to the next neuron.

Vocabulary:

- Action potential
- Axon
- Dendrite
- Depolarization
- Electrodes
- Ions
- Neurotransmitters
- Polarization
- Postsynaptic
- Presynaptic
- Synaptic cleft
- Volt meter

Standards Alignment: This lesson addresses the following high school Next Generation Science Standards (NGSS) and Common Core State Standards (CCSS).

NGSS Disciplinary Core Ideas (DCIs)

- **HS-PS1-3:** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.
- **HS-PS1-6:** Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.
- **HS-ETS1-2 Engineering Design:** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- **HS-ETS1-3 Engineering Design:** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
- **HS-ETS1-4 Engineering Design:** Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

NGSS Crosscutting Concepts

- Stability and Change

NGSS Science & Engineering Practices

- Developing and using models.
- Planning and carrying out investigations.
- Constructing explanations and designing solutions.

Common Core State Standards—Literacy

- **WHST.9-12.5**: Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
- **WHST.9-12.7:** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- **WHST.11-12.8:** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

- **WHST.9-12.9:** Draw evidence from informational texts to support analysis, reflection, and research.
- **SL.11-12.5:** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

MATERIALS

Note: Materials are for a class of 30 students, with students working in 10 groups of 3 students/group. Adjust according to your classroom context.

Material	Description	Quantity
100mL dropper bottles of the following: ● 0.1M NaCl, KI, $CaCl_2$, $AlCl_3$ ● 1M NaCl KNO_3, $CaCl_2$, $AlCl_3$ ● 3 M NaCl KNO_3, $CaCl_2$, $AlCl_3$ ● Sugar in water ● Gatorade ● Pure water		10 bottles of each solution
Copper metal	Cut into 1x2 cm pieces	1 per group
Zinc metal	Cut into 1x2 cm pieces	1 per group
Aluminum metal	Cut into 1x2 cm pieces	1 per group
4 petri dishes		4 per group
Volt meter		1 per group
Ruler		1 per group
Science notebooks		1 per student
Sticky notes	To be used during Gallery Walk activity	Assortment
Student Handout 3.1	*Determining the Optimum Voltage*	1 per student
Student Handout 1.1	*Science Poster Template.* From *Lesson One*	1 per student
Teacher Resource 3.1	*Science Poster Scoring Rubric*	1

TEACHER PREPARATION

1. Make all solutions as listed in the **Materials** table.
2. Cut metals into 1x2 cm pieces.
3. Test set-up to make sure it works.
4. Make copies of ***Student Handout 3.1,*** one per student.
5. Divide students into groups of 2 or 3. (Lesson is written for 10 groups).

PROCEDURE

DAY 1

Engage: Engineering the Synapse (5 minutes)

1. As an entry task, ask students to answer the following question in their science notebooks and then turn and talk with a partner.
   - What are the differences between an engineer and a scientist?
   - Explain in your words how you would represent a synapse in a lab?

Explore: Optimize the Synapse Design Challenge (45 minutes)

2. Introduce the lab. Then, divide students into groups of 2-3.

3. Distribute copies of ***Student Handout 3.1***. Review the lab procedures on the handout.

4. Guide students on how use a volt meter.

5. Allow time for students to work in their lab groups to complete the engineering design challenge. While students are working, have students keep in mind their science poster project that was introduced in *Lesson One*. Students should take notes and make drawings in their science notebooks to help them later complete their science posters.

6. Allow time at the end of the class period for students to report-out on their progress and to clean up their lab stations.

DAY TWO

Explain: Science Posters (35 minutes)

7. Students will now complete their science poster using the notes and sketches that they made in their science notebooks. Students should follow the poster template that was handed out in *Lesson One*.

Elaborate: Poster Gallery Walk (15 minutes)

8. Hang posters up around the room for a poster gallery walk.

9. Hand out sticky notes to each student. Students will peer-review the other groups' posters, write feedback on the sticky notes, and add them to each poster, as described below:
   a. On one sticky note, students will ask one question that helps clarify a process on the poster.
   b. On another sticky note, students will put a letter grade and a grade out 20 points and stick it on the back of the poster.

Evaluate: Grading the Posters

10. You can grade each poster using the poster scoring rubric provided on ***Teacher Resource 3.1***. When grading, take into consideration the peer review (the grades that students put on the back of each poster).

STUDENT ASSESSMENT

Assessment Opportunities

The following is a list of assessment opportunities related to this lesson:

- Responses to the entry task, recorded in students' science notebooks during the *Engage* section of the lesson.
- Notes and diagrams recorded in students' science notebooks during *Explore* section of the lesson.
- Each group's final science poster can be assessed using the rubric provided on ***Teacher Resource 3.1.***

Student Metacognition:

Extension Activities:

Adaptations:

TEACHER BACKGROUND & RESOURCES

Background Information:

Resources:

Neuroscience for Kids provides excellent resources about many neuroscience topics, including the synapse and action potentials.

Neuroscience for Kids
http://faculty.washington.edu/chudler/synapse.html
http://faculty.washington.edu/chudler/ap.html

Citations:

Chudler, E.H. (1996-2010). "Lights, Camera, Action Potential." Neuroscience for Kids. https://faculty.washington.edu/chudler/ap.html

Chudler, E.H. (1996-2010). "The Synapse". Neuroscience for Kids. https://faculty.washington.edu/chudler/synapse.html

Student Handout 3.1 Determining the Optimum Voltage

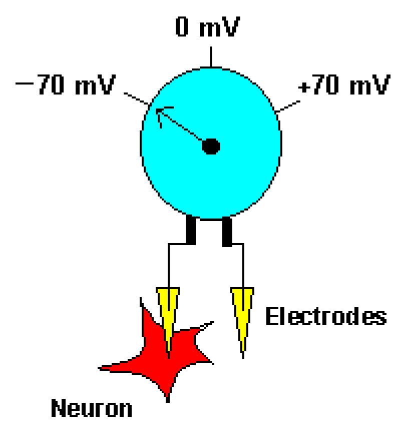
Name ________________________________ Date __________________ Period _____________

Background Information:
(Courtesy of Neuroscience for Kids)

Neurons have specialized projections called **dendrites** and **axons**. Dendrites bring information to the cell body and axons take information away from the cell body. Information from one neuron flows to another neuron across a **synapse**. The synapse contains a small gap separating neurons. The synapse consists of:

1. A presynaptic ending that contains **neurotransmitters**, mitochondria, and other cell organelles.
2. A postsynaptic ending that contains receptor sites for neurotransmitters.
3. A synaptic cleft or space between the presynaptic and postsynaptic endings.

When a neuron is not sending a signal, it is "at rest." When a neuron is at rest, the inside of the neuron is negative relative to the outside. Although the concentrations of the different ions attempt to balance out on both sides of the membrane, they cannot because the cell membrane allows only some ions to pass through channels (ion channels). At rest, potassium ions (K^+) can cross through the membrane easily. Also at rest, chloride ions (Cl^-) and sodium ions (Na^+) have a more difficult time crossing. The negatively charged protein molecules (A^-) inside the neuron cannot cross the membrane.



In addition to these selective ion channels, there is a **pump** that uses energy to move three sodium ions out of the neuron for every two potassium ions it puts in. Finally, when all these forces balance out, and the difference in the voltage between the inside and outside of the neuron is measured, you have the **resting potential**. The resting membrane potential of a neuron is about -70 mV (mV=millivolt) - this means that the inside of the neuron is 70 mV less than the outside. At rest, there are relatively more sodium ions outside the neuron and more potassium ions inside that neuron.

Design Question
What is the best practice to give you the optimum voltage between -0.15v and -0.17v?

Materials

0.1M NaCl, KI, $CaCl_2$, $AlCl_3$
1M NaCl KNO_3, $CaCl_2$, $AlCl_3$
3 M NaCl KNO_3, $CaCl_2$, $AlCl_3$
Sugar in water
Gatorade
Pure water
Copper metal
Zinc metal
Aluminum metal
4 petri dishes
Volt meter
Ruler

Design your experiment using the following guidelines. Your teacher will give you one of three variables to test:

1. Concentration of solution
2. Type of electrode
3. Distance electrodes are from each other.

In your design you will have a minimum of 5 trials. Describe how you will collect data. Have your teacher approve your design before beginning the experiment.

When finished with the experiment compile your data and be ready to make a short presentation of your findings (2-3 minutes). While listening to other groups' presentations, be thinking of ways you can improve your experiment.

Take what have learned from the other groups and take 5 minutes to redesign your experiment to make your output of voltage at the optimum.

During your experiment keep a detailed science notebook/lab book of the process, results, and discussions as you will use this information to complete you science poster.

Teacher Resource 3.1: Science Poster Scoring Rubric

Teacher Name:

Student Name:

CATEGORY	4	3	2	1
Introduction	The purpose of the lab or the question to be answered during the lab is clearly identified and stated.	The purpose of the lab or the question to be answered during the lab is identified, but is stated in a somewhat unclear manner.	The purpose of the lab or the question to be answered during the lab is partially identified, and is stated in a somewhat unclear manner.	The purpose of the lab or the question to be answered during the lab is erroneous or irrelevant.
Methods	Procedures are listed in clear steps. Each step is numbered and is a complete sentence.	Procedures are listed in a logical order, but steps are not numbered and/or are not in complete sentences.	Procedures are listed but are not in a logical order or are difficult to follow.	Procedures do not accurately list the steps of the experiment.
Results	Professional looking and accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.	Accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.	Accurate representation of the data in written form, but no graphs or tables are presented.	Data are not shown OR are inaccurate.
Discussion	The relationship between the variables is discussed and trends/patterns logically analyzed. Predictions are made about what might happen if part of the lab were changed or how the experimental design could be changed.	The relationship between the variables is discussed and trends/patterns logically analyzed.	The relationship between the variables is discussed but no patterns, trends or predictions are made based on the data.	The relationship between the variables is not discussed.
Drawings/Diagrams	Clear, accurate diagrams are included and make the experiment easier to understand. Diagrams are labeled neatly and accurately.	Diagrams are included and are labeled neatly and accurately.	Diagrams are included and are labeled.	Needed diagrams are missing OR are missing important labels.
Totals				

Lesson Four: Neuroethics and Brain-Computer Interfaces

Center for Sensorimotor Neural Engineering
Lesson Plan Authors: Paul Zimmer, South Kitsap High School
and Denise Thompson, Orting High School

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary: In this lesson, students will read an article introducing them to some of the societal and ethical implications of neural engineering devices, with a specific focus on security and privacy issues surrounding Brain-Computer Interfaces (BCIs). Students will align themselves with "agreeing" or "disagreeing" with a statement about the article, and then discuss their opinion with evidence from the article.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- **Neuroethics:** By examining the ethical implications of neural engineering devices—such as Brain-Computer Interfaces—we can make connections between our scientific understanding of the sensorimotor neural system and applications to the real world.

Essential Question:

- Should BCIs and neuron transmission be monitored for more than just scientific applications, or should we consider social and ethical implications as well?

Learning Objectives:

Students will know…

- Neural engineering innovations, including BCIs, have ethical implications that diverse groups of people are currently evaluating (including engineers, end-users, lawyers, ethicists, and more).
- Basic understandings of how BCIs work.

Students will be able to…

- Read a scientific journal article and identify evidence that supports a statement.
- Identify several threats to BCI devices (such as hacking, security threats, and privacy threats) and make connections to their ethical and societal implications.
- Engage in a philosophical debate, using evidence from a journal article to validate and support their claims and opinions.

Vocabulary:

- Brain-Computer Interfaces (BCIs)
- Neuroethics
- Brain spyware

- Brain fingerprints
- Neuromarketing

Standards Alignment: This lesson addresses the following high school Next Generation Science Standards (NGSS) and Common Core State Standards (CCSS).

NGSS Understandings about the Nature of Science and Cross-Cutting Concepts

- Science is a human endeavor.
- Science addresses questions about the natural and material world.

NGSS Science & Engineering Practices

- Engaging in argument from evidence.
- Obtaining, evaluating, and communicating information.

Common Core State Standards—Literacy

- **RH.9-10.4:** Determine the meaning of words and phrases as they are used in a text, including vocabulary describing political, social, or economic aspects of history/social science.
- **RST.9-10.7:** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.
- **WHST.9-10.8:** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- **WHST.9-10.9:** Draw evidence from informational texts to support analysis, reflection, and research.

MATERIALS

Material	Description	Quantity
Copies of the article "App Stores for the Brain."	Tamara Bonaci, Ryan Calo, and Howard Chizeck, 2015. "App Stores for the Brain." *IEEE Technology and Society Magazine* June 2015: 32-39. http://brl.ee.washington.edu/eprints/9/	1 per student
Student Handout 4.1	*Philosophical Chairs: Rules of Engagement*	1 per student
Student Handout 4.2	*Philosophical Chairs: Written Evaluation Sheet*	1 per student
Student Handout 4.3	*Philosophical Chairs: Reflection*	1 per student

TEACHER PREPARATION

1. Access the article, “App Stores for the Brain,” from the EPrints website: http://brl.ee.washington.edu/eprints/9/.

2. Read the article “App Stores for the Brain.” Create a central statement about the article that will be discussed.

3. Go through the article and assign a letter of the alphabet to each major heading in the article. Within each major heading, number each paragraph starting over at one for each major heading. Then, make copies of the annotated article, one per student.

4. Print out copies of the article as well as *Student Handouts 4.1, 4.2,* and *4.3*, one per student.

PROCEDURE

Note: The Philosophical Chairs activity, procedures, and Student Handouts are an adaptation of an activity of the same name from AVID’s *The Write Path 1 Science Teacher Guide.* Copyright 2012. Used with permission from AVID Center.

Engage: Privacy, Security, and BCIs (5 minutes)

1. Tell students to Turn and Talk with a neighbor and discuss the following:
    - If you had a brain implant and someone developed the technology to hack your implant and read your thoughts, how would you feel?
    - What kind of information would you want to protect?
    - Should brain hacking be illegal?
    - Should the government protect people with these types of implants?

Explore: Agree/Disagree (2 minutes)

2. Present a central statement about the article to the students. The statement should be one that will divide the class into those who agree with the statement and those who disagree with the statement. Be sure that the statement is written on the board for reference during the activity. (**Note:** Allowing for a group of students who are undecided is addressed later in these guidelines.)

3. Have students write down the central statement in their science notebooks for later discussion.

Explain: App Stores for the Brain Article (30 minutes)

4. Break students up into groups of four. Distribute copies of the article, “App Stores for the Brain.”

5. Have each student read the article. While reading, have them pick out four statements that support their personal opinions about the central statement. They should circle or highlight these statements.

Elaborate: Philosophical Chairs (10 minutes)

6. Set up chairs/desks in two groups facing each other, with about half facing one way and half facing the opposite way. Students who agree with the central statement will sit on one side and those who disagree will sit on the other side.

7. Refer to *Student Handout 4.1* for students' rules of engagement for the Philosophical Chairs activity.

8. A mediator, who will remain neutral and call on sides to speak, is positioned between the two sides. (This role is usually filled by the teacher if this is the first time engaging in a philosophical debate. Eventually, students should take on this role.) In addition to facilitating the discussion, the mediator may at times paraphrase the arguments made by each side for clarification. It is important that the mediator always remains neutral.

9. The mediator identifies someone from the side of the classroom that agrees with the central statement to begin the discussion with an argument in favor of the position stated. Next, the mediator will identify someone from the other side to respond to the argument. This continues throughout the activity. Part of the job of the mediator is to ensure participation by as many students as possible and to keep just a few students from dominating the discussion. The mediator may also put a time limit on how long each side addresses the issue on each turn.

10. In addition to speaking in the discussion, students may express their opinions by moving from one side to other. Anyone may change seats at any time. Changing seats does not necessarily mean that a person's mind is changed, but rather that the argument made is compelling enough to sway opinions. Students may move back and forth throughout the discussion.

11. The discussion and movement go on for a designated period of time—usually one class period. The mediator may bring the discussion to a close at any time. Each side may be given an opportunity to make a final statement on the issue. If time allows, each participant states his/her final opinion and may also tell which arguments he/she found most convincing.

12. An additional piece to this activity can be to have a few students observe the process and take notes instead of participating. These students will debrief their observations to the class at the end of the activity. You may have students who were absent or unprepared to participate fulfill this role.

Evaluate: Reflection (2 minutes)/homework

13. Leave time at the end of the period for students to reflect on the activity. Refer to *Student Handouts 4.2 and 4.3* for evaluation and reflection. Students may begin the reflection in class and finish it for homework.

STUDENT ASSESSMENT

Assessment Opportunities

- *Student Handouts 4.2 and 4.3* provide opportunities for student reflection and for assessment.

Extension Activities

- Once students are accustomed to the Philosophical Chairs format, you may choose to add this additional component: You may add a third section of seats with a few chairs for students who are **undecided**. This section is placed between the two opposing sides. During the discussion, you may allow students from the undecided section to participate, or you may require that they take a position before participating. Students may move from the sides that agree or disagree with the statement to the undecided section if they wish. Before you end the discussion, require that all students still seated in the undecided zone move to one side or the other depending on which they believe made the most compelling arguments.

- Additional questions for discussion or reflection:

  1. What are some ways in which genetic information can be used unethically or illegally? Could neural signals be used in the same ways?
  2. How is studying a BCI user's neural signals different from studying someone's genome? Should people have the right to keep their neural signals private? Why or why not?
  3. How can we protect people from "brain spyware"?
  4. Should we allow companies to pursue "neuromarketing" techniques?

TEACHER BACKGROUND & RESOURCES

Background Information:

Read the article before implementing this lesson. Also review the suggested Extension Activities to determine if you want to use these activities ideas or not.

Resources:

Tamara Bonaci, Ryan Calo, and Howard Chizeck, 2015. "App Stores for the Brain." *IEEE Technology and Society Magazine*, June 2015: 32-39. Available from the EPrints website: http://brl.ee.washington.edu/eprints/9/

Abstract: Brain computer interfaces (BCIs) that allow users to interface with computers through carefully trained thought procedures are now a reality. To work with this BCI technology, software companies are developing applications so that users can control a computer mouse or keyboard, play an arcade game, or exercise their memory and attention. However, not all these applications are beneficial. Some companies have developed "brain spyware" – applications for BCIs that can extract personal data such as credit card PINs, addresses, and birthdates. Companies have also proposed using neural signals to create "brain fingerprints" that would determine whether information about a person is true, while others have suggested studying neural responses to marketing to develop "neuromarketing" techniques.

Citations:

Molloy, K., Arno, K., Martin, M., and Robinson, D. (2012). "Philosophical Chairs" lesson plan. In *The Write Path 1 Science Teacher Guide*. AVID Center.

Bonaci, T., Calo, R., and Chizeck, H.J. (2014). "App Stores for the Brain: Privacy and Security in Brain-Computer Interfaces." *IEEE Technology and Society Magazine*, June 2015: 32-39.

Sullivan, L.S and Soloff, H. (2015). *Neuroethics Case Studies Discussion Question*s. Center for Sensorimotor Neural Engineering.

Student Handout 4.1: Philosophical Chairs—Rules of Engagement

Name:___________________________ Date:______________ Period:__________

Rules of Engagement

1. Be sure you understand the central statement or topic before the discussion begins. Decide which section you will sit in.

2. Listen carefully when others speak and seek to understand their arguments even if you don't agree.

3. Wait for the mediator to recognize you before you speak; only one person speaks at a time.

4. You must first summarize briefly the previous speaker's argument before you make your response.

5. If you have spoken for your side, you must wait until three other people on your side speak before you speak again.

6. Be sure that when you speak, you address the ideas, not the person stating them.

7. Keep an open mind, and move to the other side or the undecided section if you feel that someone made a good argument or your opinion is swayed.

8. Support the mediator by maintaining order and helping the discussion to progress

Molloy, K., Arno, K., Martin, M., and Robinson, D. (2012). "Philosophical Chairs" lesson plan. In *The Write Path 1 Science Teacher Guide*. AVID Center.

Student Handout 4.2: Philosophical Chairs--Written Evaluation Sheet
Name:___________________________ Date:______________ Period:__________

Directions: Answer each of the following questions about today's Philosophical Chairs activity in a few sentences.

1. What was the most frustrating part of today's discussion?

2. What was the most successful part?

3. What statements led you to change your seat or to remain sitting in your original position?

4. What conclusions can you draw about how you form your beliefs based on today's discussion?

5. What would you change about your participation in today's activity? Do you wish you had said something that you did not? Did you think about changing seats but didn't? Explain.

Molloy, K., Arno, K., Martin, M., and Robinson, D. (2012). "Philosophical Chairs" lesson plan. In *The Write Path 1 Science Teacher Guide*. AVID Center.

Student Handout 4.3: Philosophical Chairs Reflection

Name:____________________________ Date:______________ Period:__________

Directions: Provide a written reflection of the philosophical discussion you heard in class. Be sure you include the following in your reflection points:

- The statement that was discussed.
- The arguments for the statement.
- The arguments against the statement.
- Your position and reasons for this position.
- Whether or not you changed your mind during the discussion, which arguments swayed your thinking, and why.

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Molloy, K., Arno, K., Martin, M., and Robinson, D. (2012). “Philosophical Chairs” lesson plan. In *The Write Path 1 Science Teacher Guide*. AVID Center.