Introduction to Neural Engineering:

Neuroprosthetics & Brain-Computer Interfaces

A Curriculum Unit for Grades 6-12 STEM Classes

CENTER FOR SENSORIMOTOR NEURAL ENGINEERING

Research Experience for Teachers (RET) Program

Draft for Piloting, September 2014

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

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NSF

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Neural Engineering Project Rubric

Alignment to National Learning Standards

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

	1: Entry Event	2: Intro to Systems	3: Reaction Time Lab	4: SpikerBox Lab Part I	5: Action Potential	6: SpikerBox Lab Part II	7: Neural Engineering	8: Intro to Neuroethics	9: Arduino Uno	10: Pugh Charts	11: Searches & Abstracts	Final Project
Engineering, Technology, and Applications of Science												
MS-ETS1-1 Engineering Design: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.				🧠		🧠	🧠	🧠	🧠	🧠		🧠
MS-ETS1-2 Engineering Design: Evaluate competing design solutions using a systemic process to determine how well they meet the criteria and constraints of the problem.										🧠		
Life Sciences												
MS-LS1-3 Structure, Function, and Information Processing: Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.			🧠	🧠	🧠	🧠						
MS-LS1-8 Structure, Function, and Information Processing: Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.			🧠	🧠		🧠		🧠				

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: Middle School (Grades 6-8)

	1: Entry Event	2: Intro to Systems	3: Reaction Time Lab	4: SpikerBox Lab Part I	5: Action Potential	6: SpikerBox Lab Part II	7: Neural Engineering	8: Intro to Neuroethics	9: Arduino Uno	10: Pugh Charts	11: Searches & Abstracts	Final Project
WHST.6-8.7 Writing: Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.												
WHST.6-8.8 Writing: Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard form for citation.												
RST.6-8.3 Key Ideas & Details: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.												
RST.6-8.4 Craft & Structure: 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 6-8 texts and topics*.												

RST.6-8.7 Integration of Knowledge & Ideas: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).												

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.

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

	1: Entry Event	2: Intro to Systems	3: Reaction Time Lab	4: SpikerBox Lab Part I	5: Action Potential	6: SpikerBox Lab Part II	7: Neural Engineering	8: Intro to Neuroethics	9: Arduino Uno	10: Pugh Charts	11: Searches & Abstracts	Final Project
Engineering, Technology, and Applications of Science												
HS-ETS1-1 Engineering Design: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.				✓		✓	✓	✓	✓	✓		✓
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.				✓		✓			✓			✓

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.											
HS-LS1-3 Structure and Function: Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.											
Physical Sciences											
HS-PS3-3 Energy: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.											

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: Entry Event	2: Intro to Systems	3: Reaction Time Lab	4: SpikerBox Lab Part I	5: Action Potential	6: SpikerBox Lab Part II	7: Neural Engineering	8: Intro to Neuroethics	9: Arduino Uno	10: Pugh Charts	11: Searches & Abstracts	Final Project
RST.9-10.3 Key Ideas & Details: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.												
RST.11-12.3 Key Ideas & Details: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.												
RST.9-10.4 Craft & Structure: 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 Integration of Knowledge & Ideas: Integrate 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.												

RST.11-12.7 Integration of Knowledge & Ideas: Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.												
WHST.9-10.7 & WHST.11-12.7 Writing: 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 Writing: 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 citations.												

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.

Lesson One: Entry Event - Launching the Neuroprosthetics Project

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Steve Pratt, Cleveland High School, Seattle, WA

LESSON OVERVIEW

Activity Time: One to two 50 minute class periods. With a guest speaker, two 50 minute class periods or perhaps one long block period. Without a guest speaker, one 50 minute class period.

Lesson Plan Summary: In this lesson, students will be introduced to the Neuroprosthetics unit. They will learn the purpose and required outcomes of the neural engineering project through a memorable entry event.

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:

Students will understand that…

- **Neural Prosthetics:** Neural prosthetics can be used to restore or enhance human function.
- **Neural Engineering:** Neural engineering is based on the loop between sensory information that is received by the brain, information that the central nervous system (CNS) sends out, and computers/machines that receive input and produce outputs that feed back into the CNS.

Essential Questions:

- How can science play a role in improving the lives of injured veterans returning from war?
- What is neural engineering and how can it be used to improve the lives of people?

Learning Objectives:

Students will know…

- What neural engineering is.
- What a neural prosthetic is.
- The requirements and objectives for the neural engineering project.

Students will be able to…

- Articulate the main learning objectives of this project and how they will use them to develop their own neural engineering models.

Standards Alignment: This lesson is intended as a simple introduction/hook activity for the project and is not clearly aligned to specific learning standards.

Common Preconceptions & Misconceptions:

- Robotic systems and the human brain operate using two completely different systems.
- Every problem has one "perfect" solution that can be developed quickly.

MATERIALS

Material	Quantity
Student Handout 1.1: Neuroprosthetics Project Entry Document	1 per student
Introduction to Neural Engineering Powerpoint	1 copy (for teacher use)
Student Handout 1.2: Neuroprosthetics Project T-Chart	1 copy to display on screen
Student Handout 1.3: Exit Ticket—Introduction to Neural Engineering	1 per student
Chart paper and pens for making large t-chart	1 sheet
Classroom computer, projector, speakers, internet access for displaying PowerPoint presentation and videos	As needed

TEACHER PREPARATION

1. If a guest speaker is desired (see below in *Procedure*), arranging the speaker will take some advance planning. Do this as early as you can.
2. Make copies of ***Student Handouts 1.1, 1.2,*** and ***1.3,*** one each per student.
3. Make a larger version of the t-chart on ***Student Handout 1.3*** on chart paper.
4. Download and review the **Introduction to Neural Engineering** Powerpoint. Ensure embedded videos are working prior to showing class. Prepare for presentation.

PROCEDURE

Note to Teacher: To introduce this unit, you can choose from several different paths to help "hook" the students:

- **Path 1:** Use a guest speaker to help "hook" the students. Ideas include:
  - Make contact with the local VA hospital or clinic to see if a veteran with some kind of (neuro)prosthetic could come share with the students their story and life with a prosthetic. Ask the speaker to share on life before vs. after having a prosthetic.
  - Invite a person with a cochlear implant to talk with the students. Cochlear implants are one of the most successful brain-computer interfaces currently in use.
  - Invite a professor or graduate student team from a local university (or even the CSNE if you teach near Seattle) to present a short talk on the advancements and current research in the field of neural engineering.
- **Path 2:** Introduce the field of neural engineering using the suggested PowerPoint and YouTube videos.
- **Path 3:** Do a combination of Paths 1 & 2, or your own unique "hook".

After that, you'll want to give students the Entry Document so that they can read it, understand the format of the project, and get any questions answered they might have.

This project is to be done in groups. It is up to you to decide how you want students to break into their groups. It can be done either before this Entry Event or after the Entry Event.

Engage

1. Introduce guest speaker to the class. If they need a PowerPoint or whiteboard to present, allow them access to this beforehand. As speaker presents, have students take notes (optional) or think of questions to ask the speaker.

2. Distribute ***Student Handout 1.1: Neuroprosthetics Project Entry Document***, one per student. Allow time for students to read the document.

Explore

3. Distribute ***Student Handout 1.2: Neuroprosthetics Project T-Chart***. As they reflect on the Project Entry Document, students need to record at least five "Know's" about the project and at least five "Need to Know's" about the project.

4. After five to ten minutes of reading silently and independently filling out this chart, complete as a class the "Knows" and "Need to Know's" on a large version of the t-chart on chart paper. This will give a more complete list of all the requirements for the project as well as address students' questions.

Explain

5. Write the Problem Statement as a class, which is essentially an overarching question for the project that you can refer back to throughout the unit. It usually follows the format of "How do we as __________ do ___________ so that __________?" The first blank would be the students' roles on the project (engineers, designers, etc.), the second would be what they are actually doing (presenting a model of a neural prosthetic), and the third is the real world relevant "why" of what this project is trying to solve or model. An example would be: *How do we as engineers develop a model of a neuroprosthetic so that we can better understand the nervous system?*

6. Complete the "Next Steps" section of the t-chart with the students to show them the lesson flow for the unit. This will show students how their "Need to Know's" will flow into the activity list for the unit. It should be the following:
   a. What is a system? (*Lesson Two: Introduction to Systems*)
   b. More about systems (*Lesson Three: Reaction Time Lab*)
   c. What is a neural system? (*Lesson Four: SpikerBox Lab—Part I*)
   d. Neurons and action potential (*Lesson Five: Action Potential*)
   e. Analyzing neural spikes (*Lesson Six: SpikerBox Lab—Part II*)
   f. Brain-Computer Interfaces (*Lesson Seven: Neural Engineering & Brain-Computer Interfaces)*
   g. What ethical issues are involved? (*Lesson Eight: Introduction to Neuroethics*)
   h. Electronic systems (*Lesson Nine: Getting to Know the Arduino Uno*)
   i. Design your neuroprosthetic (Independent group work)
   j. Peer feedback on models and re-design (*Lesson Ten: Pugh Chart & Peer Review*)
   k. *Optional:* Online research and abstracts (*Lesson Eleven: Online Searches & Writing Abstracts)*
   l. Final presentation

Elaborate

7. Show students the **Introduction to Neural Engineering** PowerPoint presentation, which features embedded videos illustrating how neural engineers seeks to use science and math to solve real-world problems.

Evaluate

8. With any remaining time in class, have students complete a neural engineering reflection as an Exit Ticket. Either distribute copies of Student Handout 1.3: Exit Ticket, or share the prompts with students for them to turn in digitally or in their science notebook.

STUDENT ASSESSMENT

Assessment Opportunities

- Students will complete an Exit Ticket (see Step 8 in *Procedure* above) that will be a reflection on what they now know about neural engineering as a result of this activity.

Student Metacognition

- Students will use the “Knows / Need to Know’s” list to be a goal-setting reference list for students so that they can anticipate the specific activities and outcomes that will help them complete their project.

Scoring Guide

- Student work will not be “scored” for correctness in any of these introductory activities. Instead, it can be graded for completion or just used for formative assessment purposes (i.e. what did students understand from the activity)

EXTENSION ACTIVITIES

Extension Activities:

- Provide a homework assignment that asks students to watch the videos below (see *Resources*) and asks them to make connections to the fundamental ideas in the lesson about neural engineering.

Adaptations:

- For students who struggle in reading, ask them to complete only the “Know’s” section of the document.
- Incorporate a demonstration into the PowerPoint to keep the activity centered on experiential science.
- Reduce the PowerPoint to only a few slides and videos to limit time.
- If more structure is desired, provide response questions after every video that students see. These can be a set of questions that are consistently used to both increase student engagement as well as thinking. Example: *Describe what you saw. What problem was being addressed? How did they use neural engineering to solve it?*

TEACHER BACKGROUND & RESOURCES

Background Information

- The **Introduction to Neural Engineering** PowerPoint presentation provides a lot of background information on the scope, purpose, and development of the neural engineering discipline. Going through this will provide the teacher with a relatively good background on the field.
- **CSNE Braintech Journal from Dr. Lise Johnso**n is a collection of writings that unpack current CSNE research in neural engineering. (http://www.csne-erc.org/csne-blogs/braintech-journal)
- **Research @ CSNE** provides a quick summary of the different foci of research for the CSNE. (http://www.csne-erc.org/research)

Resources

The following videos could be used for Extension Activities or incorporated as further engaging student "hooks" for this activity:

Can Robots Become More Human?
National Geographic, July 13, 2013 (3:05 minutes)
http://video.nationalgeographic.com/video/news/jenkins-robot-vin

7 Myths about the Brain Debunked
ASAP Science, July 6, 2014 (2:43 minutes)
http://www.youtube.com/watch?v=DfgkAJmp9-A

Citations

Powerpoint: Intro to Neural Engineering, used with permission of the author, Lise Johnson, Ph.D, Center for Sensorimotor Engineering

Image of boy hearing for first time. Source: http://www.dailymail.co.uk/health/article-1283703/Moment-deaf-baby-Jonathan-hears-mothers-voice-time.html

Image of robotic bioprosthetic leg on treadmill.
Source: http://www.gizmodo.com.au/tags/prosthetics/page/2/

Image of robotic arm schematic.
Source: http://starwarsfanclub2.wordpress.com/2011/03/18/anakins-machanical-arm/

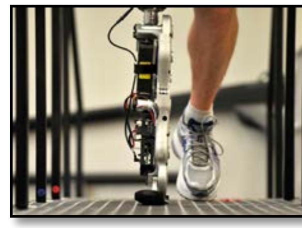
Image of woman feeding herself using a neuroprosthetic .
Source: http://www.ineffableisland.com/2012/12/giant-medical-leap-mind-controlled.html

Student Handout 1.1 Neuroprosthetics Entry Document

Name:________________________________ Date:__________________ Period:__________

Imagine...

...a world where infants who could not hear can finally hear their mother's voice.



...a world where veterans with amputated limbs could have more than just a steel pole for a prosthetic.

...a world where a person with quadriplegia who cannot use any of their limbs can learn to control robotic arms with their mind.

This "imaginary" world isn't just possible...it's becoming reality. And all of this is made possible by the field of neural engineering, which we will study during your next project.

So what is neural engineering?

Neural engineering is a field of engineering that focuses on integrating the nervous system, which controls how you move, feel, and interact with the world around you. The nervous system as you may know includes your brain, spinal cord, motor nerves to control your movement, and sensory nerves to gather information from the world around you. Without your nervous system, you would not be "you": your personality, your intelligence, your desires all come from your nervous system.

Engineering is the key to repairing and utilizing the nervous system. Engineering is basically the practice of using math and science to solve real-world problems. The world as we know it is in disrepair, and more than ever we need engineers to help solve our world's problems.

For this project, you will become an engineer—you will use science, research, and even a bit of programming to model and improve a neuroprosthetic.

Full disclaimer here: We recognize that you as a high school student will not actually create nor understand all the inner workings of a real-life neuroprosthetic[1]. That takes years of study, research, and access to a lot of money. However, your research team will make a **model** of your potential neuroprosthetic. Remember, a model is a representation of the real thing—so it could be physical or digital in form.

Neuroprosethtics are complicated systems of inputs, outputs, sub-systems, and feedback loops. In order to understand the main idea of how neural engineers create a neuroprosthetic system, we will need to learn what makes up a system. Then, we'll learn about the nervous system and bring together the world of electronics with the world of neural engineering in the one of a kind system known as a...cockroach leg. Yes, like a real cockroach leg. We'll be examining cockroach legs and seeing how they model the type of system you'll be modeling for your own neuroprosthetic.

What exactly will your group be doing? Each group will be responsible for the following:

- Conduct research related to a neuroprosthetic to explain how it works.
- Address any ethical concerns related to the real-world use of your neuroprosthetic.
- Use a SpikerBox to record real, live nerve action potentials.
- Creating your digital or physical model of your neuroprosthetic.
- Create a physical OR digital model of an improved version of your neuroprosthetic.
- Presenting your neuroprosthetic model to the class in a formal presentation.

...you didn't think that neural engineering would be easy, would you?

But it is a lot of fun. Let's get learning. And thanks to the generous folks at the University of Washington and the Center for Sensorimotor Neural Engineering, we'll have access to some gadgets that will make our learning about systems even more interesting.

And now, let's get engineering!

[1] Because, well, if you did, I would take full credit for being your inspirational science teacher and you'd hopefully give me 50% of your billion-dollar royalties and fame so that I could finish re-modeling my basement.

Student Handout 1.2: Neural Engineering Project T-Chart

Name:________________________________ Date:__________________ Period:__________

Know's	Need to Know's

Problem Statement

Next Steps

Student Handout 1.3: Exit Ticket—Introduction to Neural Engineering

Name:________________________________ Date:__________________ Period:__________

1. Based on today's lesson, how would you define the term "neural engineering?" Explain.

2. What was one thing that surprised you the most from the lesson on neural engineering OR the guest speaker? Why was it surprising?

3. What questions or ideas do you have after today's presentation?

4. How can you use the information today for your project?

Student Handout 1.3: Exit Ticket—Introduction to Neural Engineering

Name:________________________________ Date:__________________ Period:__________

1. Based on today's lesson, how would you define the term "neural engineering?" Explain.

2. What was one thing that surprised you the most from the lesson on neural engineering OR the guest speaker? Why was it surprising?

3. What questions or ideas do you have after today's presentation?

4. How can you use the information today for your project?

Lesson Two: Introduction to Systems

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Renee Poitras, Kent-Meridian High School, Kent, WA

LESSON OVERVIEW

Activity Time: Two 50 minute class period. Additional time for homework.

Lesson Plan Summary: In this lesson, students will be introduced to systems, networks, and disturbance by having students model a cell phone network and adding in key terms. This lesson is an adaptation of the Institute for System Biology's Ecological Networks lesson plan and assorted materials (used with permission of the Baliga Lab at the Institute for Systems Biology).

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:

Students will understand that…

- **Systems:** A system is a network of sub-systems that contains inputs, outputs, and feedback mechanisms in order to control/regulate a specific outcome. Disturbances and affect the outcome of the system**.**
- **Neural Engineering:** Neural engineering is based on the loop between sensory information that is received by the brain, information that the central nervous system (CNS) sends out, and computers/machines that receive input and produce outputs that feed back into the CNS.

Essential Questions:

- How does a cell phone phonebook model a network and system?

Learning Objectives:

Students will know…

- Systems and networks exist in nature and can also be human-made.
- The components of a system (inputs, outputs, subsystem, equilibrium, dynamic, +/- feedback, disruption) and networks (node and edge).
- That systems and networks can be drawn into a flowchart.
- Disruption/disturbance stops the flow of information, matter, and/or energy within a system. It breaks the edges and disconnects nodes.

Students will be able to…

- Define the components of a system (inputs, outputs, subsystem, equilibrium, dynamic, +/- feedback, disruption) and networks (node and edge).
- Label the parts of given systems and networks.
- Give an example of systems on their own and label its parts.
- Draw a systems flowchart
- State what happens to a given system with a specific disruption/disturbance (what edges, nodes are affected).
- Give examples of systems vocabulary within the human body.

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

- **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.

- **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.

Common Preconceptions & Misconceptions:

- Every problem has one “perfect” solution.
- Systems are only found in physics (or physical science) except when talking about body systems.

MATERIALS

***Note:** The Teacher Resources and Student Handouts marked with an asterisk (*) can be downloaded from the Institute for Systems Biology at: http://baliga.systemsbiology.net/drupal/education/?q=content/lesson-1-cell-phone-network-introduction. Do not use the PowerPoint offered at this website; instead use the one created specifically to accompany the Neuroprosthetics Unit.

Material	Quantity
Teacher Resource 2.1: Cell Phones, PDF of student numbers and who they can talk to.	1 copy (for teacher use)
Teacher Resource 2.2: Information Sheet for A, B, C, for each letter team to use to create/check their poster.	1 copy for each group or make into overheads
Teacher Resource 2.3: Intro to Networks Teacher Key.	1 copy (for teacher use)
Teacher Resource 2.4: Systems Student Vocab Guidance	1 copy (for teacher use)
Cell Phone Network PowerPoint.	1 copy (for teacher use)
Student Handout 2.1: Cell Phone Student Instructions.	1 per student
Student Handout 2.2: Information Collecting Sheets, allows for students to write down their information.	1 per student
Student Handout 2.3: Intro to Networks Student Questions, asks questions about the activity.	1 per student
Student Handout 2.4: Systems Vocab Sheet, students will fill this in for Day Two.	1 per student
Blank white paper (both sides should be blank), for students to write their challenge homework questions	1 per student
Tape, for posting posters and challenge questions around the room	1 roll
Student science notebooks, for recording definitions and notes	1 per student
Sticky notes, for adding vocabulary words to posters on Day Two	1 pad per group (~4 students/group)
Butcher paper or large sticky-note poster paper, for making cell network posters	7 per class
Markers or colored pencils, for making posters	3 different colors per team
Classroom computer, projector, speakers, internet access for displaying PowerPoint presentation and videos	As needed

TEACHER PREPARATION

For Day 1: Cell Network

1. Preview the PowerPoint presentation.

2. Refer to the information below to figure out how many teams you need.

    a. There are 35 cards in a class set. All the information is needed for this activity. If you have more than 35 students, two students will have to share an information card.
    b. If you have less than 35 students, deal with the extra cards as follows:
        - 34 students – don't hand out 7A
        - 33 students – don't hand out 7A, 6A
        - 32 students – don't hand out 7A, 6A, 5A
        - 31 students – don't hand out 7A, 6A, 5A, 4A
        - 30 students – don't hand out 7A, 6A, 5A, 4A, 3A
        - 29 students – don't hand out 7A, 6A, 5A, 4A, 3A, 2A
        - 28 students – don't hand out 7A, 6A, 5A, 4A, 3A, 2A, 1A
        - Then, after the jigsaw portion of the lesson, make sure every group (1-7) has "information sheet for A" (see teacher resources), or make this into an overhead.
        - 27 students – don't hand out 7A, 6A, 5A, 4A, 3A, 2A, 1A, 7B
        - 26 students – don't hand out 7A, 6A, 5A, 4A, 3A, 2A, 1A, 7B, 6B
        - 25 students – don't hand out 7A, 6A, 5A, 4A, 3A, 2A, 1A, 7B, 6B, 5B, etc. until minimum class size of 14 students
            - A class of 14 students will only have cards with D and E (the A, B, and C sets will not be handed out).
            - Some teachers have gotten very creative with less than 14 students by having students each have a "home" and "work" phone.
        - Then, after the jigsaw portion of the lesson, make sure every group (1-7) has ***Teacher Resource 2.2: Information Sheet for A, B, C*** or make these into an overhead.

3. This activity requires an in-depth setup involving making multiple copies of handouts. Here are the directions:

- Clearly identify 7 numbered stations (1-7, make signs) so that students know where to go meet their numbered groups.
- Clearly identify 5 lettered stations (A-E) so students will know where to go to meet their lettered groups.
- Photocopy and cut out cell phone info cards from ***Teacher Resource 2.1: Cell Phones.*** Suggestion: Cut and laminate the cell phone info cards so you can re-use them for all of your classes.

    - Each student gets one card; you will need one set of 35 cards for each class. If you do not have 35 students in your class, please see the explanation in Step #2a above.
- Cut poster-size pieces of butcher paper, and place one piece at each numbered station.
- Place pens at each numbered station (thick pens and/or colored pencils are recommended, so the poster will be easier to read).
- Make 7 copies of ***Teacher Resource 2.2: Information Sheet for A*** and 7 copies of ***Teacher Resource 2.2: Information Sheet for B.*** You may need these if you have less than 35 students in your class. Suggestion: Make copies of these on brightly colored paper, and re-use them for all of your classes.
- Make copies of ***Student Handout 2.2: Information Collecting Sheets.*** Place 7 of these at each of the <u>lettered</u> stations. This is a template for the students so that they know what information they should be collecting from group members.
- Photocopy ***Student Handout 2.1: Cell Phone Student Instructions*** and ***Student Handout 2.3: Intro to Networks Student Questions,*** one of each per student.

For Day 2: Vocab to Posters

1. Preview the PowerPoint presentation.

2. Make copies of ***Student Handout 2.4: Systems Vocab Sheet,*** one per student.

3. Review Student Posters and make sure each team has a pad of sticky-notes.

PROCEDURE

Note to Teacher: The slide numbers provided in the *Procedure* section below refer to the **Cell Phone Network PowerPoint** presentation.

Day 1: Cell Network Posters

Engage—Slide #2 (5 minutes)

1. Ask teams what all the pictures have in common (all systems).

2. List on board so students can see each team's responses.

Explore—Slides #3-15 (45 minutes)

3. Have students take notes on networks and systems (Slides #3-6).

4. Pass out ***Student Handout 2.1: Cell Phone Student Instructions*** and pre-read (Slides #7-8).

5. Pass out the cell phone cards (from ***Teacher Resource 2.1: Cell Phones****)*.

6. Review the instructions with the students (Slides #9-13).

7. Begin the Cell Network Activity (have Slide#13 up with the directions). Have students fill in their cell phone network (on their cell phone cards from ***Teacher Resource 2.1: Cell Phones***) by talking with teammates to fill in the information.

8. Have students meet with their number groups to create a network for the class on their poster.

9. Have students meet with their letter groups to share and collect more information. This group will be using their cell phone cards from ***Teacher Resource 2.1: Cell Phones***, the ***Teacher Resource 2.2: Information Sheet for A, B, C***, and ***Student Handout 2.2: Information Collecting Sheets***.

10. Have students go back to their number groups to share their information and finish their network posters.

11. Pass out ***Student Handout 2.3: Intro to Networks Student Questions*** and have students work on the document. Students may do so independently or in their teams. Remind students to refer back to the posters as needed.

12. **Exit Ticket:** Have students pass in their completed ***Student Handout 2.3: Intro to Networks Student Questions***.

13. **Homework:** Have students create a challenge question based on the network posters (see ***Student Handout 2.3: Intro to Networks Student Questions***). Make sure to have students write down the directions as they will be turning in this document. Review the worksheets and posters for understanding. See Slide #14.

Day 2: Vocab to Posters

Explain—Slides #15-21

14. Project Slide #15. Allow students five minutes to post their challenge questions and try to answer two other questions.

15. Pass out ***Student Handout 2.4: Systems Vocab Sheet*** and ask students to pre-read the document (Slide #16).

16. Have the students work in teams to fill in the human body example on ***Student Handout 2.4: Systems Vocab Sheet*** (Slide #17). Then discuss as a class. If you need guidance, refer to ***Teacher Resource 2.4: Systems Student Vocab Guidance***.

Elaborate—Slides #19-#20

17. Show Slide #19. Have teams add the systems vocabulary to their posters from Day 1.

Evaluate—Slides #20-21

18. Have students finish ***Student Handout 2.4: Systems Vocab Sheet*** by putting the vocabulary definitions in their own words, as well as picking a system outside of the science classroom and labeling the parts of that system. Again, if you need guidance, refer to ***Teacher Resource 2.4: Systems Student Vocab Guidance*** (Slides #20-21).

STUDENT ASSESSMENT

Assessment Opportunities

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

- Pre-assessment from start of unit
- Pre-assessment for lesson: Team prediction on what all pictures have in common
- Team poster of Cell Phone Network
- ***Student Handout 2.3: Intro to Networks Student Questions***
- Questions and Challenge Question based on networks
- Team poster of Cell Phone Network with sticky-note system vocab
- ***Student Handout 2.4: Systems Vocab Sheet*** with definitions in own words
- ***Student Handout 2.4: Systems Vocab Sheet*** with system outside of science class, including labels

Student Metacognition

In this lesson, student metacognition is elicited during the following activities:

- A two-question pre-assessment for this lesson can be used to elicit students' preconceptions. It can be downloaded from the Institute for Systems Biology lesson plan web page
- Designing and answering a question based on the Cell Phone Network
- Putting the systems vocabulary definitions into own words
- Finding and labeling a system not discussed in class

Scoring Guide

- **Formative:** To assess ***Student Handout 2.3: Intro to Networks Student Questions***, use ***Teacher Resource 2.3: Intro to Networks Teacher Key.***
- **Formative:** With the student questions/challenge question, use the student posters to make sure the questions match the poster designed (this will take time). The questions should be similar to the ones on Slide #11 of the PowerPoint and from ***Student Handout 2.3: Intro to Networks Student Questions***. This is just a simple check. If students can make their own question, no further work is needed. If not, teacher assistance may be needed.

- **Formative:** Read the students' definition for the vocabulary work; does it make sense? Reinforce that pictures are okay, as some students may find it easier to draw some of the definitions. Note the definitions that gave the students the most difficulty and reinforce these vocabulary words the next day.
- **Summative:** The task of finding and labeling a system not discussed in class can be assessed using the rubric provided below:

Scoring Rubric for System Outside of Classroom Task

4	3	2	1	0
Student correctly labeled all parts of their system correctly Student labeled and explained if feedback was Negative or Positive Student explained why it is or is not apart of a network	Student correctly labeled all parts of their system correctly Student labeled if feedback was Negative or Positive Student stated if system was a part of a network or not.	Student correctly labeled majority of the parts of their system correctly Student labeled if feedback, but not if Negative or Positive Student did not state if system was a part of a network.	Student correctly labeled half the parts of their system correctly Student labeled if feedback, but not if Negative or Positive Student did not state if system was a part of a network.	Demonstrate no understanding.

EXTENSION ACTIVITIES

Extension Activities:

- The Institute for Systems Biology has a second lesson that computerizes the networks. This lesson introduces students to Cytoscape, a computer program for making and analyzing networks.

  Cytoscape Cell Phone Network Lesson Plan
  http://baliga.systemsbiology.net/drupal/education/?q=content/lesson-2-cytoscape-cell-phone-network

Adaptations:

- Instead of having each student having a phone number, make a smaller class set (directions are in Steps #2a-b in the *Teacher Preparation* section of this lesson plan) and have students work in pairs if needed so that students could work together to gather the network information.
- Same as above, have students work with a partner to fill in ***Student Handout 2.3: Intro to Networks Student Questions***.

- Give students an example of what the poster could look like; can they see how it is made (if have the network information)?
- Give the students the answers to the Introduction to ***Student Handout 2.3: Intro to Networks Student Questions*** in a sealed envelope. The student can open the envelope to check the answers if they get lost or stressed when answering on their own.
- Instead of having a student make their own question, have them answer one you have designed ahead of time. Remind them that using the poster would be helpful.
- Give students cards that have the vocabulary definitions already in different wording. Have the student match the card to the correct vocabulary word.
- Have the student pick a system in partners, and then label with their partner.

TEACHER BACKGROUND & RESOURCES

Background Information

- **Day 1:** It is imperative that you review the *Teacher Preparation* section of this lesson. It walks you through the lesson, lists needed materials, and even tells you how to manipulate the materials based on class size. Also, review the PowerPoint to understand the directions. There are some hidden slides that give the teacher some directions in outline view but that the students do not see in slide view.
- **Day 2:** Review the PowerPoint to understand the activity. To help with systems vocabulary, refer to ***Teacher Resource 2.4: Systems Student Vocab Guidance*** for sample acceptable answers.

Resources

The following article, published in Science Scope, provides additional information on how to teach this lesson: Ludwig, C.M., and Nitin S. Baliga. (2008) Systems concepts effectively taught using systems practices. *Science Scope* 31(9).

The following video provides an explanation of Systems Biology and introduces the Institute of Systems Biology.

Leroy Hood, 2011 National Medal of Science
National Medals, February 8, 2013 (2:18 minutes)
https://www.youtube.com/watch?feature=player_embedded&v=N-hB9wlr2ac&list=UUrerthJHiS8L88-7L9CW3vQ#t=0

Citations

Cell Phone Network Introduction lesson plan (part of the Ecological Networks unit), PowerPoint, and assorted materials used with permission of the Baliga Lab at the Institute for Systems Biology. Baliga, N.S., Facciotti, M.T., Ehrman, P., Ludwig, C.M., Sieler, J., Terry, K., Meislin, M.,

Tenenbaum, D., Shannon, P., Nehring, S., Scalise, C., Mirzanian, S., Hagenah, S., Manning, N., Thompson, J., Gallagher, D., Bonneau, R., Mar, P., Alvarado, G., Gil, S. (2006) *Ecological Networks*. Retrieved from http://baliga.systemsbiology.net/drupal/education/?q=content/ecological-networks-course.

The definitions for Systems, Subsystems, Input, Output came from the Office of the Superintendent of Public Instruction's Washington State Science Standards Glossary. Retrieved from http://standards.ospi.k12.wa.us/FullGlossary.aspx?subject=10,PE#S.

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.

Student Handout 2.4 Systems Vocab Sheet

Name:_________________________________ Date:__________________ Period:__________

Vocabulary	Definition	Example from Human Body	Put Definition in your Own Words (drawings ok too)
Disruption/ Disturbance	Events that cause a change to a system		
Dynamic	Constant change		
Edges	the relationships between the nodes		
Equilibrium	The condition of a system in which competing influences are balanced.		
Feedback	The process the output of a system is used to make changes in the operation of the system		
Inputs	The addition of matter, energy, or information to a system.		
Negative Feedback	A change in one direction causes an additional change in the opposite direction. This reduces the disturbance to a system		
Networks	An interconnected or interrelated chain, group, or system.		
Nodes	Members of the network		

Outputs	Matter, energy, or information that flows out of a system.		
Positive Feedback	A change in one direction causes a change in the same direction. This tends to increase the disturbance to a system.		
Subsystem	The subset of interrelated parts within the larger system.		
System	An assemblage of interrelated parts or conditions through which matter, energy, and information flow.		

<u>System Outside of Science Class:</u>

System:
Subsystems:
Inputs:
Outputs:
Feedback + if it is positive or negative:

Disturbance/Disruption:
Equilibrium:
Dynamic:
Is it a part of a Network:

Teacher Resource 2.4: Systems Student Vocab Guidance

Vocabulary	Definition	Example from Human Body	Put Definition in your Own Words (drawings ok too)
Disruption/ Disturbance	Events that cause a change to a system	Infection Cancer	
Dynamic	Constant change	Blood flow Beating of Heart Oxygen-Carbon cycle Muscle reflection/refraction (most functions within the body are based on change)	
Edges	the relationships between the nodes	If thinking of the nodes as the body systems, then an edge would be the veins/arteries connecting the different body systems	
Equilibrium	The condition of a system in which competing (opposite) influences are balanced.	Insulin regulation Body temperature Hunger	
Feedback	The process the output of a system is used to make changes in the operation of the system	Hunger Sweating Shivering Pain Feeling	
Inputs	The addition of matter, energy, or information to a system.	Food Water Energy	
Negative Feedback	A change in one direction causes an additional change in the opposite direction. This reduces the disturbance to a system	Overheated/temperature goes up → body sweats/evaporation → temperature goes down	
Networks	An interconnected or interrelated chain, group, or system.	In this example, the Human body	
Nodes	Members of the network	The different body systems	
Outputs	Matter, energy, or information that	Waste	

	flows out of a system.	Sweat	
Positive Feedback	A change in one direction causes a change in the same direction. This tends to increase the disturbance to a system.	Cut yourself → platelets attach to the cut → they send chemical signals that attract platelets → more platelets attach to the cut → they produce more chemical signals that attract more platelets →...until a clot is formed	
Subsystem	The subset of interrelated parts within the larger system.	Stomach Lung Heart Brain (any organ)	
System	An assemblage of interrelated parts or conditions through which matter, energy, and information flow.	Digestive system Circulatory system (any of the body systems)	

<u>System Outside of Science Class:</u>

System: Car
Subsystems: Engine
Inputs: Gasoline, oil, antifreeze…
Outputs: Heat, exhaust, CO2
Feedback + if it is positive or negative:

- Positive Feedback: speedometer – increase pressure on the gas pedal → sends message to speedometer to spin to a higher number (or increase spinning). Less pressure → sends message to less activation part of car that spins the speedometer (or less spinning)., less pressure on the gas pedal
- Negative Feedback: brake system – Increase pressure to the break → decrease tire spin → car slows down. Decrease pressure to the break → increase in tire spin → car speeds up

Disturbance/Disruption: Tire goes flat → cannot move properly
Equilibrium: Brake pads → friction
Dynamic: Movement of car, depends upon the constant changing of parts
Is it a part of a Network? YES – transportation (buses, trains, roads…)

Lesson Three: Reaction Time Lab

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Claudia Lemus, TAF Academy, Kent, WA

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary: In this lesson, students will be introduced to the basic workings of the nervous system and will experiment on various factors that can influence the system.

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:

Students will understand that…

- **Neuroprosthetics:** Neuroprosthetics can be used to restore or enhance human function.

Essential Questions:

- How can a model be used to test solutions within a system designed for a neuroprosthetic?

Learning Objectives:

Students will know…

- The components of a system (inputs, outputs, subsystem, equilibrium, dynamic, +/- feedback, disruption).
- The basic function of sensory and motor neurons within the nervous system.
- How feedback mechanisms can "stabilize or destabilize" a system.

Students will be able to…

- Understand the basic sensorimotor feedback loop that is required for neural engineering.
- Collect, represent, and analyze data from a lab investigation.

Vocabulary:

- Stimulus/stimuli
- Sensory pathway
- Motor pathway
- Response
- Perception
- Input/output
- System/network

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

- **MS-LS1-3 Structure, Function, and Information Processing:** Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
- **MS-LS1-8 Structure, Function, and Information Processing:** Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.
- **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.
- **HS-LS1-3 Structure and Function:** Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.
- **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.

Common Preconceptions & Misconceptions:

- The human brain is effective at multi-tasking.
- Texting while driving can be dangerous because it affects your ability to react quickly.

MATERIALS

Material	Quantity
30 cm Ruler	1 per group
Student Handout 1.1: What Can Impact Your Reaction Time? (Part I)	1 per student
Optional Extension: ***Student Handout 1.2: What Can Impact Your Reaction Time? (Part II)***	1 per student
Teacher Resource 1.1: What Can Impact Your Reaction Time? (Teacher Key)	1 copy (teacher resource)
Calculator	1 per student
Cell phone or computer (to simulate texting)	1 per group
Classroom computer, projector, speakers, internet access for displaying video	As needed

TEACHER PREPARATION

1. Make copies of ***Student Handout 1.1: What Can Impact Your Reaction Time? (Part I)***, one per student.

2. Decide if you will also want to assign the optional extension activity. If so, make copies of ***Student Handout 1.2: What Can Impact Your Reaction Time? (Part II),*** one per student.

3. Make sure each lab group has the materials they need at the tables.

PROCEDURE

Engage (5 minutes): Distracted Driving and Reaction Time

4. Have the class recall the discussion from the previous day on systems and cell phones (from *Lesson Two: Introduction to Systems*).

5. Ask students to do a Think/Pair/Share for the following three questions:
   - How is a cell phone network similar to networks of thoughts in our brains?
   - What senses do we use when we use a cell phone?
   - How are our senses tied to our actions?

6. Show students the following short video:

   The Distracted Brain and Driving (1:51 minutes)
   http://abcnews.go.com/WNT/video/distracted-brain-driving-19386520

7. Have students revisit their answers with their partners/lab groups after watching the video and share out if time permits.

Explore (20 minutes) Reaction Time Lab—Part I

8. Distribute copies of ***Student Handout 1.1: What Can Impact Your Reaction Time? (Part I)***, one per student.

9. Have students take turns reading aloud the background information section from the handout.

10. In pairs, have students read through the procedure section and come up with an explained hypothesis.

11. Working in groups, students will next work through the lab activity.

Explain (15 minutes) Reaction Time Lab—Part I Questions

12. Once having finished data collection and calculations, have students answer the conclusion questions on their handout.

13. Asks students to share their answers with the rest of their lab group and assign each lab group one of the three questions to share out to the class.

14. As lab groups share out their cumulative response to their question, the teacher can facilitate a short discussion if there are any points of disagreement.

Elaborate/Evaluate (10 minutes) Exit Ticket

15. Have students submit their final conclusion questions for teacher evaluation.

16. As an Exit Ticket, ask students to draw a simple, labeled flow chart depicting the inputs and outputs illustrated by their reaction time, in relation to the nervous system.

STUDENT ASSESSMENT

Assessment Opportunities

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

- Shared out responses from warm-up activity (distracted brain and driving video and discussion).
- Shared out responses from lab group discussion on conclusion questions.
- Final conclusion questions that students turn in.
- Exit ticket with labeled flow chart that students turn in.

Student Metacognition

- In both the engagement activity and lab group discussion, students reflect on their individual answers to questions in the lesson, then share out answers with peers and discuss as a class or in small groups in order to identify various perspectives and fine tune their knowledge.

Scoring Guide

- To assess ***Student Handouts 1.1*** and ***1.2***, refer to ***Teacher Resource 1.1: What Can Impact Your Reaction Time? (Teacher Key).***

EXTENSION ACTIVITIES

Extension Activities: (30 min) Reaction Time Lab—Part II

- After having discussed the conclusion questions as a class, have students work in pairs to design their own addition to the experiment and complete ***Student Handout 1.2: What Can Impact Your Reaction Time? (Part II)***. Alternatively, this could be assigned as homework.

Adaptations:

- **Middle School/ELL/SPED:** For the elaboration part of the lesson, when students are designing their own experiment, give specific variables that students can choose from, and provide data tables that students can use to write down their data values.
- **Higher Level High School/Gifted:** Have students design their experiment individually, and then switch papers with their partner to peer edit their design. Then they can revise their individual designs before conducting their second experiment.

TEACHER BACKGROUND & RESOURCES

Background Information

Part of the reason why animals are able to react to stimuli in their environment is due to how the sensory and motor pathways in the nervous system communicate with each other. We perceive stimuli with our sensory receptors—auditory, tactile, taste, visual, and olfactory—and they in turn send signals up to the central nervous system (spinal cord or brain). This is the sensory pathway. The central nervous system processes this information, and sends its own signals according to the stimulus. Sometimes this results in the brain or spinal cord sending a signal, via motor neurons, down to a muscle in order to elicit a physical response. This is the motor pathway.

By measuring the time it takes from when a person perceives a stimulus to when they have a motor response, we can quantify reaction time. By changing the type of stimulus, the mode of perception, or some other aspect of the environment during this process, we can study how these variables affect reaction time.

Resources

Reaction Time Lab, Open University
http://www.open.edu/openlearn/science-maths-technology/science/across-the-sciences/be-lab-rat

Citations

Diagram of the sensorimotor loop reproduced with permission of Dr. Paul Gabbott, The Open University, UK.

Gabbott, P. (2006). *The Fighter Pilot Challenge: In the Blink of an Eye.* The Open University, UK.

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.

Student Handout 1.1 What Can Impact Your Reaction Time? (Part I)

Name:________________________________ Date:__________________ Period:__________

Background

Part of the reason why animals are able to react to stimuli in their environment is due to how the sensory and motor pathways in the nervous system communicate with each other. We perceive stimuli with our sensory receptors—auditory, tactile, taste, visual, and olfactory—and they in turn send signals up to the central nervous system (spinal cord or brain). This is the **sensory pathway**. The central nervous system processes this information, and sends its own signals according to the stimulus. Sometimes this results in the brain or spinal cord sending a signal, via motor neurons, down to a muscle in order to elicit a physical response. This is the **motor pathway**.

By measuring the time it takes from when a person perceives a stimulus to when they have a motor response, we can quantify reaction time. By changing the type of stimulus, the mode of perception, or some other aspect of the environment during this process, we can study how these variables affect reaction time.

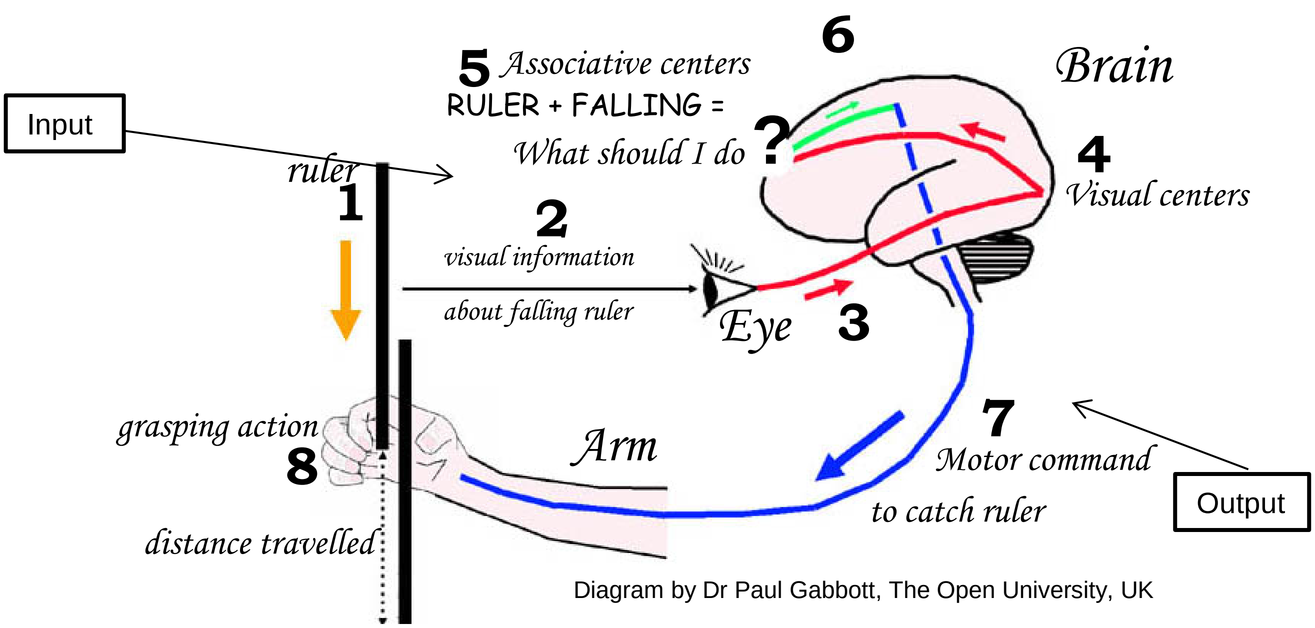


Diagram by Dr Paul Gabbott, The Open University, UK

Purpose
To explore variables that may impact a person's reaction time, and design and conduct an experiment to test one of them.

Materials
30 cm ruler
Cell phone or computer

Effect of Texting on Reaction Time

1. Have the first participant sit in an area free of distracting visuals or noises, with their dominant arm resting on a table and their hand hanging off the table so that their thumb is opposite of the rest of the fingers.
2. Hold a 30 cm ruler vertically from the 30 cm end, so that the 0 cm end is in the space between the participant's thumb and the rest of the fingers, but not touching any of the fingers.
3. Instruct the participant to close their fingers and grab the ruler as soon as he/she sees the ruler falling.
4. Let the ruler go. The participant should catch the ruler somewhere along its length.
5. Write down the distance at which the participant caught the ruler.
6. Reposition the participant's hand and hold the ruler as in Step #2 again.
7. Have the participant use his/her other hand to compose a text on a phone, or type text on a computer.
8. Let the ruler go and write down the distance at which the participant caught the ruler.
9. Repeat steps 1-9 two more times.
10. Repeat steps 1-9 for 3 other participants.
11. **Use the distance-time conversion chart to fill in the reaction time that corresponds to each distance value* for each participant.**

    *These values were calculated using the following formula:

    $$t = \sqrt{(2d/g)}$$

    Where t = reaction time, d = distance fallen, and g = gravitational acceleration (9.8 m/s^2)

12. **Hypothesis: What do you predict will happen when you test these two conditions, and why?**

Table 1 – Participants' Data on Distance Fallen by the Ruler and Corresponding Reaction Time

	Participant #	Trial #	Distance Fallen	Reaction Time (from chart)
Undistracted	1	1		
	1	2		
	1	3		
	2	1		
	2	2		
	2	3		
	3	1		
	3	2		
	3	3		
	4	1		
	4	2		
	4	3		
Texting	1	1		
	1	2		
	1	3		
	2	1		
	2	2		
	2	3		
	3	1		
	3	2		
	3	3		
	4	1		
	4	2		
	4	3		

Table 2- Distance-Time Conversion Chart

Distance Fallen (cm)	Reaction Time (ms)
1	5
2	6
3	7
4	8
5	9
6	10
7	12
8	13
9	14
10	14
11	15
12	16
13	16
14	17
15	17

Data Processing and Analysis

1. Calculate the average reaction time for all participants for the two conditions – undistracted and while texting.
2. Calculate the difference in reaction time shown for these two conditions based on your experiment.
3. **Organize your processed values (averages and differences) in a data table (create on separate sheet of paper and attach to this handout).**

Conclusion Questions
Answer these on a separate sheet of paper and attach to this handout.

1. How did participants' reaction time vary between when they were undistracted and when they were texting? How does this relate to your original hypothesis? Support your claims with data values.

2. Think of the neurological pathways involved in perception of stimuli and the subsequent reactions. What was happening in the brain and pathways of the participants in each scenario that could explain the difference in results?

3. Besides introducing texting to the participants' experience, what other variables did you not control that could have impacted the results? Describe.

Student Handout 1.2 What Can Impact Your Reaction Time? (Part II)
Name:________________________________ Date:__________________ Period:__________

Part II – Effect of ______________________ on Reaction Time

1. Design a third condition to test its effect on reaction time. Think of other stimuli you could have participants perceive, other ways of having participants perceive or sense something, or other factors in the environment that you could change. Use the same ruler-dropping protocol to test this new condition.

2. Describe the procedure for your test:

3. Display your raw data in a data table:

4. What calculations could you do with your new values and the previous data values (from **Part I**) in order to draw more meaning from the results? Show your work and organize your processed values into a data table.

5. What final conclusion claim would you make based on ***all*** of your collected data? Support your claim with data values from both ***Parts I*** and ***II***, and explain what could account for the differences in your results.

Teacher Resource 1.2: What Can Impact Your Reaction Time (Answer Key)

What Can Impact Your Reaction Time? (Part I)

Effect of Texting on Reaction Time

12. Hypothesis: What do you predict will happen when you test these two conditions, and why?

Answers will vary. Hypothesis should be a prediction statement about which condition will lead to a higher or lower reaction time. Response should also try to explain the rationale behind that prediction.

Data Processing and Analysis

1. Calculate the average reaction time for all participants for the two conditions – undistracted and while texting.
2. Calculate the difference in reaction time shown for these two conditions based on your experiment.
3. Organize your processed values (averages and differences) in a data table below.

Data table should include labeled rows and columns so that there is one value for the average reaction time undistracted, one value for the average reaction time while texting, and one value for the difference between the averages for these two conditions.

Conclusion Questions

1. How did participants' reaction time vary between when they were undistracted and when they were texting? How does this relate to your original hypothesis? Support your claims with data values.

Answers will vary. Responses should describe the data in the previous data tables (either higher values for while texting [most likely], or higher values for undistracted). Response should include a statement about whether or not these values support their hypothesis, citing specific data values in support of their claim.

2. Think of the neurological pathways involved in perception of stimuli and the subsequent reactions. What was happening in the brain and pathways of the participants in each scenario that could explain the difference in results?

Answers will vary. Responses should include some explanation of the visual pathway as the input of the system, and the brain having to process more information within this pathway when texting than when undistracted, resulting in a quicker response time when undistracted, due to a faster connection between the visual pathway (input) and the motor pathway (output).

3. Besides introducing texting to the participants' experience, what other variables did you not control that could have impacted the results? Describe.

Answers will vary. Sample responses include other distractions in the classroom, background noise, whether or not the ruler was at eye level for each participant, etc.

Part II – Effect of ________________________ on Reaction Time

2. Describe the procedure for your test:

Answers will vary. Responses should focus on a new variable tested. Examples include testing reaction time with visual pathway vs. auditory pathway, reaction time while not talking vs. talking, reaction time with heartbeat at rest vs. after exercise, etc. Procedure should include the number of participants, number of trials, and all details of how measurements will be taken.

3. Display your raw data in a data table:

As before, data table should have labeled rows and columns so that values for the reaction time for the new variables are clearly displayed for each trial and participant.

4. What calculations could you do with your new values and the previous data values (from Part I) in order to draw more meaning from the results? Show your work and organize your processed values into a data table.

Answers will vary. Sample responses include calculating the difference between undistracted vs. new variable tested, difference between texting vs. new variable tested, new average for distracted texting plus new distraction tested, etc. Data table should have labeled rows and columns so the new calculated values are clearly displayed.

5. What final conclusion claim would you make based on ***all*** of your collected data? Support your claim with data values from both ***Parts I*** and ***II***, and explain what could account for the differences in your results.

Answers will vary. Conclusion should refer to data from both parts of the lab and make a statement about which condition led to higher/lower reaction times. Conclusion should also include an explanatory statement about what parts of the system were at play (visual, auditory, input, output, etc.) and in what capacity in order to account of the differences noted.

Lesson Four: SpikerBox Lab Part I—Spikes for All

Center for Sensorimotor Neural Engineering
Lesson Plan Author: Angelica Sauceda, TAF Academy, Kent, WA

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary: In this lesson, students will be able to see and hear neural spikes in real time using a SpikerBox (a bioamplifier) and a cockroach leg. This lab is an adaptation of several lesson plans from Backyard Brains. Part II of the lab is continued in *Lesson Six: SpikerBox Lab Part II—Analyzing Spikes.*

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:
Students will understand that…

- **Systems:** A system is a network of sub-systems that contains inputs, outputs, and feedback mechanisms in order to control/regulate a specific outcome. Disturbances affect the outcome of the system
- **Neurons:** Neurons (nerve cells) transmit information via electronic signals within the nervous system. Neurons communicate using electrical and chemical signals.
- **Sensorimotor Pathway:** Sensory neurons are nerve cells that transmit a signal to the brain from a stimulus/input in the body (touch, smell, etc.). Motor neurons carry signals from the spinal cord to activate muscle movement.
- **Electrophysiology:** Electrophysiology is the study of the electrical properties of cells.

Essential Questions:

- How do neurons communicate with each other?
- How can I use technology to help me see and hear this communication?
- What is a neural spike and what is its significance of research in the area of neuroprosthetics?

Learning Objectives:
Students will know…

- The components of a system include input, output and feedback.
- The function of the sensory and motor neurons within the nervous system.
- Neurons communicate using electrical and chemical signals.
- Sensory stimuli are converted into electrical signals.

Students will be able to answer or understand the following:

- What is a neural spike and what is the significance of research in this area?
- What are neurons and how do they communicate?
- In terms of our experiment, what is the input and output, and is feedback established?

- Understand the basic sensorimotor feedback loop that is required for neural engineering.

Vocabulary:

- Electrophysiology
- Neuroprosthetic
- Neuron
- Input
- Output
- System
- Motor neuron
- Sensory neuron
- Neural spike/action potential

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

- **MS-LS1D-3 Structure, Function, and Information Processing:** Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
- **MS-LS1D-8 Structure, Function, and Information Processing:** Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.
- **MS-ETS1-1 Engineering Design:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **HS-PS3-3 Energy:** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- **HS-ETS1-1 Engineering Design:** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **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.

Common Preconceptions & Misconceptions:

- Robots can “think for themselves” with an artificial intelligence (i.e., don’t need human input/programming).
- Every problem has one “perfect” solution.

MATERIALS

Material	Quantity
SpikerBox (the SpikerBox Bundle with audio cables adapter is recommended). Can be ordered from https://backyardbrains.com/products/spikerbox	1 per group
Cockroach.* Adult orange heads, discoids, or discoid/cranifer hybrid cockroaches. Can be ordered from Backyard Brains or Carolina Biological.	1 cockroach leg per group
Dissecting scissors	1 per class
Ice water in vessel, for anesthetizing cockroaches	1 per class
Gloves, for use when handling cockroaches	As needed
Student Handout 4.1: SpikerBox Lab Part I—Spikes for All	1 per student
Student Handout 4.2: KWL Chart	1 per student
Teacher Resource 4.1: SpikerBox Lab Part I Teacher Key	1 copy
Laptops or Smartphones	1 per group
Free “Backyard Brains” app downloaded to Smartphone. Available from iTunes or app store for Android phones. -or- Audacity Software for PC or Mac downloaded to laptop. Free download from http://audacity.sourceforge.net/	1 per phone or laptop
Classroom computer, projector, speakers, internet access for displaying video	As needed

***Animal Husbandry Information:** Care instructions are usually included with the shipment of cockroaches and an internet search of “cockroach husbandry” will offer additional information. You will need to prepare a small terrarium in advance of the cockroach’s arrival that provides a water source, bedding material (soil and/or wood chips), and food (such as lettuce, carrots, and/or dog kibble). You may decide to maintain a breeding colony of cockroaches. To dispose of cockroaches, place them in a doubled plastic zipper bag and put in the freezer for at least 24 hours to euthanize them. They can then be disposed of (in the plastic bags) in the garbage.

Safety Note: When handling and preparing cockroaches, wear gloves.

TEACHER PREPARATION

1. Make copies of ***Student Handouts 4.1*** and ***4.2,*** one of each per student.

2. This lab will be conducted in small groups, depending on the number of SpikerBoxes you have available. We recommend 2-3 students per SpikerBox.

3. Familiarize yourself with the preparation of the cockroach legs (see the Procedure section on ***Student Handout 4.1***). The preparation of the cockroach legs can be done beforehand by the teacher or the teacher can ask the students to prepare the cockroach leg as part of the lab activity, as laid out in the handout.

4. Ensure that each SpikerBox is functioning correctly.

5. Make sure that each phone has the Backyard Brains app installed and/or that each laptop has the Audacity software installed.

6. If you have not already discussed the topic of animal research (including the use of animals in the science classroom) with your students, please engage your students in a discussion about the ethical issues involved and the importance of respectfully handling the cockroaches during this lab.

PROCEDURE

Engage

1. Pass out copies of ***Student Handout 4.1: SpikerBox Lab Part I—Spikes for All***, one per student.

2. Ask the students to think about and listen for the pre-lab questions in the YouTube clip you will show them:
   - In your own words, explain what the study of electrophysiology is. What do you think electrophysiological readings are?

     Electrophysiology is the study of the electrical properties of cells.
     Electrophysiological readings are recordings of electrical signals transmitted by neurons.

- In your own words, explain what a neuron is.

  Neurons (nerve cells) transmit information via electrical and chemical signals within the nervous system.
- In your own words, explain what you think a neural spike or action potential is.

  An action potential is a fast moving electric signal that transmits chemical information to another neuron.
- What is the difference between sensory neurons and motor neurons?

  Sensory neurons are nerve cells that transmit a signal to the brain from a stimulus/input in the body (touch, smell, etc.). Motor neurons carry signals from the spinal cord to activate muscle movement.

3. Show the students the YouTube clip, watching from (0:00 to 2:30).

   Neurons or Nerve Cells: Structure Function and Types of Neurons
   eLearnin, April 27, 2013 (4:09 minutes)
   https://www.youtube.com/watch?v=cUGuWh2UeMk

4. Pass out copies of **Student Handout 4.2: KWL Chart**. Ask students to complete the first two columns independently. *Optional:* Also create a class KWL chart (K-What I Know; W-What I Want to Know; L-What I Learned) on the board and work together as a class to fill out the first two columns (K and W).

Explore/Explain

5. Based on the video, ask the students to do a Think Pair Share with the pre-lab questions.

6. Introduce the lab by reading aloud the opening paragraph of ***Student Handout 4.1***.

7. Ask students, working within their groups, to take turns reading the *Procedure* section of the handout.

8. When each group finishes reading the *Procedure*, they are to summarize the procedure and prepare to share out.

9. Choose one group to summarize the lab procedures in their own words.

10. Ask the students to begin the lab, as described in ***Student Handout 4.1***. **Note:** The preparation of the cockroach leg can be done beforehand by the teacher or the teacher can ask the students to prepare the cockroach leg, as laid out in the *Procedure*.

11. Allow time for student groups to work through the lab procedure.

Elaborate/Evaluate

12. Ask students to complete the third column (L-What I Learned) in their KWL charts. You will return to this chart and update it at the conclusion of *Lesson Six: SpikerBox Lab Part II—Analyzing Spikes.*

13. This inquiry lab is meant to grab students' attention and spark their interest and curiosity for the Neuroprosthetics unit. The lab questions in Student Handout 1.1 are meant to challenge students' thinking. They can be used as an Exit Ticket. Sample answers are provided in ***Teacher Resource 4.1 SpikerBox Part I Teacher Key***.

14. Part II of this lab is continued in *Lesson Six: SpikerBox Part II—Analyzing Spikes.*

STUDENT ASSESSMENT

Assessment Opportunities

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

- This is an inquiry lesson intended to spark the interest and curiosity of the students. As a result, the extension questions provide a formative assessment.

Student Metacognition

The following is a list of opportunities for student metacognition integrated into this lesson:

- The creation and revision of the KWL chart provides an opportunity for students to reflect on what they already knew, wanted to know, and learned.
- With the pre-lab questions, students reflect on their individual answers to questions, share their answers with peers, and then discuss as a class.

Scoring Guide

- This is an inquiry activity intended to spark students' interest and curiosity. As long as they participated and were engaged in the activities, they can be considered successful.
- Sample answers to the pre-lab questions are provided in the Engage section of the *Procedure*.
- Sample answers to the lab questions from ***Student Handout 4.1*** are provided on ***Teacher Resource 1.1***.

EXTENSION ACTIVITIES

Extension Activities:

- This lab should be followed up by presenting *Lesson Five: Neurons and Action Potentials*. The lab is continued, with more depth and opportunities for data collection and analysis, in *Lesson Six: SpikerBox Part II—Analyzing Spikes.*

Adaptations:

- This inquiry lesson is differentiated in the sense that students are not required to come into this activity with extensive background knowledge, instead they must be inquisitive and willing to learn.

TEACHER BACKGROUND & RESOURCES

Background Information

It is important to familiarize yourself with the SpikerBox before teaching this lab. The following TED-Ed video provides a fun and accessible introduction, and features Backyard Brains co-founder Greg Gage. It is also a wonderful video to share with students.

The Cockroach BeatBox with Greg Gage
TED-Ed, March 11, 2012 (6:15 minutes)
https://www.youtube.com/watch?v=tr4gWi9Jf6k#t=223

For more in-depth information about the SpikerBox, as well as basic cockroach leg anatomy, visit the link below, read through the text, and watch the videos.

Experiments: Getting Started with the SpikerBox
Backyard Brains
https://backyardbrains.com/experiments/spikerbox

In order to familiarize yourself with the components of a system (input, output, feedback, etc.), please reference *Lesson Three: Reaction Time Lab* of this Neuroprosthetics unit.

Resources

- Backyard Brains Experiments, https://backyardbrains.com/experiments/
- Backyard Brains Teacher Guides, https://backyardbrains.com/experiments/teachersGuide/

Citations

Backyard Brains. (n.d.). *Experiment: Getting Started with the SpikerBox.* Retrieved July 22, 2014, from https://www.backyardbrains.com/experiments/spikerbox.

Backyard Brains. (n.d.). *Teacher's Guide—Experiment: Getting Started with the SpikerBox.* Retrieved July 22, 2014, from https://www.backyardbrains.com/experiments/spikerbox.

Backyard Brains. (n.d.). *LAB ONE: SPIKES FOR ALL!.* Retrieved July 22, 2014, from http://wiki.backyardbrains.com/images/b/bb/ByB_Entire_Manual.pdf.

Illustrations credit: Backyard Brains.

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.

Student Handout 4.1 SpikerBox Lab Part I—Spikes for All

Name:________________________________ Date:__________________ Period:__________

Credit: This activity is adapted from Backyard Brains, *Lab One: Spikes for All!* All images are from Backyard Brains.

Pre-Lab Questions:

1. In your own words, explain what the study of electrophysiology is. (Hint: The answer can be found somewhere in this handout).

2. In your own words, explain what a neuron is.

3. In your own words, explain what you think a neural spike or action potential is.

4. What is the difference between a sensory neuron and a motor neuron?

Cockroaches

Today we will listen to and see the spikes of real living neurons in a cockroach leg using a bioamplifer known as a SpikerBox. But why a cockroach? Cockroaches have neurons similar to ours but they do not have as many as us. To put this into perspective, a cockroach has 1 million neurons and we have 100 billion! How do you think this difference separates us from a cockroach? Your brain uses a combination of chemicals and electricity to operate. Cockroaches' bodies are filled with nerves to control movement and sensation.

Learning Objectives

In this lab you will:

- Learn how to prepare a cockroach leg for electrophysiological readings.
- Observe and record action potentials generated in a cockroach leg using a SpikerBox and a computer.
- Investigate how different types of stimulations affect the generation of action potentials in a cockroach leg preparation.

After doing this lab you should be able to explain:

- What is a neural spike and what is the significance of research in this area?
- What are neurons and how do they communicate?
- In terms of our experiment you will be able to describe what the input/s and output/s are.
- Whether we are analyzing spikes coming from the sensory neurons or motor neurons.
- How sensations enter into the nervous system

Materials

- SpikerBox with audio cable adapter
- Laptop or Smartphone
- Prepared cockroach leg or else:
    - Cockroach
    - Ice water or access to a freezer
    - Dissection scissors

Introduction

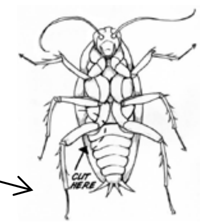
Electrophysiology is the study of the electrical properties of cells which allows researchers to study how neurons communicate with each other and form complex neural networks. In particular, scientists and physicians use electrophysiology to measure the properties of action potentials in living neurons.

For this lab, you will be removing a leg from the cockroach (last and largest leg closest to the abdomen). The major benefits of this approach are that the leg will grow back, and the cockroach nervous system provides wonderfully large action potentials that can be observed using the SpikerBox. Why is this? Sensory neurons detect movement of the spines of the leg and send an electrical message through a particularly large diameter axon all the way to central nervous system.

Lab Procedure

Follow Steps #1-3 if you will be preparing the cockroach leg yourself. If your teacher gives you an already-prepared leg, then skip to Step #4.

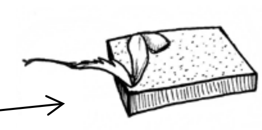
1. Take a cockroach and put it in a jar of ice water. Wait a few minutes until it stops moving.



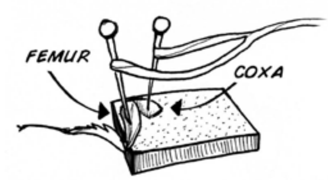
2. Remove the cockroach from the water. Use dissection scissors to cut off one of the large legs near the body, as shown in the illustration.

3. Return the cockroach to its habitat.

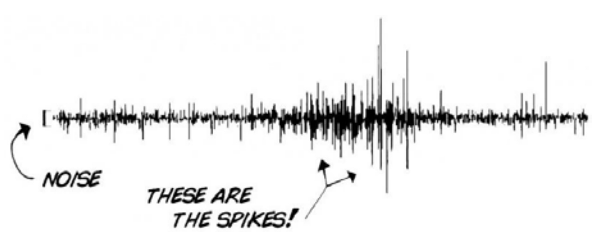
4. Place the leg on the cork of your SpikerBox, allowing a bit of the leg to overhang, like this:



5. Put the two electrodes in as shown in the illustration.
   - Why do you think we put the electrodes in two different parts of the cockroach leg?



6. Turn your SpikerBox on! If you hear a popcorn sound, congratulations, you have just heard your first neurons! Now let's see what the electrical discharge looks like. Plug your sound cable from the SpikerBox into your smartphone or into the microphone input of your computer. Start up the "Backyard Brains" app (Android or iPhone) on your mobile device, or, if on a laptop, Audacity. You should see:



7. Zoom in and the spikes look like: 

This is due to ion channels opening and closing in the neurons, causing the pulse.

8. ***Optional:*** Play music to the cockroach leg and observe what happens.

Lab Questions

1. Draw the components of the system represented in today's lab. Be sure to label the inputs and outputs of the system. Is a feedback loop present? Explain.

2. In your own words, explain what you think a neuron is.

3. In your own words, explain how you think neurons communicate with each other.

4. Based upon your initial results, are you primarily listening to spikes coming from motor neurons (neurons that tell muscles to contract) or to sensory neurons (neurons that send information from the periphery into the brain). Why?

5. How do you think that we are able to learn more about our brains by analyzing these spikes?

6. What do you think that we can we do with the information we have gained by analyzing these spikes?

7. Do you have further questions regarding the spikes we've seen and heard?

8. ***Optional:*** Describe what happened to the cockroach leg when you played music.

Student Handout 4.2 KWL Chart

Name:_________________________________ Date:__________________ Period:__________

What I Know about neurons and action potentials/spikes	What I Want to know about neurons and action potentials/spikes	What I've Learned about neurons and action potentials/spikes (include the information you acquired during the action potential lesson and the SpikerBox labs).

Teacher Resource 4.1 SpikerBox Lab Part I Teacher Key
Sample answers to the Lab Questions are provided below:

1. Draw the components of the system represented in today's lab. Be sure to label the inputs and outputs of the system. Is a feedback loop present? Explain.

Student's drawing should include the components of the SpikerBox system, with the inputs and outputs labeled. The feedback loop should be identified and explained.

2. In your own words, explain what you think a neuron is.

A neuron is a nerve cell that transmits information via electronic signals within the nervous system.

3. In your own words, explain how you think neurons communicate with each other.

Neurons communicate via chemical signaling.

4. Based upon your initial results, are you primarily listening to spikes coming from motor neurons (neurons that tell muscles to contract) or to sensory neurons (neurons that send information from the periphery into the brain). Why?

We are listening to the sensory neurons that send information to the brain. The leg is stimulated by touch and a sensory neuron sends an electrical signal transmitting this message to the brain.

5. How are we able to learn more about our brains by analyzing these spikes?

The pattern and frequency of spikes or action potentials that we hear can help us distinguish a strong external stimulus from a weak one and can tell us which hair cells are being stimulated, thus giving us information on the location the cockroach perceives the stimulation.

6. What can we do with the information we have gained by analyzing these spikes?

Answers will vary. We can determine what part of the brain is responsible to certain things (example: pain). We can use the electric signals and use them as outputs to make something happen (example: A person who is paralyzed can use their thoughts which are sent to the brain and can cause an output—make a bionic body part move).

7. Do you have further questions regarding the spikes we've seen and heard?

Answers may vary.

8. ***Optional:*** Describe what happened to the cockroach leg when you played music.

Students should describe the movement of the cockroach leg.

Lesson Five: Action Potential

Center for Sensorimotor Neural Engineering
Lesson Plan Author: Claudia Lemus, TAF Academy, Kent, WA

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary: In this lesson, students will observe diffusion occurring across a membrane. They 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.

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:

Students will understand that…

- **Neural Engineering:** Neural engineering is based on the loop between sensory information that is received by the brain, information that the central nervous system (CNS) sends out, and computers/machines that receive input and produce outputs that feed back into the CNS.
- **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.

Essential Questions:

- What does communication look like in neurons?

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.

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.

Vocabulary:

- Concentration
- Diffusion
- Semi-permeable
- Concentration gradient
- Channel protein
- Protein pump
- Resting potential
- Action potential
- Na^+/K^+ pump

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

- **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.

Common Preconceptions & Misconceptions:

- Neurons communicate only using electricity.

MATERIALS

Note: The lesson is designed for a class of 28 students, divided up into two teams/groups.

Material	Quantity
Piece of string or yarn, 15 feet long	2 per group
Small beads, two different colors	34 of one color and 26 of another color per group
Toilet paper tubes or mailing tube (cut into 6 cylinders)	6 per group
Dominoes	56 per group
Blindfolds	2 per group
Index cards with tape on the back or a loop of string, to use as labels	1 per student
Iodine solution (purchased from pharmacy)	50 mL

Corn starch (purchased from baking aisle of grocery store)	3 grams
Water, to make iodine and corn starch solutions	600 mL
Clear plastic cups, short	2 per class
Ziploc bags, sandwich size	2 per class
Timer	1 per class
Student Handout 5.1: Action Potential Interactive Animation	1 per student
Student Handout 5.2: Action Potential Race Analysis Chart	1 per student
Teacher Resource 5.1: Action Potential Interactive Animation Teacher Key	1 copy (teacher resource)
Computers/laptops for students to view online animation (students can pair up)	As needed

TEACHER PREPARATION

1. Make copies of ***Student Handouts 5.1*** and ***5.2***, one of each per student.

2. See *Teacher Instructions* below for simulation set-up and demo preparation.

3. Arrange for students to be able to use computers/laptops for the online animation.

Teacher Instructions for Setting up the Action Potential Race

For each team:

4. **Please 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

5. 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.

6. Place the two Na^+ channels (tubes) on opposite sides of the strings, toward one end, perpendicular to the string.
   a. 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.

7. Place the two K^+ channels (tubes) about two feet further down from the Na^+ channels, in the same manner.

a. 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.

8. 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.

9. 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.

Teacher Instructions for Setting up the Diffusion Demo

For each class:

10. Prepare a 500 mL starch solution by mixing in 500 mL water with 3 g starch. Stir until dissolved.

11. Prepare an iodine solution by mixing in 500 mL water with 50 mL iodine. Stir.

12. Pour 250 mL starch solution into a sandwich sized Ziploc bag, and seal the bag, with as little air as possible inside.

13. Pour 250 mL iodine solution into a sandwich sized Ziploc bag, and seal the bag, with as little air as possible.

14. Pour the remaining 250 mL starch solution into a clear plastic cup.

15. Pour the remaining 250 mL iodine solution into a clear plastic cup.

PROCEDURE

Engage (5 minutes): Interactive Diffusion Model

1. Begin by posing the question, "How do molecules move?"

2. After a few students have shared their answer, let students know they will now simulate how this happens.

3. Have all students stand in one half of the room. Provide an imaginary or physical barrier that separates one half of the room from the other and let the kids know they ***cannot*** go to the other side of the room during this demo.

4. Have students walk with their arms extended in front of them for 30 seconds, ***without*** bumping into anyone else, and trying to move as far as possible from their initial location.

5. After 30 seconds, have students stop and put their hands down.

6. Open up the barrier between the two halves of the room.

7. Still having students start in the first half of the room, instruct them to do the same as before, for 30 seconds, but this time they are allowed to cross over to the other side of the room. After the second 30 second simulation, debrief the students on the activity.

8. Discussion questions (shared out or in writing):
    - Compare how difficult your task was from the first 30 seconds to the second 30 seconds. What made the first part more difficult? (Answers will vary…should get to something related to students being "too close," "squished together," etc.)
    - Introduce the term "concentration." State that students were more concentrated in the first part of the demo than the second part.
    - When students were able to move freely to occupy the rest of the classroom, does anyone know the term for when molecules do this? (Answers will vary…you're trying to get to "diffusion".)
    - In which direction were most people "diffusing" during the second part of the demo? Use answers to introduce the concept of "concentration gradient," and how molecules follow this gradient, which determines the net movement during diffusion.

Explore (5 minutes): Diffusion Demo

9. Show the students a demo of iodine diffusing through a membrane to react with starch. First, have the following materials ready at the font of the room:
    - Ziploc bag with iodine solution
    - Ziploc bag with starch solution
    - Clear plastic cup with iodine solution
    - Clear plastic cup with starch solution
    - Timer

10. Explain to students that the Ziploc bags act as semi-permeable membranes that allow very small molecules through but not larger ones. State that iodine is small enough that it can diffuse through the membrane, but that starch is too large to diffuse through. Explain that starch and iodine react when they come into contact with each other and produce a solution purple in color.

11. Show students the materials, and let them know you will place the iodine bag in the starch cup, and the starch bag in the iodine cup.

12. Before placing the bags in the cups, ask students to turn to their partners and predict what they will see after 20 minutes. If there is time, have some groups share out their predictions.

13. When placing the bags in the cups, start the timer for 20 minutes.

Explain (20 minutes): Digging Deeper into Diffusion

14. Hand out copies of ***Student Handout 5.1: Action Potential Interactive Animation.***

15. 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.

    Action Potential Interactive Animation
    http://outreach.mcb.harvard.edu/animations/actionpotential_short.swf

16. Have students answer the questions provided as they watch and interact with the site.

17. After 20 minutes, have students turn their attention from their online animation back to the demo at the front of the room (they can finish the online animation for homework if they need more time).

18. Have the class recall the predictions that were made about the diffusion demo at the beginning of class.

19. Lift up one bag at a time, and have students make observations about where the purple color is present – call volunteers to the front, or use a doc cam if available.
    - Theoretically, there should be purple in the starch cup and in the starch bag

20. Have students recall the reason why there would be no purple in either of the iodine solutions.
    - Starch is too large of a molecule to diffuse through the membrane.

Elaborate (15 minutes): Action Potential Race

21. 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).

22. 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
- Two 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

23. Assign the following roles to students in the 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

24. 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, higher concentration of K^+ inside the cell.

25. 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.

Evaluate (5 minutes): Analysis Charts

26. Hand out copies of ***Student Handout 5.2: 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:

- Shared out responses from diffusion demo.
- Shared out responses from diffusion demo
- Responses turned in from the Action Potential Race Analysis Chart.

Student Metacognition

- In the diffusion demo, students will get to draw from previous knowledge in order to make predictions. They will then be able to test their predictions during the 20 minute waiting period, and will then be able to discuss any changes in their understanding with their partners and/or the class.

Scoring Guide

- To assess ***Student Handout 5.1***, refer to ***Teacher Resource 5.1: Action Potential Interactive Animation Teacher Key.***

EXTENSION ACTIVITIES

Extension Activities: (30 min) Diffusion Experiment

Instead of doing the iodine/starch diffusion activity as a demo, allow each group to perform the experiment on their own.

1. Tell students they will investigate how diffusion can happen across a membrane, which simulates how this happens with cells.

2. Materials (per group):
   - 2 Ziploc bags
   - Iodine solution (see *Teacher Preparation* instructions)
   - Starch solution (see *Teacher Preparation* instructions)
   - 2 Clear cups or beakers

3. Provide background reading that goes over the molecular size difference between iodine and starch, the term "permeability," and the fact that the membranes used are permeable to iodine and not starch. Also introduce to groups the reaction of starch coming into contact with iodine resulting in purple color.

4. Have groups put together two different set-ups:
   - One in which an iodine solution-filled bag is placed in a starch solution cup.
   - One in which a starch solution-filled bag is placed in an iodine solution cup.

5. Have groups predict where they will see purple form in each cup, based on what they know about diffusion and concentration gradients.

6. After setting up the cups, wait 20 minutes and have students record observations, draw, and/or take pictures every five minutes.

7. After 20 minutes, have students come up with a group conclusion based on their results or conclusion questions. Students should be able to observe purple outside of the iodine bag, and inside the starch bag.

Adaptations:

- **Middle School/ELL/SPED:** Have students do the online animation on the action potential in pairs.
- **Higher Level High School/Gifted:** For the diffusion demo, have students carry out the diffusion demo themselves, in pairs or in groups (as suggested in *Extension*). For the action potential race, after describing the materials and the roles and what cell parts they represent, have students deduce how the race should proceed. The first team that "correctly" finishes the race wins.

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

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

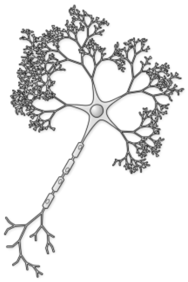
Genetics Science Learning Center. (2014, August 5). *Print-and-Go Index: Pom Pom Potential*. Teach.Genetics. Retrieved August 5, 2014 from http://teach.genetics.utah.edu/content/.

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.

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.

Student Handout 5.1 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?

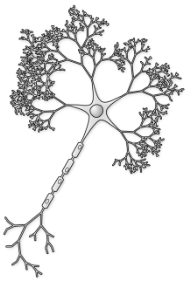
14. How does this action potential in one axon relate to a person's brain directing a foot to move?

Student Handout 5.2 Action Potential Race Analysis Chart

Name:________________________________ Date:__________________ Period:__________

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

Teacher Resource 5.1 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 Six: SpikerBox Lab Part II—Analyzing Spikes

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Angelica Sauceda, TAF Academy, Kent, WA

LESSON OVERVIEW

Activity Time: Two 50 minute class periods.

Lesson Plan Summary: In this lesson, students will use several methods to record data from a cockroach leg. In ***Lesson Four: SpikerBox Lab Part I—Spikes for All,*** they observed and listened to spikes. In this lesson, students are ready to record, quantify, and graphically present electrophysiology data. This lab is an adaptation of several lesson plans from Backyard Brains.

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:

Students will understand that…

- **Systems:** A system is a network of sub-systems that contains inputs, outputs, and feedback mechanisms in order to control/regulate a specific outcome. Disturbances affect the outcome of the system
- **Neurons:** Neurons (nerve cells) transmit information via electronic signals within the nervous system. Neurons communicate using electrical and chemical signals.
- **Sensorimotor Pathway:** Sensory neurons are nerve cells that transmit a signal to the brain from a stimulus/input in the body (touch, smell, etc.). Motor neurons carry signals from the spinal cord to activate muscle movement.
- **Electrophysiology:** Electrophysiology is the study of the electrical properties of cells.
- **Neural Spikes:** A cockroach's nervous system generates large action potentials (neural spikes) making them ideal for analysis.

Essential Questions:

- How do neurons communicate with each other?
- How can I use technology to help me see and hear this communication?
- What is a neural spike and what is its significance of research in the area of neuroprosthetics?

Learning Objectives:

Students will know…

- The chemical nature of an action potential and how signals are generated through chemical means.
- The basic sensorimotor feedback loop that is required for neural engineering.
- Neurons communicate using electrical and chemical signals.
- Sensory stimuli are converted into electrical signals.

Students will be able to…

- Describe a neural spike and identify the significance of research in this area.
- Explain how neurons communicate.
- In terms of our experiment, identify the input and output, and determine if feedback is established.
- Collect and analyze electrophysiology data.

Vocabulary:

- Electrophysiology
- Neuroprosthetic
- Neuron
- Input
- Output
- System
- Neural spike/action potential
- Amplitude
- Frequency

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

- **MS-LS1D-3 Structure, Function, and Information Processing:** Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
- **MS-LS1D-8 Structure, Function, and Information Processing:** Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.
- **MS-ETS1-1 Engineering Design:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **HS-PS3-3 Energy:** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- **HS-ETS1-1 Engineering Design:** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **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.

Common Preconceptions & Misconceptions:

- Robots can "think for themselves" with an artificial intelligence (i.e., don't need human input/programming).
- Every problem has one "perfect" solution.

MATERIALS

Material	Quantity
SpikerBox (the SpikerBox Bundle with audio cables adapter is recommended). Can be ordered from https://backyardbrains.com/products/spikerbox	1 per group
Y Stereo splitter—Male 3.5 mm plug to 2x Female 3.5 mm plugs. Available at http://www.cablesforless.com/Stereo-Splitter-Male-35mm-Plug-To-2x-Female-35mm-Plugs-P4952.aspx	1 per group
Speaker (amplifier), such as RadioShack Mini Audio Amplifier, available at http://www.radioshack.com/search/index.jsp?kwCatId=13384949&kw=mini%20amplifier&origkw=mini+amplifier&sr=1	2 per class for demo
Audio cable, such as Monoprice 3 Feet Stereo Cable, Male to 3.5 mm Stereo Male Gold Plated Cable for Mobile, available at http://www.amazon.com/Monoprice-109296-3-Feet-Stereo-Plated/dp/B00847Q6EU/ref=pd_tcs_subst_e_2?ie=UTF8&refRID=120NSDQKVZQA8T7506QD	1 per group
Toothpick	1 per group
Drinking straw	1 per group
Cockroach.* Adult orange heads, discoids, or discoid/cranifer hybrid cockroaches. Can be ordered from Backyard Brains or Carolina Biological.	1 cockroach leg per group
Dissecting scissors	1 per class
Ice water in vessel for anesthetizing cockroaches	1 per class

Gloves, for use when handling cockroaches	As needed
Rope Neuron model, see notes in *Teacher Preparation* section on how to assemble	1 per class
Student Handout 6.1: SpikerBox Lab Part II—Analyzing Spikes	1 per student
Student Handout 6.2: Analyzing Spikes Exit Ticket	1 per student
Student Handout 4.2: KWL Chart (from Lesson Four)	1 per student
Teacher Resource 6.1 SpikerBox Lab Part II Teacher Key	1 copy
Laptops	1 per group
Audacity Software for PC or Mac downloaded to laptop. Free download from http://audacity.sourceforge.net/	1 per phone or laptop
Classroom computer, projector, speakers, internet access for displaying video	As needed

***Animal Husbandry Information:** Care instructions are usually included with the shipment of cockroaches and an internet search of "cockroach husbandry" will offer additional information. You will need to prepare a small terrarium in advance of the cockroach's arrival that provides a water source, bedding material (soil and/or wood chips), and food (such as lettuce, carrots, and/or dog kibble). You may decide to maintain a breeding colony of cockroaches. To dispose of cockroaches, place them in a doubled plastic zipper bag and put in the freezer for at least 24 hours to euthanize them. They can then be disposed of (in the plastic bags) in the garbage.

Safety Note: When handling and preparing cockroaches, wear gloves.

TEACHER PREPARATION

1. Make copies of ***Student Handouts 6.1*** and ***6.2***, one per student.

2. This lab will be conducted in small groups, depending on the number of SpikerBoxes you have available. We recommend 2-3 students per SpikerBox.

3. Familiarize yourself with the preparation of the cockroach legs (see the *Procedure* section on ***Student Handout 4.1***). The preparation of the cockroach legs can be done beforehand by the teacher or the teacher can ask the students to prepare the cockroach leg as part of the lab activity, as laid out in the handout.

4. Ensure that each SpikerBox is functioning correctly.

5. Make sure that each laptop has the Audacity software installed.

6. If you decide to show students the class demo of a SpikerBox neuroprosthetic, then see the *Elaborate* section of this lesson plan for set-up instructions.

7. If you have not already discussed the topic of animal research (including the use of animals in the science classroom) with your students, please engage your students in a discussion about the ethical issues involved and the importance of respectfully handling the cockroaches during this lab.

8. A Rope Neuron model can be assembled using rope, plastic containers, a pool float, and ping pong balls. Instructions on assembling the model are available at the Neuroscience for Kids website (a video at this web page also shows the model in action). If you choose not to use the actual model, instead you can show students the 3:57 minute video clip of the model in action.

   Modeling the Nervous System: Rope Neuron Model
   Neuroscience for Kids
   http://faculty.washington.edu/chudler/chmodel.html

PROCEDURE

Engage

1. Ask for some volunteers to help you operate a giant, interactive model of a neuron. Explain that the Rope Neuron physically models neurons communicating with each other using electrical and chemical signals. Assign students to the different parts of the neuron model:
   - Dendrites (group of students who hold the smaller ropes representing dendrites)
   - Cell body (one student who works the pool float)
   - Axon terminal (one student who holds the plastic container full of ping pong balls)
   - Dendrites of another, nearby neuron (one student who "receives" the ping pong ball neurotransmitters)

   Alternatively, if you do not have the materials to assemble a Rope Neuron, you can show the video clip (listed in the *Teacher Preparation* section) in place of the demo.

2. Show the students the following video, which profiles a young man named Erik Ramsy with locked-in syndrome as the result of injuries sustained in a car accident. The video

shows the use of a neural implant and brain-computer interface (BCI) to decode signals in the speech-related area of the motor cortex of his brain.

Sounds of Silence
BU Today, July 10, 2009 (3:12 minutes)
https://www.youtube.com/watch?v=cUGuWh2UeMk

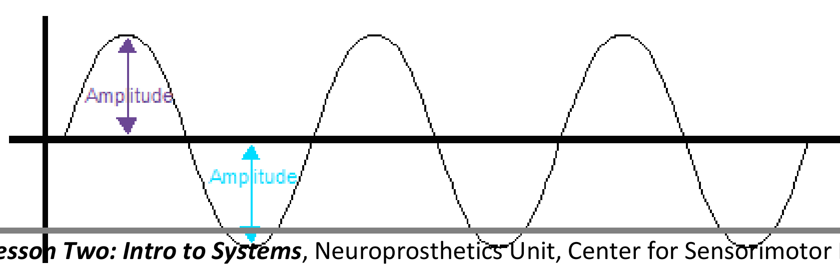
3. Relate the video to today's lab. Explain that the neuroscientists in the video collected neural information from the part of Eric's brain that causes speech. They used a neural implant (electrode), FM transmitter and receiver, computer, neural decoder software, and a speech synthesizer to allow Eric to translate his thoughts of word sounds, with the ultimate goal of allowing Eric to be able to better communicate with his family. In today's lab, we will not be using a human brain, but instead we will be using a cockroach leg. We will be analyzing real life neural spikes coming from the cockroach leg.

Explore

4. Distribute copies of ***Student Handout 6.1: SpikerBox Lab Part II—Analyzing Spikes***, one per student.

5. Ask students to do a Think/Pair/Share in order to answer the pre-lab questions on the handout. It is okay if students do not know the answers to the questions. Ask them to answer to the best of their ability.
   - In your own words explain what the amplitude and frequency of a wave is.
   - Draw a picture of the wave and label the amplitude and frequency.
   - What would happen if the amplitude stayed the same, but the frequency increased? Why?
   - What would happen if the frequency stayed the same, but the amplitude increased? Why?

6. Draw a picture on the board of a wave and label the amplitude and frequency. In addition, provide the following definitions:
   - **Frequency**: How many waves are passing a point per second.
   - **Amplitude**: Measures how big a wave is.



7. Using the classroom computer, open up the phet simulation at the following website:

    Radio Waves & Electromagnetic Fields
    PhET Interactive Simulations
    http://phet.colorado.edu/en/simulation/radio-waves

8. Explain that the wave represented in the simulation is a radio wave (which we cannot see with our eyes, but if we could this is what it would look like). Show the students the amplitude and describe the frequency of the wave.

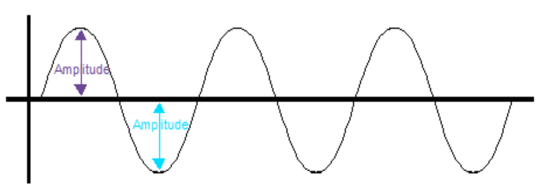
9. Set the amplitude and frequency to the midway point. Ask students what they think will happen if they leave the amplitude alone and change (increase or decrease) the frequency. Set the parameters accordingly and discover what would really happen.

10. Ask the students what they think will happen if they leave the frequency alone, but change (increase or decrease) the amplitude. Set the parameters accordingly and discover what would really happen.

11. Return to the pre-lab questions. Allow students to make notes on their handout in order to capture what happened in the simulation.

    - In your own words explain what the amplitude and frequency of a wave is.
      Frequency: How many waves are passing a point per second.
      Amplitude: Measures how big a wave is.

    - Draw a picture of the wave and label the amplitude and frequency.



    - What would happen if the amplitude stayed the same, but the frequency increased? Why?
      The vibration will be faster (frequency affects the pitch-low frequency drops the pitch). There will be more waves per unit time.

- What would happen if the frequency stayed the same, but the amplitude increased? Why?
  The sound would amplify. The larger the amplitude/vibration, the louder the sound.

12. Ask students, working within their groups, to take turns reading the *Procedure* section of the handout.

13. When each group finishes reading the *Procedure*, they are to summarize the procedure and prepare to share out.

14. Choose one group to summarize the lab procedures in their own words.

15. Ask the students to begin the lab, as described in ***Student Handout 6.1***. **Note:** The preparation of the cockroach leg can be done beforehand by the teacher or the teacher can ask the students to prepare the cockroach leg, as previously described in the *Procedure* of ***Student Handout 4.1*** (from ***Lesson Four***).

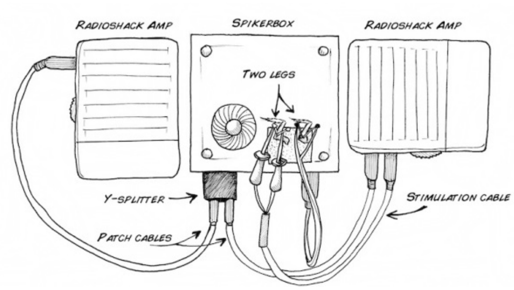
16. Allow time for student groups to work through the lab procedure. The students will be gathering neural data from a cockroach leg based on the different stimulations using a SpikerBox and Audacity software (Refer to ***Student Handout 6.1***, *Initial Setup*, *Procedure*, and *Table 1*; for an example of the table already filled-in, refer to ***Teacher Resource 6.1***). Students will be able to analyze the spikes and make sense of them by graphing the number of neural spikes generated from each stimulation over a 5 second period (an example graph is provided in ***Teacher Resource 6.1***).

Explain

17. After students have completed the graph in ***Student Handout 6.1***, challenge them to answer the discussion questions at the end of the handout. (Sample answers to these questions are provided in ***Teacher Resource 6.1***).

Elaborate

18. Show students a demo of a neuroprosthetic device using two cockroach legs. The set-up is explained on the Backyards Brain website; be sure to watch the video. You will need a SpikerBox, two cockroach legs, a y-splitter, two amplifiers/speakers, two patch cables, and a stimulation cable.



Experiment: NeuroProsthetic
Backyard Brains

https://www.backyardbrains.com/experiments/neuroprosthetics

Evaluate

19. Ask students to return to their KWL charts from *Lesson Four* and complete the third column (L-What I Learned) with new information that they learned during this lab.

20. Pass out copies of ***Student Handout 1.2: Analyzing Spikes Exit Ticket***. Allow time for students to complete the Exit Ticket.

STUDENT ASSESSMENT

Assessment Opportunities

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

- **Formative assessment:** Listening to conversations among students throughout the lab.
- **Formative assessment:** Check for student understanding of the discussion questions on ***Student Handout 6.1***.
- **Summative assessment:** Check for student understanding of the exit ticket questions on ***Student Handout 6.2***.

Student Metacognition

The following is a list of opportunities for student metacognition integrated into this lesson:

- The revision of the KWL chart provides an opportunity for students to reflect on what they learned.
- With the pre-lab questions, students reflect on their individual answers to questions, share their answers with peers, and then discuss as a class.
- After the lesson, students can be asked to go over the discussion questions within their group and as a class.
- The students can be asked to reflect on their responses to the exit ticket questions after they receive teacher feedback.

Scoring Guide

- Sample answers to the pre-lab questions are provided in the Engage section of the *Procedure*.
- Sample answers to the lab questions from ***Student Handout 6.1*** are provided on ***Teacher Resource 6.1***.

EXTENSION ACTIVITIES

Extension Activities:

- This lab should be followed up by presenting *Lesson Seven: Neuroengineering and Brain-Computer Interfaces.*

Adaptations:

- This inquiry lesson is differentiated in the sense that students are not required to come into this activity with extensive background knowledge, instead they must be inquisitive and willing to learn. Analyzing the data from this lab will help answer some the questions that students might have.

TEACHER BACKGROUND & RESOURCES

Background Information

It is important to familiarize yourself with the SpikerBox before teaching this lab. The following TED-Ed video provides a fun and accessible introduction, and features Backyard Brains co-founder Greg Gage. It is also a wonderful video to share with students.

> **The Cockroach BeatBox with Greg Gage**
> TED-Ed, March 11, 2012 (6:15 minutes)
> https://www.youtube.com/watch?v=tr4gWi9Jf6k#t=223

For more in-depth information about the SpikerBox, as well as basic cockroach leg anatomy, visit the link below, read through the text, and watch the videos.

> **Experiments: Getting Started with the SpikerBox**
> Backyard Brains
> https://backyardbrains.com/experiments/spikerbox

In order to familiarize yourself with the components of a system (input, output, feedback, etc.), please reference *Lesson Three: Reaction Time Lab* of this Neuroprosthetics unit.

It is also important to understand a wave, its amplitude, and frequency.

Resources

- Backyard Brains Experiments, https://backyardbrains.com/experiments/
- Backyard Brains Teacher Guides, https://backyardbrains.com/experiments/teachersGuide/
- PhET, http://phet.colorado.edu/

Citations

Backyard Brains. (n.d.). *Experiment: Getting Started with the SpikerBox.* Retrieved July 22, 2014, from https://www.backyardbrains.com/experiments/spikerbox.

Backyard Brains. (n.d.). *Teacher's Guide—Experiment: Getting Started with the SpikerBox.* Retrieved July 22, 2014, from https://www.backyardbrains.com/experiments/spikerbox.

Backyard Brains. (n.d.). *LAB ONE: SPIKES FOR ALL!.* Retrieved July 22, 2014, from http://wiki.backyardbrains.com/images/b/bb/ByB_Entire_Manual.pdf.

Illustrations credit: Backyard Brains.

Wave Diagram credit: http://www.studyphysics.ca/newnotes/20/unit03_mechanicalwaves/chp141516_waves/lesson44.htm.

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.

Student Handout 6.1 SpikerBox Lab Part II—Analyzing Spikes

Name:_________________________________ Date:__________________ Period:__________

Credit: This activity is adapted from Backyard Brains, *Lab One: Spikes for All!* All images are from Backyard Brains.

Pre-Lab Questions:

1. In your own words explain what the amplitude and frequency of a wave is.

2. Draw a picture of the wave and label the amplitude and frequency.

3. What would happen if the amplitude stayed the same, but the frequency increased? Why?

4. What would happen if the frequency stayed the same, but the amplitude increased? Why?

How to Record and Analyze Spikes

In this exercise, you will use several methods to record data from your cockroach leg. Now that you have successfully witnessed spikes you are ready to record, quantify, and graphically present electrophysiology data. Listen to the spikes coming from the SpikerBox speaker. Can you understand what the neurons are saying to each other? What patterns can you detect while listening?

Materials

- SpikerBox with audio cable adapter
- Laptop with Audacity software
- Prepared cockroach leg
- Toothpicks
- Drinking straw

Lab Procedure

Either use an already-prepared cockroach leg, or else follow Steps #1-3 on Student Handout 4.1 if you will be preparing the cockroach leg yourself.

Initial Setup

1. Plug the audio adapter cable into the SpikerBox and your computer. **Note:** For the SpikerBox to record properly, your computer's audio input jack must be audio only, not a combined audio In/Out jack.

2. Turn on Audacity and open a new window.

3. Turn off your cell phone and Wi-Fi. Signal interference from these devices is significant.

4. Record from your SpikerBox by clicking the Red Circle at the top of the screen. **Note:** You can stop recording at any time by pressing the Yellow Square. If you begin to record again, the new "Track" will appear below the previous recordings. You can rename each track by selecting the Audio Track button next to your waveform. If you want to delete a track, select the X button in the upper left of each track.

5. During each experiment, record without stopping. **Note:** Noise created from cell-phones, moving the electrodes, or a variety of other sources can be removed prior to analysis. However, turning your recording on and off may become confusing. The easiest way to keep track of what your data corresponds to is to keep good notes in the space provided.

6. Save your file before you begin. Audacity will save your "Project" in two forms that may be confusing. The first file saved is a folder ending in "_data" and the second is a file ending in ".aup." The .aup file must be in the folder holding the _data folder. In other words, keep the .aup file in the parent directory of the _data folder.

Rate Coding

7. You can now begin experimenting with your cockroach leg! With your cockroach leg, you will compare how neurons in the leg communicate with no stimulation, a light touch from a toothpick, and a strong blow of air through a straw. Think about how your brain can tell the difference between a finger lightly touching your arm and a more forceful poke.

8. There are several reasons for why you differentiate the two stimuli. First, the light touch likely stimulates nerves from a very small area while the more forceful poke may stimulate neurons from much more of your arm. Second, the light touch may only stimulate neurons that respond to being compressed. These neurons, among them Merkel cells, send action potentials to the spinal cord and brain in response to light touch. These cells fire faster when stimulated. Therefore a light touch increases their firing rate, which in kind is interpreted by your spinal cord and brain as a light touch. With the more forceful poke, the Merkel cells fire faster, but they may do so much more strongly. Additionally, there may be other neurons stimulated for fire faster that convey another sensation such as pain.

9. Start Audacity and begin collecting data from your SpikerBox. Ensure your setup is functional by poking the leg a few times. If you see no response, you may need to adjust your electrodes.

10. When you have stable recordings, isolate your leg from any wind and begin the actual recording. Take notes when anything happens to the leg.

11. Record the spontaneous spiking patterns from the leg for one minutes. Note the beginning and end time of your control recordings in ***Table 1***.

12. Take a toothpick and stimulate the hairs on the tibia of the leg. Try several variations of stimulation including constant pressure or repetitive poking, until you find one that gives you consistent reactions. Write your stimulation method in ***Table 1***.

13. Once you have a stimulation method, stimulate the leg repeatedly for one minute. If you need to take a break, do not stop your recording. Take note of the times you are stimulating or resting in ***Table 1***.

14. Next, take a drinking straw and blow on the leg. How does the leg react to this stimulation? Try blowing with different amounts of force. Find an amount of force that allows you to maintain a relatively constant flow on the leg.

15. Blow on the cockroach leg for one minute. As with the toothpick, take note of times you need to break in ***Table 1***, but do not stop your recordings. What happens to the reaction to your blowing over time and after breaks?

Table 1: Experimental Conditions

Condition	Method Notes	Timing Notes
No Stimulation		
Toothpick Stimulation		
Blow through Straw		

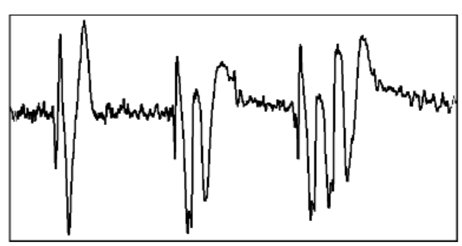
Use the following method to isolate sections of your recordings

16. Find a representative section of spikes between 5-10 seconds long and select it with your cursor. Press the left click and drag across the waveform to select. Select a region with clear spikes and as little noise as possible.

17. Copy the selection (Control-C), open a new Audacity window (Control-N), and paste the selected 5-10 second waveform (Control-V).

18. In the Effect drop down menu, select Amplify. A dialogue box will appear which asks you to select the amount of amplification. The default selection is the amplification that keeps the audio from reaching beyond 1.0 or -1.0 on the scale.

19. Record the Amount of Amplification value from the dialogue box in ***Table 2***. Use the default settings and click OK.

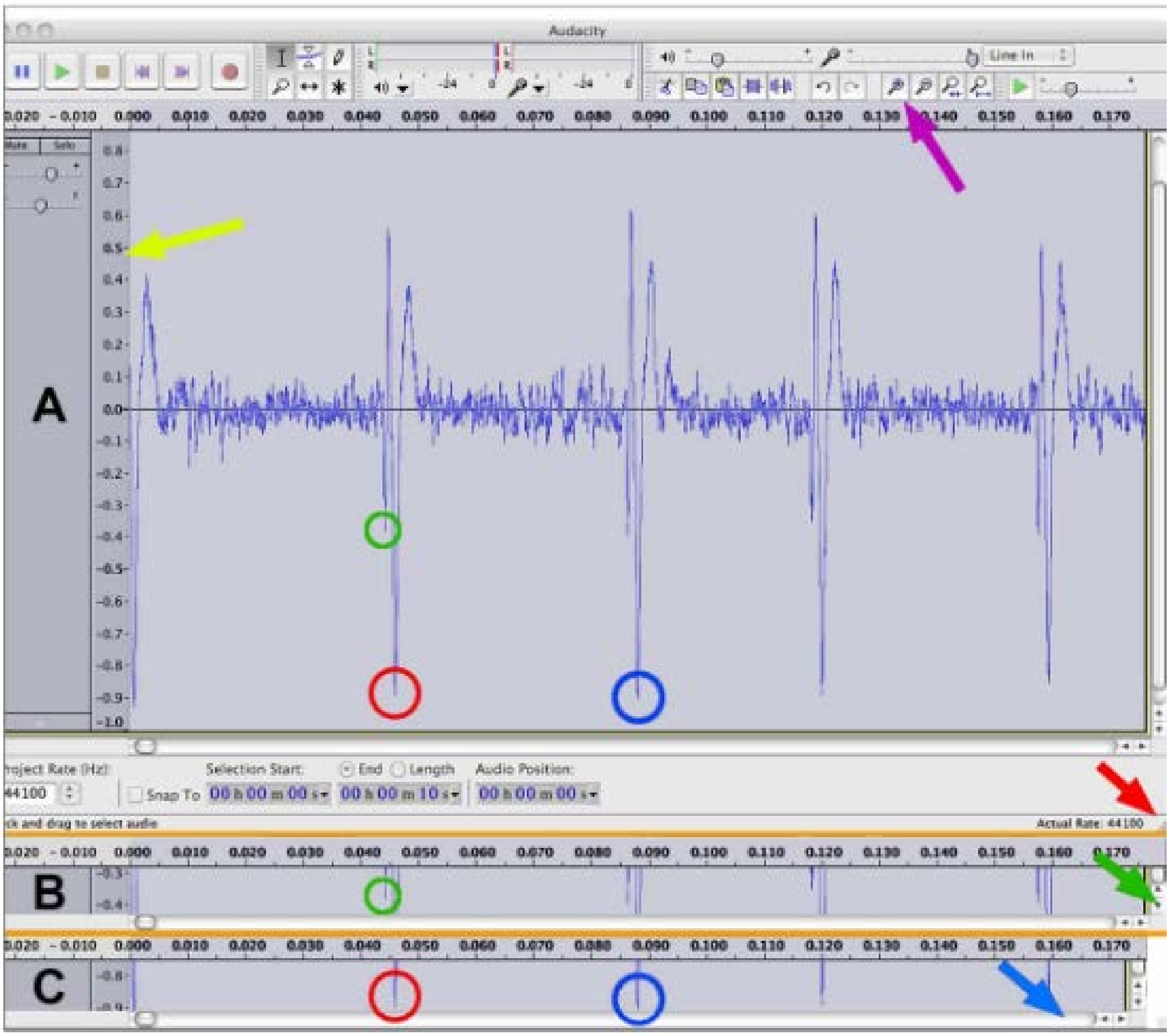


20. One of the first things you may see is that spikes do not always occur in a regular fashion. You may also notice that not all spikes look the same. As shown in this figure, spikes may have 2, 3, or even 4 peaks to them. These are

not special action potentials, but groups of action potentials.

Amplitude Analysis-Distribution of Action Potential Amplitudes

21. For this exercise, you will be asked to quantify the relative frequency and size of action potentials produced by a cockroach leg in response to your stimulations. The figure below provides a screen shot of Audacity that will help you in this process. You will be categorizing the spike peaks by amplitude in a process called binning. The bins will be the scale used by Audacity (Yellow Arrow). Keep in mind that you are measuring negative peaks.



22. Isolate and amplify a five second section of recording using the above method. Ensure you have recorded the Amount of Amplification in ***Table 2***.

23. Widen your Audacity window to fill the width of your screen using the Window Resize tool (Red Arrow). Use the Zoom In tool (Fig. above; Purple Arrow) so that you can visualize a small section of your trace, and easily identify the peaks of your spikes. At this point it is easy to eyeball the difference between peaks like those circled in Green and Red. However, for the purposes of quantification, you want to have a consistent methodology that will allow you to reproducibly determine if the peak circled in Blue is different than that in Red.

24. Look over your data briefly and decide on a threshold for what is noise and you will accept as data. If a peak measuring between -0.2 and -0.3 is sufficiently distinct from the background noise, use this as your minimum negative threshold. Your threshold may be a larger negative number depending on how much noise was recorded. Write the Threshold Value in ***Table 2***, keeping the number in tenths (i.e. -0.2, -\0.3, -0.4).

Table 2: Amplification and Threshold

Condition	**Amplification**	**Threshold**
No Stimulation		
Toothpick Stimulation		
Blowing Through a Straw		

25. Using the Window Resize tool (Red Arrow), shrink the Audacity window vertically, so that the scale on the left of the screen shows only 0.1 of the total waveform (Fig. on the last page). This will allow you more accurately determine the bin a peak is in. Some peaks are clearly inside one bin, but some, like the one in the Blue Circle, require a judgment call on your part. Remain consistent in these close calls.

26. Record in ***Table 3*** using hash marks, the number of peaks that end in the bin you have isolated. For example, the peak in the Green Circle has a minimum inside the -0.3 to -0.4 bin, while the peaks found in the Red and Blue Circles do not. Clicking the empty slider at the bottom of the window (Blue Arrow) will move the waveform smoothly, and will allow you to quickly count the peaks that fall within each bin. In many instances, you may have no peaks across an entire waveform inside a bin; this is OK.

27. Once you have counted all peaks in a bin for the entire five second waveform, click the down arrows (Green Arrow) to isolate a new bin. Record the number of peaks in each bin in ***Table 3***.

Table 3: Spike Amplitudes—No Stimulation

Bin	Peaks Observed	Total
-0.2 to -0.3		
-0.3 to -0.4		
-0.4 to -0.5		
-0.5 to -0.6		
-0.6 to -0.7		
-0.7 to -0.8		
-0.8 to -0.9		
-0.9 to -1.0		

Table 4: Spike Amplitudes—Toothpick Stimulation

Bin	Peaks Observed	Total
-0.2 to -0.3		
-0.3 to -0.4		
-0.4 to -0.5		
-0.5 to -0.6		
-0.6 to -0.7		
-0.7 to -0.8		
-0.8 to -0.9		
-0.9 to -1.0		

Table 5: Spike Amplitudes—Blowing Through Straw

Bin	Peaks Observed	Total
-0.2 to -0.3		
-0.3 to -0.4		
-0.4 to -0.5		
-0.5 to -0.6		

-0.6 to -0.7		
-0.7 to -0.8		
-0.8 to -0.9		
-0.9 to -1.0		

Graphing Your Data

28. Plot the total number of spikes from each bin on the graph below for each of your experimental conditions. Draw and label a line for each condition. Make sure you include units and label your axes.

Graph Title:____

Answer the following:

29. What is the independent variable (x-axis)?

30. What is the dependent variable (y-axis)?

Discussion Questions

31. How does the frequency of spikes for the different types of stimulations compare?

32. How did the neurons respond to blowing? Was there any sort of attenuation (loss in intensity) in the neural response over time?

33. How did the neurons respond to the toothpick? Was there any sort of attenuation in the neural response over time?

34. How many neurons were excited by the toothpick? How many by the straw? How do these responses differ from one another?

Student Handout 6.2 Analyzing Spikes Exit Ticket

Name:________________________________ Date:__________________ Period:__________

1. Explain what we did in today's lab.

2. What are neural spikes and how are we able to hear and or see them?

3. What did you learn in today's lab?

4. What questions do you have?

5. ***Make a connection:*** In your own words how might you use the electrical signals (neural spikes) rom the a human brain to informs research in neural prosthetics? Does it matter where on the brain we place the electrode/s? Feel free to draw a picture if it helps.

Teacher Resource 6.1 SpikerBox Lab Part II Teacher Key

Sample answers to the Lab Questions are provided below:

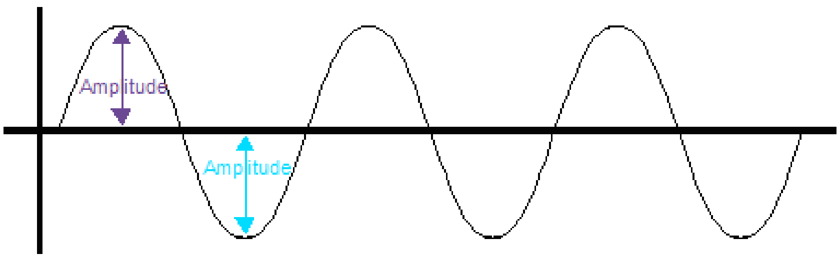
Wave Diagram credit: http://www.studyphysics.ca/newnotes/20/unit03_mechanicalwaves/chp141516_waves/lesson44.htm.

Pre-Lab Questions

1. In your own words explain what the amplitude and frequency of a wave is.

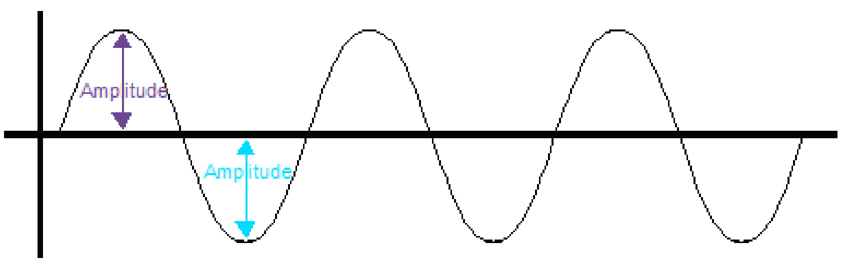
Frequency: How many waves are passing a point per second.

Amplitude: Measures how big a wave is.



2. Draw a picture of the wave and label the amplitude and frequency.

Frequency: If this picture represents 1 second the frequency would be 3 waves per second.



3. What happens if the amplitude stays the same, but the frequency increases? Why?

The vibration will be faster (frequency affects the pitch-low frequency drops the pitch). There will be more waves per unit time.

4. What would happen if the frequency stayed the same, but the amplitude increases? Why?

The sound would amplify. The larger the amplitude/vibration, the louder the sound.

Graphing Your Data

28. Plot the total number of spikes from each bin on the graph below for each of your experimental conditions. Draw and label a line for each condition. Make sure you include units and label your axes.

- Student's graph should plot the total number of spiked from each bin, for each of the experimental conditions, with a line drawn and labeled for each condition.
- Axes should be labeled and units provided.
- Graph title should be provided. For example, Stimulation's Effect on the Frequency of Neural Spikes.

Answer the following:

29. What is the independent variable (x-axis)?

The independent variable is the type of stimulation.

30. What is the dependent variable (y-axis)?

The dependent variable is the frequency of spikes within each bin for each stimulation.

Discussion Questions

31. How do you compare the frequency of the spikes for the different types of stimulation?

- Note: No stimulation should have few spikes.
- Blowing on the leg should yield more spikes and should stimulate more neurons.
- Poking on the leg should yield the most spikes and should stimulate the most neurons (amplitude corresponds to a specific neuron).

32. How did the neurons respond to blowing? Was there any sort of attenuation (loss in intensity) in the neural response over time?

May be negligible.

33. How did the neurons respond to the toothpick? Was there any sort of attenuation in the neural response over time?

There should be high intensity of spikes as the leg is being stimulated and directly after the stimulation, but the intensity will begin to decrease afterward.

34. How many neurons were excited by the toothpick? How many by the straw? How do these responses differ from one another?

Answers will vary and will be dependent on student's actual data.

Lesson Seven: Neural Engineering & Brain-Computer Interfaces

Center for Sensorimotor Neural Engineering
Lesson Plan Author: Renee Poitras, Kent-Meridian High School, Kent, WA

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary: In this lesson, students will be introduced to neural engineering by exploring three devices (cochlear implant, retinal implant, and deep brain stimulator) currently used in the United States. Students then will take notes and sketch out a Brain-Computer Interface (BCI) in preparation for further research conducted during subsequent lessons in this unit.

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:
Students will understand that…

- **Neural Engineering:** Neural engineering is based on the loop between sensory information that is received by the brain, information that the central nervous system (CNS) sends out, and computers/machines that receive input and produce outputs that feed back into the CNS. It is informed by knowledge of systems biology and can be applied to correct disturbances to the nervous system.
- **Brain-Computer Interfaces (BCIs):** Devices that connect the human brain and nervous system with computers and/or machines.

Essential Questions:

- How does a systems approach to neural engineering allow for solutions to be developed to solve injury to the nervous system?

Learning Objectives:
Students will know…

- Neural engineering (also known as neuroengineering) is a discipline within the field of biomedical engineering that focuses on repairing, replacing, or enhancing properties of the nervous system through the use of neural prosthetics, neural implants, and brain-computer interfaces; it is an multi-disciplinary field.
- That a systems approach to neural engineering can be used to find solutions to diseases, disorders, and injuries of the nervous system.
- That a BCI is a device that connects the human brain and nervous system with computers and/or machines.
- That a BCI functions as a system.

Students will be able to…

- Apply their understanding of the human nervous system to systems terminology.
- Label the parts of a system using a neural engineering example.

- Name three examples of BCIs currently in use in patients in the United States.
- Sketch a BCI of their own design.
- List five questions they would like to research about neural engineering and BCIs.

Vocabulary:

- Motor Neurons
- Sensory Neurons
- Axon
- Neurotransmitters
- Synapse
- Action Potential
- Reaction Time
- Brain
- Spinal cord
- Disruption/Disturbance
- Dynamic
- Edges
- Equilibrium
- Feedback
- Inputs
- Negative Feedback
- Networks
- Nodes
- Outputs
- Positive Feedback
- Subsystem
- System
- Brain-Computer Interface (BCI)
- Neural Implant
- Neural Prosthetic

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

- **MS-ETS1-1 Engineering Design:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **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.

- **HS-ETS1-1 Engineering Design:** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **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.

Common Preconceptions & Misconceptions:

- Technology does not impact living organisms.
- Engineering does not impact living organisms (or is just for design of objects/machines).
- There is one "perfect" solution to every problem (no room for improvement).

MATERIALS

Note: The lesson is designed for the class to be divided into groups of three students each.

Material	Quantity
Butcher paper or large Sticky-note poster paper	5
Stickers	5 per student
Manila Envelope (9"x12") to place fact sheets in	1 per group
~1/2 sheet of blank paper for Exit Tickets	1 per student
Student lab notebooks or paper for note-taking	1 per student
Student Handout 7.1: Brain-Computer Interface Fact Sheets	1 per group
Student Handout 7.2: Neural Engineering Examples	1 per student
Teacher Resource 7.1: Neural Engineering Examples Teacher Key	1 copy (teacher resource)
Brain-Computer Interfaces PowerPoint presentation	1 PPT file
Classroom computer with speakers and internet connection, connected to projector	As needed

TEACHER PREPARATION

1. Make copies of ***Student Handouts 7.1***, one per group. Place one set of fact sheets into a manila envelope for each student group.

2. Make copies of ***Student Handout 7.2***, one per student.

3. Pre-read the ***Brain-Computer Interface*** PowerPoint as it gives directions for the students and for you (there are hidden slides with teacher instructions, so make sure to also view it in "outline view").

4. Break the class into groups with three students per group. Adjust class seating arrangement if needed (heterogeneous seating is recommended).

5. Make the posters for the *Engage* activity (See *Engage* section of *Procedure* below). Each poster should have the statement at the top and a range ½ down from Highly Agree to Highly Disagree (see *Slide #2* of PowerPoint). Post the posters throughout the room in locations so that the students will be able to easily place stickers on them.

6. Have an Exit Ticket (1/2 sheet of paper) ready to pass out to students, one per student.

PROCEDURE

Note: The slide numbers mentioned in the *Procedure* are from the ***Brain-Computer Interface*** PowerPoint Presentation.

Engage: Slides #2-6

1. Pre-read *Slides #2-4* as they give directions to the teacher on how to set up the room plus details on the each statement in case students should ask.

2. Display *Slide #5* for the students. Pass out five stickers to each student. Have the students read the statement on each poster and place their sticker on the range based on their beliefs of the statement, one sticker per poster. Do not give any hints.

3. Show *Slide #6* and go through the answers. If students ask, feel free to explain the statements. Ask which statement deals with their problem (#2).

Explore: Slides #7-11

4. Have students get out their notebooks (or note-taking paper) and take notes along with you.

5. Show *Slide #7*. Begin by having students sketch out what they think neural engineering means. Then, show the definition.

6. Next, have groups work together to answer the question posed on *Slide #7:* “What are the parts of the nervous system? (Think, what have you already learned?)”. Give students about three minutes. Show them the list of nervous system components and ask students to help explain each part.

7. Show *Slide #8* and allow students about seven minutes to fill in the table with their group mates. Check the progress of each team. Look at *Slide #9* if you need some guidance on how to help the students fill in the table.

8. When each group has completed the table, show *Slide #10*. Make a class list of injuries on the board (see *Slide #11* if you need guidance on examples to help class discussion).

Explain: Slides #12-14

9. Pass out a manila envelope containing a set of fact sheets to each group. Hand out copies of ***Student Handout 7.2: Neural Engineering Examples***, one per student.

10. Show *Slide #12* and read the directions as a class. Give the students no more than ten minutes to independently read and fill in the table. Give each team about ten minutes to share their information. By the end of this time, all three tables based on the readings should be completed. See ***Teacher Resource 7.1: Neural Engineering Examples Teacher Key*** if you need guidance on the readings and tables.

11. Show *Slide #14*. This is a video that students will use to fill in their last table. Click on the URL to open the video in your web browser. The video is 7:24 minutes long and tells the story of Tim Hemmes who was paralyzed as a result of a motorcycle accident. As a participant in an ECoG Trial at the University of Pittsburgh Medical Center, Tim is learning to control a computer screen and a robotic arm using his thoughts.

Elaborate: Slides #15-17

12. Project *Slide #15*. Explain that the video showed an example of a brain-computer interface.

13. Show students the image on *Slide #15* and walk through what a brain-computer interface is and how it works.

14. Give students five minutes to fill in the table on *Slide #15*, which relates the concepts of “systems” to a “brain-computer interface.” If you need guidance, see *Slide #16*.

15. Ask students if the image shows feedback (it does not).

16. Show *Slide #17*. Explain that current research is looking at feedback systems and sensory input. Explain the two graphics. Click on the link to the Center for Sensorimotor Neural Engineering. Explain the Center and the focus of its research.

Evaluate: Slides #18-19

17. Project *Slide #18*. Pass out the ½ sheet of blank paper to each student. This will be their Exit Tickets.

18. Challenge students to sketch out a brain-computer interface. They may use their notes.

19. If students finish early, they may begin their homework, as described on *Slide #18*.

20. Collect the Exit Tickets. Assess the Exit Tickets that evening (see *Slide #19*).

STUDENT ASSESSMENT

Assessment Opportunities

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

- **Formative:** *Engage* posters will give you an idea of student preconceptions.
- **Formative:** Nervous System table will allow you to see which students remember systems vocabulary and which do not. It is important that you circulate around the room and assess groups throughout this time.
- **Formative:** Brain-Computer Interface Systems table discussion should let you know what students learned this lesson as it will be the fifth systems table they have filled in this period.
- **Summative:** Exit Tickets. This should be entered into the grade book as students had five examples given in class. See rubric on ***Teacher Resource 7.1: Neural Engineering Examples Teacher Key.*** It should be noted that students be given a chance to redo this assignment if they neglected to label their sketch with systems vocab (this is not in the directions, but will allow the teacher to note who truly understands systems). As stated on *Slide #19*, pass back the Exit Tickets the next day and allow students to add systems vocabulary. These should be collected and re-graded.

Student Metacognition

- The *Engage* activity will allow students to notice their knowledge on brain basics.
- The *Explore* sketch before learning will allow students to think about their prior knowledge.
- Students will be given a chance to reflect on their prior learning of systems and the nervous system.
- Students will apply this knowledge to five new examples.
- Students will be sketch out a brain-computer interface with their notes. If they compare with their sketch from the beginning of the period, they should see growth.

Scoring Guide

- Student success will be a complete sketch of a brain-computer interface integrating systems vocabulary. As noted above, students should be given a chance the next day to add in systems vocabulary. See rubric on ***Teacher Resource 7.1: Neural Engineering Examples Teacher Key.***

EXTENSION ACTIVITIES

Extension Activities:

- **Exploring STEM careers:** This is an opportunity to have students explore STEM careers by using the Center for Sensorimotor Neural Engineering website. This website introduces students to the current projects and partners with these projects. Students could explore what careers are mentioned on the website and then use a career site to learn more about these jobs. Check in with your career counselor for good sites. If you don't know of one, try mapping your career as it is STEM focused. http://www.mapyourcareer.org/

Adaptations:

- Print out the PowerPoint slides and ***Teacher Resource 7.2*** for those students with language issues so they can focus on learning versus taking notes.
- Have students work with a partner to read the fact sheets and complete the tables. One partner could be the reader, the other the writer.
- Have students computerize the brain-computer interface using a graphic organizer program.

TEACHER BACKGROUND & RESOURCES

Background Information

The following background knowledge is needed to successfully deliver this lesson:

- Basic understanding of systems vocabulary and the nervous system. This information is covered earlier in this neural prosthetics curriculum unit.
- Basic understanding of neural engineering and brain-computer interfaces. Reading the fact sheets will give the teacher a good background. It is also recommended to explore the website of the Center for Sensorimotor Neural Engineering.
- The hidden slides in the Brain-Computer Interface PowerPoint, along with ***Teacher Resource 7.2***, provides all the information needed for this lesson.

Resources

Workforce Development Council of Seattle-King County. (2010). Map Your Career, career maps and resources for major Puget Sound industries. Retrieved August 12, 2014, from http://www.mapyourcareer.org/

University of Pittsburgh Medical Center. (2011, October 7). Paralyzed man moves robotic arm with his thoughts [Video file]. Retrieved from http://www.upmc.com/media/pages/video.aspx?k=tim%20hemmes

Citations

Artificial Retina Project Spurs New Technologies. (2009, September 3). Retrieved August 12, 2014, from http://artificialretina.energy.gov/technologies.shtml

Balougador. (2007, December 15). InterfaceNeuronaleDirecte-fr.svg [Brain-computer interface schema]. Retrieved from http://commons.wikimedia.org/wiki/File:InterfaceNeuronaleDirecte-fr.svg

Center for Sensorimotor Neural Engineering. (n.d.). Projects | The NSF Engineering Research Center for Sensorimotor Neural Engineering (CSNE). Retrieved August 12, 2014, from http://csne-erc.org/projects

National Institute of Mental Health. (n.d.). NIMH · Brain Stimulation Therapies. Retrieved August 12, 2014, from http://www.nimh.nih.gov/health/topics/brain-stimulation-therapies/brain-stimulation-therapies.shtml

NIDCD. (2011, March). NIDCD Fact Sheet Cochlear Implants. Retrieved August 12, 2014, from http://www.nidcd.nih.gov/staticresources/health/hearing/FactSheetCochlearImplant.pdf

Rivers, S. (2013, February 14). FDA approves first retinal implant for adults with rare genetic eye disease. Retrieved August 12, 2014, from http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm339824.htm

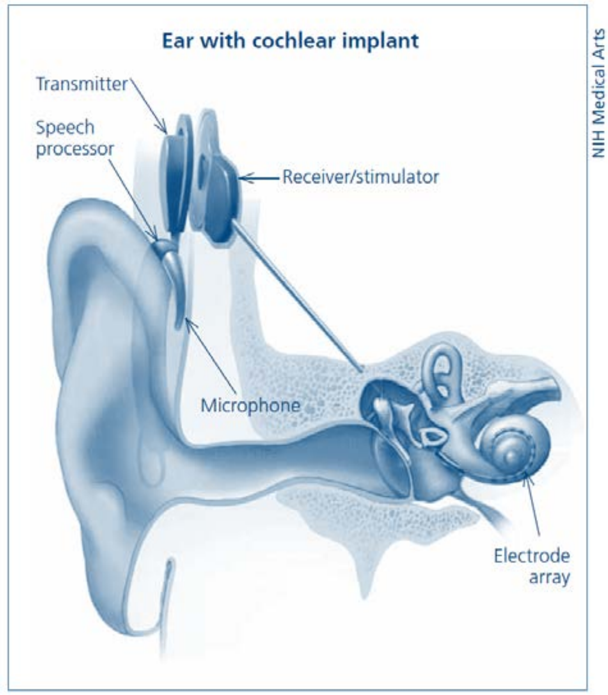
Ahuja, A.K., Dorn, J.D., Caspi, A., McMahon, M.J., Dagnelie, G., daCruz, L., . . . Argus II Study Group. (2011). Blind subjects implanted with the Argus II retinal prosthesis are able to improve performance in a spatial-motor task. *British Journal of Ophthalmology*. 95: 539-543. Retrieved September 17, 2014 from http://bjo.bmj.com/content/95/4/539.full

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.

Student Handout 7.1 Brain-Computer Interface Fact Sheets
Name:_______________________________ Date:_________________ Period:__________

NIDCD FACT SHEET: COCHLEAR IMPLANTS
U.S. Department of Health & Human Services | National Institutes of Health |
National Institute on Deafness and Other Communication Disorders

What is a Cochlear Implant?
A cochlear implant is a small, complex electronic device that can help to provide a sense of sound to a person who is profoundly deaf or severely hard-of hearing. The implant consists of an external portion that sits behind the ear and a second portion that is surgically placed under the skin (see figure).



An implant has the following parts:

- A microphone, which picks up sound from the environment.
- A speech processor, which selects and arranges sounds picked up by the microphone.
- A transmitter and receiver/stimulator, which receive signals from the speech processor and convert them into electric impulses.
- An electrode array, which is a group of electrodes that collects the impulses from the stimulator and sends them to different regions of the auditory nerve.

An implant does not restore normal hearing. Instead, it can give a deaf person a useful representation of sounds in the environment and help him or her to understand speech.

How Does a Cochlear Implant Work?
A cochlear implant is very different from a hearing aid. Hearing aids amplify sounds so they may be detected by damaged ears. Cochlear implants bypass damaged portions of the ear and directly stimulate the auditory nerve. Signals generated by the implant are sent by way of the auditory nerve to the brain, which recognizes the signals as sound. Hearing through a cochlear implant is different from normal hearing and takes time to learn or relearn. However, it allows many people to recognize warning signals, understand other sounds in the environment, and enjoy a conversation in person or by telephone.

Who Gets Cochlear Implants?
Children and adults who are deaf or severely hard-of-hearing can be fitted for cochlear implants. According to the U.S. Food and Drug Administration (FDA), as of December 2010, approximately 219,000 people worldwide have received implants. In the United States, roughly 42,600 adults and 28,400 children have received them. Adults who have lost all or most of their hearing later in life often can benefit from cochlear implants. They learn to associate the signal provided by an implant with sounds they remember. This often provides recipients with the ability to understand speech solely by listening through the implant, without requiring any visual cues such as those provided by lip reading or sign language. Cochlear implants, coupled with intensive post-implantation therapy, can help young children to acquire speech, language, and social skills. Most children who receive implants are between 2 and 6 years old. Early implantation provides exposure to sounds that can be helpful during the critical period when children learn speech and language skills. In 2000, the FDA lowered the age of eligibility to 12 months for one type of cochlear implant.

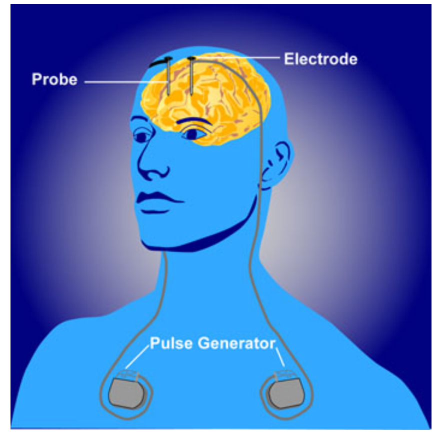
How Does Someone Receive a Cochlear Implant?
Use of a cochlear implant requires both a surgical procedure and significant therapy to learn or relearn the sense of hearing. Not everyone performs at the same level with this device. The decision to receive an implant should involve discussions with medical specialists, including an experienced cochlear-implant surgeon. The process can be expensive. For example, a person's health insurance may cover the expense, but not always. Some individuals may choose not to have a cochlear implant for a variety of personal reasons. Surgical implantations are almost always safe, although complications are a risk factor, just as with any kind of surgery. An additional consideration is learning to interpret the sounds created by an implant. This process takes time and practice. Speech-language pathologists and audiologists are frequently involved in this learning process. Prior to implantation, all of these factors need to be considered.

What Does the Future Hold for Cochlear Implants?
With advancements in technology and continued follow-up studies with people who already have received implants, researchers are evaluating how cochlear implants might be used for other types of hearing loss. The National Institute on Deafness and Other Communication Disorders (NIDCD) is supporting research to improve upon the benefits provided by cochlear implants. It may be possible to use a shortened electrode array, inserted into a portion of the cochlea, for individuals whose hearing loss is limited to the higher frequencies. Other studies are exploring ways to make a cochlear implant convey the sounds of speech more clearly. Researchers also are looking at the potential benefits of pairing a cochlear implant in one ear with either another cochlear implant or a hearing aid in the other ear.

Text and Image Source: NIDCD. Retrieved August 12, 2014,
from http://www.nidcd.nih.gov/staticresources/health/hearing/FactSheetCochlearImplant.pdf

NATIONAL INSTITUTE OF MENTAL HEALTH
Mental Health Information: Brain Stimulation Therapies

Excerpt of NIMH website text



Deep Brain Stimulation

Deep brain stimulation (DBS) was first developed as a treatment for Parkinson's disease to reduce tremor, stiffness, walking problems and uncontrollable movements. In DBS, a pair of electrodes is implanted in the brain and controlled by a generator that is implanted in the chest. Stimulation is continuous and its frequency and level is customized to the individual.

DBS has only recently been studied as a treatment for depression or obsessive compulsive disorder (OCD). Currently, it is available on an experimental basis only. So far, very little research has been conducted to test DBS for depression treatment, but the few studies that have been conducted show that the treatment may be promising. One small trial involving people with severe, treatment-resistant depression found that four out of six participants showed marked improvement in their symptoms either immediately after the procedure, or soon after.[1] Another study involving 10 people with OCD found continued improvement among the majority three years after the surgery.[2]

How Does it Work?

DBS requires brain surgery. The head is shaved and then attached with screws to a sturdy frame that prevents the head from moving during the surgery. Scans of the head and brain using MRI are taken. The surgeon uses these images as guides during the surgery. Patients are awake during the procedure to provide the surgeon with feedback, but they feel no pain because the head is numbed with a local anesthetic.

Once ready for surgery, two holes are drilled into the head. From there, the surgeon threads a slender tube down into the brain to place electrodes on each side of a specific part of the brain. In the case of depression, the part of the brain targeted is called Area 25. This area has been found to be overactive in depression and other mood disorders.[1] In the case of OCD, the electrodes are placed in a different part of the brain believed to be associated with the disorder.

After the electrodes are implanted and the patient provides feedback about the placement of the electrodes, the patient is put under general anesthesia. The electrodes are then attached to wires that are run inside the body from the head down to the chest, where a pair of battery-operated generators are implanted. From here, electrical pulses are continuously delivered over the wires to the electrodes in the brain. Although it is unclear exactly how the device works to reduce depression or OCD, scientists believe that the pulses help to "reset" the area of the brain that is malfunctioning so that it works normally again.

What Are the Side Effects?

DBS carries risks associated with any type of brain surgery. For example, the procedure may lead to:

- Bleeding in the brain or stroke
- Infection
- Disorientation or confusion
- Unwanted mood changes
- Movement disorders
- Lightheadedness
- Trouble sleeping

Because the procedure is still experimental, other side effects that are not yet identified may be possible. Long-term benefits and side effects are unknown.

Citations

[1]Mayberg HS, Lozano AM, Voon V, McNeely HE, Seminowicz D, Hamani C, Schwalb JM, Kennedy SH. Deep brain stimulation for treatment-resistant depression. *Neuron*. 2005 Mar 3; 45(5):651-660.

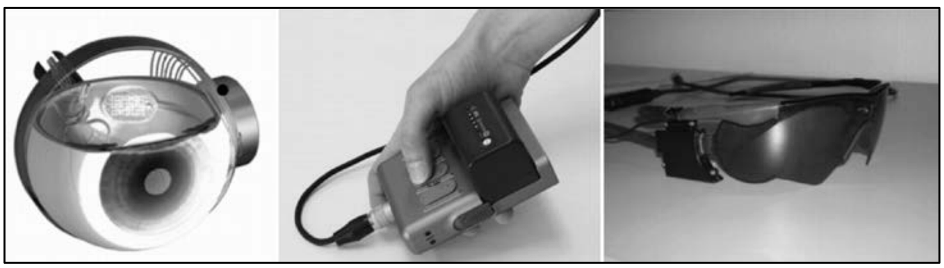
[1]Greenberg BD, Malone DA, Friehs GM, Rezai AR, Kubu CS, Malloy PF, Salloway SP, Okun MS, Goodman WK, Rasmussen SA. Three-year outcomes in deep brain stimulation for highly resistant obsessive compulsive disorder. *Neuropsychopharmacology*. 2006 Nov; 31(11):2384-2393.

Text and Image Source: NIMH. Retrieved August 12, 2014, from http://www.nimh.nih.gov/health/topics/brain-stimulation-therapies/brain-stimulation-therapies.shtml

FDA NEWS RELEASE
February 14, 2013

FDA Approves First Retinal Implant for Adults with Rare Genetic Eye Disease

The U.S. Food and Drug Administration today approved the Argus II Retinal Prosthesis System, the first implanted device to treat adult patients with advanced retinitis pigmentosa (RP). The device, which includes a small video camera, transmitter mounted on a pair of eyeglasses, video processing unit (VPU) and an implanted retinal prosthesis (artificial retina), replaces the function of degenerated cells in the retina (a membrane inside the eye) and may improve a patient's ability to perceive images and movement. The VPU transforms images from the video camera into electronic data that is wirelessly transmitted to the retinal prosthesis.



A schematic illustration showing the surgically implanted stimulating microelectrode array, and inductive coil telemetry link of the Argus II system (left). The external portions of the system consist of a video processing unit (VPU) (middle) and a miniature camera mounted on a pair of glasses (right). **Image and caption credit:** Ahuja, A.K., et al. (2011). Blind subjects implanted with the Argus II retinal prosthesis are able to improve performance in a spatial-motor task. *British Journal of Ophthalmology*. 95: 539-543. Retrieved September 17, 2014 from http://bjo.bmj.com/content/95/4/539.full

RP is a rare genetic eye condition that damages the light-sensitive cells that line the retina. In a healthy eye, these cells change light rays into electrical impulses and send them through the optic nerve to the area of the brain that assembles the impulses into an image. In people with RP, the light-sensitive cells slowly degenerate resulting in gradual loss of side vision and night vision, and later of central vision. The condition can lead to blindness.

"This new surgically implanted assistive device provides an option for patients who have lost their sight to RP – for whom there have been no FDA-approved treatments," said Jeffrey Shuren, M.D., director of the FDA's Center for Devices and Radiological Health. "The device may help adults with RP who have lost the ability to perceive shapes and movement to be more mobile and to perform day-to-day activities."

The Argus II system is intended for use in adults, age 25 years or older, with severe to profound RP who have bare light perception (can perceive light, but not the direction from which it is coming) or no light perception in both eyes, evidence of intact inner layer retina function, and a previous history of the ability to see forms. Patients must also be willing and able to receive the recommended post-implant clinical follow-up, device fitting, and visual rehabilitation.

In addition to a small video camera and transmitter mounted on the glasses, the Argus II Retinal Prosthesis System has a portable video processing unit (VPU) and an array of electrodes that are implanted onto the patient's retina. The VPU transforms images from the video camera into electronic data that is wirelessly transmitted to the electrodes. The electrodes transform the data into electrical impulses that stimulate the retina to produce images. While the Argus II Retinal Prosthesis System will not restore vision to patients, it may allow them to detect light and dark in the environment, aiding them in identifying the location or movement of objects or people.

The FDA approved the Argus II Retinal Prosthesis System as a humanitarian use device, an approval pathway limited to those devices that treat or diagnose fewer than 4,000 people in the United States each year. To obtain approval for humanitarian use, a company must demonstrate a reasonable assurance that the device is safe and that its probable benefit outweighs the risk of illness or injury. The company also must show that there is no comparable device available to treat or diagnose the disease or condition.

The FDA reviewed data that included a clinical study of 30 study participants with RP who received the Argus II Retinal Prosthesis System. Investigators monitored participants for adverse events related to the device or to the implant surgery and regularly assessed their vision for at least two years after receiving the implant.

Results from the clinical study show that most participants were able to perform basic activities better with the Argus II Retinal Prosthesis System than without it. Some of the activities tested included locating and touching a square on a white field; detecting the direction of a motion; recognizing large letters, words, or sentences; detecting street curbs; walking on a sidewalk without stepping off; and matching black, grey and white socks.

Following the implant surgery, 19 of the 30 study patients experienced no adverse events related to the device or the surgery. Eleven study subjects experienced a total of 23 serious adverse events, which included erosion of the conjunctiva (the clear covering of the eyeball), dehiscence (splitting open of a wound along the surgical suture), retinal detachment, inflammation, and hypotony (low intraocular pressure).

Three government organizations provided support for the development of the Argus II. The Department of Energy, National Eye Institute at the National Institutes of Health and the National Science Foundation collaborated to provide grant funding totaling more than $100 million, support for material design and other basic research for the project.

Second Sight Medical Products, Inc. is based in Sylmar, Calif.

Text Source: U.S. Food and Drug Administration. Retrieved August 12, 2014, from http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm339824.htm

Student Handout 7.2 Neural Engineering Examples

Name:___________________________________ Date:____________________ Period:___________

Retinal Implants

Inputs:	
Outputs:	
Disturbance:	
Description of how device fixes disturbance:	
Nodes: (main parts)	
Edges: (how connected?)	

Cochlear Implants

Inputs:	
Outputs:	
Disturbance:	
Description of how device fixes disturbance:	

Nodes: (main parts)	
Edges: (how connected?)	

Deep Brain Stimulators

Inputs:	
Outputs:	
Disturbance:	
Description of how device fixes disturbance:	
Nodes: (main parts)	
Edges: (how connected?)	

Motor Implants: Watch video and try to fill in the information.

Inputs:	
Outputs:	
Disturbance:	
Description of how device fixes disturbance:	
Nodes: (main parts)	
Edges: (how connected?)	

Teacher Resource 7.1 Neural Engineering Examples Teacher Key

Retinal Implants

Inputs:	Visual images
Outputs:	Electrical data
Disturbance:	Retinitis pigmentosa (RP)
Description of how device fixes disturbance:	Images from video camera into electronic data transmitted to retinal prosthesis
Nodes: (main parts)	Small video camera, transmitter mounted on eyeglasses, video processing unit, implanted retinal prosthesis (EEG), brain
Edges: (how connected?)	Electric

Cochlear Implants

Inputs:	Sound waves
Outputs:	Brain recognize sound (electric signal)
Disturbance:	Profoundly deaf or severely hard of hearing.
Description of how device fixes disturbance:	Bypass damaged portions of ear and directly stimulates the auditory nerve
Nodes: (main parts)	Microphone, speech processor, transmitter + receiver, electrode array, auditory nerve, brain
Edges: (how connected?)	Sound waves and electric

Deep Brain Stimulators

Inputs:	Electrical stimulation
Outputs:	Controlled movements
Disturbance:	Parkinson’s disease

Description of how device fixes disturbance:	Reduce tremor, stiffness, walking problems, and uncontrollable movements.
Nodes: (main parts)	Electrodes (probes), brain, generator
Edges: (how connected?)	Electrical stimulation

Motor Implants: Watch video and try to fill in the information.

Inputs:	Electrical
Outputs:	Required/wanted movement
Disturbance:	Paralysis
Description of how device fixes disturbance:	Person thinks of outcome → brain → electrode → computer → outcome
Nodes: (main parts)	Brain, electrode, computer
Edges: (how connected?)	Electrical

Brain-Computer Interface Exit Ticket Rubric:

4	3	2	1	0
Student correctly labeled all parts of a BCI. Student added systems vocabulary to sketch without prompt and they are used correctly.	Student correctly labeled all parts of a BCI. Student added systems vocabulary to sketch when prompted by teacher and the vocab are used correctly.	Student correctly labeled all parts of a BCI. Student could not add systems vocabulary correctly.	Student could only correctly label some of the BCI. Student could not add systems vocabulary correctly.	Demonstrate no understanding.

Lesson Eight: Introduction to Neuroethics

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Claudia Lemus, TAF Academy, Federal Way, WA

LESSON OVERVIEW

Activity Time: Four 50 minute class periods.

Lesson Plan Summary: In this lesson, students will learn about various ethical issues that are connected to the design and implementation of neuroprosthetics, about appropriate and community-building strategies conducive to discussions about these ethical issues, and about the multiple perspectives through which these issues can be approached.

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:

Students will understand that…

- **Neuroethics:** The development and use of neuroprosthetics and neural implants brings up a variety of ethical issues including the ethics of the methodology of research studies, questions of accessibility to devices, legality of rights and patents, and questions of delineating the line between human/animal consciousness and volition and computer/machine influence.

Essential Questions:

- Why are neuroprosthetics an ethically challenging new field, and what are the arguments for/against their use and development?

Learning Objectives:

Students will know…

- Although neuroprosthetics are designed to restore or enhance function, their use also brings with them unintended consequences for the targeted populations that need to be kept in mind when designing them.
- Some of the ethical issues surrounding neuroprosthetics, such as:
  - The impact of using a neuroprosthetic on a user's sense of identity.
  - The potential loss of privacy of a user of a neuroprosthetic that is connected to a larger network.
  - The definition of what is "normal," and who gets to decide on this definition and whether or not a neuroprosthetic is needed by a person.
  - Questions surrounding who has access to data collected by a neuroprosthetic, and who is able to act on that data.
  - Questions about security in a system that can be hacked.

- The potential disconnect between what capabilities researchers are focusing on for neuroprosthetics versus the simple life functions that potential users may be more interested in (sensation vs. motor control, etc.).
- Questions about who has access to these neuroprosthetic devices, given their cost, and who determines accessibility.

Students will be able to…

- Formulate their own opinions, based on researched information, about various ethical issues and questions surrounding neuroprosthetics.
- Formulate discussion-provoking questions based on researched information relating to neuroprosthetics.
- Discuss multiple perspectives and opinions regarding the questions generated about ethical issues related to neuroprosthetics.

Vocabulary:

- Ethics
- Neuroethics
- Brain-Computer Interface (BCI)
- Neural implant
- Socratic seminar
- Cochlear implant

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

- **MS-LS1-8 Structure, Function, and Information Processing:** Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.
- **MS-ETS1-1 Engineering Design:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **HS-ETS1-1 Engineering Design:** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **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.

Common Preconceptions & Misconceptions:

- If a device can improve the quality of life for a person with a disability, that is irrefutably a good thing.

- A person with a disability would obviously want to restore "normal function" if they had the opportunity to do so.

MATERIALS

Note: For portions of this lesson, students will be working in groups of four students each.

Material	Quantity
Lego® model pieces (See *Teacher Preparation* section for details), for students to use to replicate teacher's model. One set includes 8-10 pieces of various colors. Each set should contain the same number/size of pieces.	1 set per student pair, plus 1 additional set for teacher's model
Ziploc bags, snack or sandwich size, for Lego® pieces	1 per student pair
Newsprint or poster paper, for graffiti activity	4 per class
Student Handout 8.1: Socratic Seminar Structure & Rubric	1 per student
Student Handout 8.2: The Thought Experiment, printed from http://www.technologyreview.com/featuredstory/528141/the-thought-experiment/	1 per group
Teacher Resource 8.1: Short Scenarios on Ethical Issues	1 copy (teacher resource)
Ethical Issues Surrounding Neuroprosthetics and BCIs PowerPoint presentation	1 PPT file
Safe Discussions in the Classroom PowerPoint presentation	1 PPT file
Classroom computer with speakers and internet connection, connected to projector	As needed

TEACHER PREPARATION

1. Make copies of ***Student Handouts 8.1***, one per student.

2. Print the scenarios from ***Teacher Resource 8.1*** in large text, cut individually, and post on newsprint hung on the walls around the classroom.

3. Arrange students into groups, four students per group.

4. On the day of the seminar, arrange the room so that there are only chairs for students to sit on, and that these are in two concentric circles, evenly spaced out.

Instructions for Preparing the Lego Model and Lego Sets:

5. Build a structure (can be abstract, does not have to make anything recognizable) using 8-10 Lego® pieces of different colors. The size of the Lego® pieces does not matter as long as they can all be connected together somehow.

6. Set up Ziploc® bags – one for each pair of students in your class – each with enough Lego® pieces so to replicate the structure you just built. Make sure the pieces in the bag are loose and are not connected.

Instructions for Preparing *The Thought Experiment Article* for the Jigsaw Activity

7. Print "The Thought Experiment" article from MIT Technology review from the following website: http://www.technologyreview.com/featuredstory/528141/the-thought-experiment/

8. This article will serve as ***Student Handout 8.2***. Cut the article into four separate sections using the following guide:
   - Section 1 = from beginning of article until before the heading "Reanimation" (pg. 3)
   - Section 2 = from "Reanimation" until before the heading "Interface Problems" (pg. 5)
   - Section 3 = from "Interface Problems" until before the heading "Numbers Game" (pg. 6)
   - Section 4 = from "Numbers Game" until the end (pg. 7)

9. Write "Section 1" at the top of section 1. Write "Section 2" at the top of section 2. Write "Section 3" at the top of section 3. Write "Section 4" at the top of section 4.

10. Make enough copies of each section so each group of students will have one (groups of four students) of each section.

PROCEDURE

DAY ONE

Engage (10 minutes)

1. Remind students of the fact sheet they previously read about cochlear implants (from *Lesson Seven*). What do they remember about cochlear implants?

2. Show students the following two videos, to give them a brief introduction of how these devices work and an example of how powerful they can be.

How a Cochlear Implant Works
Advanced Bionics, January 2013 (2:10 min)
https://www.youtube.com/watch?v=zeg4qTnYOpw

8 Month Old Deaf Baby's Reaction to Cochlear Implant Being Activated
June 2010 (0:50 min)
https://www.youtube.com/watch?v=HTzTt1VnHRM

3. Ask students to conduct a Think/Pair/Share with these questions:
    - What is your initial reaction to seeing how a cochlear implant can work?
    - What are some benefits of cochlear implants?
    - What may be some negative consequences of cochlear implants?

4. If time permits, have pairs share out their responses, especially if they were able to come up with some negative consequences.

Explore (20 minutes)

5. Tell students you will show them a short documentary that presents a different perspective on deafness and cochlear implants. Show the class the "United by Language" documentary.

United by Language Documentary
Health Equity Institute Documentaries (15:01 min) https://www.youtube.com/watch?v=OsaCDAPXBJ0

6. After watching the documentary, ask students answer the following questions individually:
    - How is the portrayal of Deaf people in the documentary different from how you might normally think of them?
    - What is Deaf culture?
    - How might cochlear implants impact Deaf culture?
    - How might cochlear implants impact a Deaf individual's sense of identity?
    - Why might some people in the Deaf community oppose the practice of using cochlear implants to treat babies that are born deaf?
    - If you had a child (in the future!) who was born deaf, would you consider a cochlear implant for him/her? Why/why not?

Explain (10 minutes)

7. Let the class know that they will be able to share and discuss their responses to the questions the following class period.

8. Go over the ***Safe Discussions in the Classroom*** PowerPoint Presentation. At the end of the presentation, have students write down their individual brainstormed ideas for whole-class guidelines.

Elaborate/Evaluate (10 minutes)

9. Have students share their individual guidelines with their groups, and tell the groups to agree on three group guidelines they will adhere to for tomorrow's group seminar.

10. Have groups turn in their group guidelines as their Exit Ticket.

DAY TWO

Engage (15 minutes)

11. Have students use the questions based on the documentary from the previous day to share their responses and have a group seminar.
    - Remind groups to keep in mind the group guidelines they agreed on the day before.
    - Encourage students to ask questions in addition to sharing their responses.

12. After ten or so minutes of discussion, have students do a quick individual reflection on how the seminar went and ways it could have been better.

Explore (15 minutes)

Note: In preparation for this class day, post the short scenarios from ***Teacher Resource 8.1*** (from the article, *Ethical Issues in Brain-Computer Interface Research, Development, and Dissemination)* in large font, each on newsprint posted around the room.

13. Let students know they will be participating in a graffiti brainstorming activity that will help them prepare for the upcoming Socratic Seminar. They will begin by reading about ethical issues surrounding BCIs, as opposed to cochlear implants.

14. Have a student volunteer read each scenario out loud.

15. Instruct students to travel in groups to each scenario poster, with one or two groups (depending on class size) visiting one scenario at a time. While at the newsprint of the scenario, group members should re-read the scenario and then each student should write down on the newsprint the following:
    - Their reaction to the scenario
    - One ethical issue or question that this scenario raises

16. Give each group about three minutes at each scenario, and have them move onto the next scenario until they have read and responded to all four scenarios.

Explain (10 minutes)

17. Show students the ***Ethical Issues Surrounding Neuroprosthetics and BCIs*** PowerPoint presentation.

18. The first slide will prompt the teacher to ask students to share some of the issues they came up with during the previous graffiti activity.

19. Teacher can choose to facilitate discussion on some of the questions brought up if time is available.

Elaborate (10 minutes)

20. Remind students that they will participate in a whole-class seminar at the end of this lesson.

21. Pass out copies of ***Student Handout 8.3: Socratic Seminar Structure & Rubric***. Review structure of the Socratic Seminar and the rubric.
    - Structure:
        - Class is set up with two concentric circles of chairs. Students will be assigned to either the inner or outer circle.
        - Inner circle discusses.
        - Outer circle listens and takes notes.
        - If a student in the outer circle wants to switch into the inner circle to speak, he/she will need to raise his/her hand.
        - If a student in the inner circle wants to switch out, he/she will need to find a student in the outer circle with their hand raised. Once this occurs, they make eye contact and switch without interrupting the discussion.
    - Rubric:
        - See document at the end of the lesson.

22. Based on their experience with the group seminar, have groups share out the group guideline they feel is ***most*** critical in order to ensure a safe environment on the day of the seminar. Ideally, there should be three to four whole class guidelines that everyone can agree on (some may overlap).

Evaluate (5 minutes)

23. Have each student to write down the class guidelines and sign their name at the bottom, agreeing to follow them on the day of the seminar. These “contracts” can be turned in as Exit Tickets.

Homework (*optional*)

24. Give students a choice from the following articles to read and familiarize themselves more with the topic. These articles can be accessed and printed from the internet using the provided URLs.

    Ethical and Social Challenges of Brain Computer Interfaces
    Wolpe, P. (2007). Ethical and social challenges of brain-computer interfaces. *American Medical Association Journal of Ethics*, 9(2), 128-131. Retrieved August 11, 2014 from http://virtualmentor.ama-assn.org/2007/02/msoc1-0702.html

    Ethical Issues in Brain-Computer Interface Research, Development, and Dissemination (the rest of the article, besides the scenarios)
    Vlek, R., Steines, D., Szibbo, D., Kubler, A., Schneider, M., Haselager, P., & Nijboer, F. (2012). Ethical issues in brain-computer interface research, development, and dissemination. *Journal of Neurologic Physical Therapy*, 36(2), 94-99. Retrieved August 11, 2014,
    from http://eprints.eemcs.utwente.nl/21870/01/Vlek_Nijboer_2012.pdf

    A Note on Ethical Aspects of BCI
    Haselager, P., Vlek, R., Hill, J., & Nijboer, F. (2009). A note on ethical aspects of BCI. *Neural Networks*, 22, 1352-1357. Retrieved August 11, 2014
    from http://www.sciencedirect.com/science/article/pii/S0893608009001531

    Today's Athletic Prosthetics are Causing Controversy
    Smith, A. (2007, August 7). *Today's Athletic Prosthetics Are Causing Controversy*. Retrieved August 11, 2014,
    from http://blog.syracuse.com/healthfitness/2007/08/todays_athletic_prosthetics_ar.html

DAY THREE
Engage (10 minutes)

25. Students will work in pairs to simulate a brain-computer interface (BCI). Each pair of students should choose a person to be "A" and a person to be "B."
    - Person A will play the role of someone missing a limb.
        - Cannot use their arm (they need to keep it behind their back).
    - Person B will play the role of a neuroprosthetic limb.
        - Cannot "see" the task, but can get directions from brain (they will have their eyes closed, listening to person A's directions).

26. Once everyone is ready in their roles, give each Person A a Ziploc® bag with the appropriate Lego® pieces to build one that you have modeled. Show the model to all students playing a Person A.
    - Together, each pair of Person A and Person B will tackle the task, trying to replicate the model shown, following the rules of their roles.

27. After five minutes, have students share out responses to the activity, and how this might help illustrate problems/challenges with BCIs.

Explore (15 minutes)

28. Explain that students will now participate in a jigsaw activity that will allow them to become experts in one section of a comprehensive article about the ethics of neuroprosthetics. Then they will be re-arranged in groups where they will share their expertise with students who are experts from the other sections of the article.

29. Have students count off from 1 – 4. Have all 1s sit together, all 2s sit together, all 3s sit together, and all 4s sit together.

30. Give all students who are "1" a copy of the Section 1 of ***Student Handout 8.2: The Thought Experiment.*** Give all students who are "2" a copy of the Section 2 of ***Student Handout 8.4.*** Give all students who are "3" a copy of the Section 3 and give all students who are "4" a copy of the Section 4.

31. Allow five minutes for students to read their assigned section of the article.

32. Allow one minute for students to ask the other students in their same-number group any clarifying questions they may have before they are re-shuffled.

33. Re-arrange groups so that students are in groups where there is one member from each number represented (groups of 4). Instruct group members to share the main point of their section. Then, as a group, they should summarize the four main points and ethical arguments they feel were brought up in the article.

Explain (10 minutes)

34. Based on their jigsaw activity and/or their readings from homework, have students individually write out three open ended questions they could use in the Socratic Seminar. Have students also generate their responses to these three questions, in a "CEE" format. This format requires students to state a CLAIM (C), provide EVIDENCE for that claim (E), and then ELABORATE with their opinion (E). Tell students to cite the texts they have read so far when they are referring to their evidence.

Elaborate (10 minutes)

35. Have students trade questions (without their responses) with a partner. Then, challenge students to generate responses to their partner's questions, in a CEE format. Students can finish this section of the lesson for homework, if necessary.

Evaluate (5 minutes)

36. Have students write out two or three goals and one or two strategies they will use the following day in order to be successful in the Socratic Seminar. Remind students to review the rubric to understand how they will be evaluated.

DAY FOUR
Socratic Seminar

37. Allow the full period for the Socratic Seminar. Make sure to set up the room as described in the *Teacher Preparation* section.

38. As students enter the room, assign each one of them to either the inner circle or the outer circle. Have students sit in their respective circle with any notes and/or paper they might want to use for the seminar.

39. Begin by reminding the students of the class guidelines they all agreed to follow and the importance of everyone feeling like the classroom is a safe place for them to voice their opinions. Remind students that this seminar is between them, and that you will act as the facilitator. Tell them to try to make eye contact with each other instead of with you, since they will be responding to their peers and you will be mainly listening and taking notes.

40. Remind students that part of their participation is asking questions, as well as responding to questions asked by their peers, and that they have questions they have prepared from the day before that they could use for this purpose.

41. Remind students of the structure of the seminar, in that students in the inner circle will be actively discussing, while students in the outer circle will be listening and taking notes. Remind them that if they are in the outer circle and have something to say, they should raise their hand and make eye contact with someone from the inner circle that wants to switch seats with them. Remind them that when they're in the inner circle part of the "peer relation" criteria is to help facilitate discussion, and one way to do this is to periodically look around to those in the outer circle and switch with anyone that would like to switch in, if possible.

42. Let the discussion begin by asking a volunteer to start the conversation by sharing one of his/her questions. If no student wants to volunteer you can begin by asking the lesson guiding question and then letting students take it from there.

43. During the seminar, allow students to speak freely, and keep notes on who participates, who uses evidence in support of their claim, who cites their evidence, and who helps to

facilitate discussion. It will be helpful to develop a short-hand key that you can follow with a roster of all your students in order to make this process easier.

44. If the discussion slows down at any point, ask students who have not shared yet to share their questions/responses in order to get the conversation going. Or you can throw out your own questions as well.

45. Give students a five minute warning before you wrap up the Socratic Seminar at the end of the period. Remind students that this is their last chance to participate if they have not already done so.

STUDENT ASSESSMENT

Assessment Opportunities

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

- Shared out responses (individual, paired, and in groups) from the various activities and over the course of the four days.
- Responses to their own questions and partner's questions in CEE format.
- Individual student participation in Socratic Seminar, given the rubric[

Student Metacognition

- Student metacognition will take place during every discussion opportunity over the course of the three days – this includes the group seminars, the graffiti activity, the jigsaw group activity, and the final Socratic seminar. In each of these events, students will get the chance to reflect on material viewed or read, hear other peer's perspectives, reflect on whether or not their knowledge or attitudes have changed, and share out any new learning based on this cycle.

Scoring Guide

- See ***Student Handout 8.3: Socratic Seminar Structure & Rubric***. This can be used by the teacher to score students based on notes taken by the teacher during the Socratic Seminar.

EXTENSION ACTIVITIES

Extension Activities:

- Students could write a brief essay that includes their responses to various questions from the seminar.
- Students could turn in a CEE on multiple articles from the list of choices (see *Day Two Homework).*

Adaptations:

- Teacher can be more deliberate in forming groups (for group seminar and for jigsaw activity) in order to allow stronger students to be in a group and help those that might have more challenges.
- For students who struggle participating verbally, teacher could have them turn in their notes/questions/responses in writing at the end of the seminar.
- For struggling readers or younger students, if time permits, teacher can include the homework article readings as part of a class activity.

TEACHER BACKGROUND & RESOURCES

Background Information

The field of neural engineering, and especially the design and development of neuroprosthetics, brings up many ethical issues and questions that are important to be aware of and discuss. Although the intent of neuroprosthetics and neural implants is to better the lives of potential users by either helping them regain or enhance an aspect of their sensory or motor performance, there are some unintended consequences that might impact users negatively. These include how the devices might influence their perception of their identity (what does it mean to be able-bodied or disabled?), might render them vulnerable to breeches of security and privacy when it comes to devices that are connected to the internet, might be seen as a threat to their culture, and might not readily have just policies in place to make sure that there is equity in their accessibility.

As these devices become more sophisticated and mainstream, it is critical that students learn about not just how these devices work and their potential benefits, but also about all of the ethical questions that come with their development and use, in order to be well-informed citizens, consumers, and policy makers in the future.

Resources

Advanced Bionics. (2013, January 7). *How a Cochlear Implant Works by Advanced Bionics*. Retrieved from https://www.youtube.com/watch?v=zeg4qTnYOpw

Haselager, P., Vlek, R., Hill, J., & Nijboer, F. (2009). A note on ethical aspects of BCI. *Neural Networks*, 22, 1352-1357. Retrieved August 11, 2014 from http://www.sciencedirect.com/science/article/pii/S0893608009001531

Health Equity Institute Documentaries. (2013, August 7). *United by Language*. Retrieved from https://www.youtube.com/watch?v=OsaCDAPXBJ0

Regalado, A. (2014, June 7). *The Thought Experiment*. Retrieved August 11, 2014 from http://www.technologyreview.com/featuredstory/528141/the-thought-experiment/

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Vlek, R., Steines, D., Szibbo, D., Kubler, A., Schneider, M., Haselager, P., & Nijboer, F. (2012). Ethical issues in brain-computer interface research, development, and dissemination. *Journal of Neurologic Physical Therapy*, 36(2), 94-99. Retrieved August 11, 2014, from http://eprints.eemcs.utwente.nl/21870/01/Vlek_Nijboer_2012.pdf

Wolpe, P. (2007). Ethical and social challenges of brain-computer interfaces. *American Medical Association Journal of Ethics*, 9(2), 128-131. Retrieved August 11, 2014 from http://virtualmentor.ama-assn.org/2007/02/msoc1-0702.html

Zoot Cadillac. (2010, June 5). *8 Month Old Deaf Baby's Reaction to Cochlear Implant Being Activated*. Retrieved from https://www.youtube.com/watch?v=HTzTt1VnHRM

Citations

Vlek, R., Steines, D., Szibbo, D., Kubler, A., Schneider, M., Haselager, P., & Nijboer, F. (2012). Ethical issues in brain-computer interface research, development, and dissemination. *Journal of Neurologic Physical Therapy*, 36(2), 94-99. Retrieved August 11, 2014, from http://eprints.eemcs.utwente.nl/21870/01/Vlek_Nijboer_2012.pdf

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.

Student Handout 8.1: Socratic Seminar Structure & Rubric
Name:________________________________ Date:__________________ Period:__________

Socratic Seminar Structure

- Class is set up with two concentric circles of chairs. Students will be assigned to either the inner or outer circle.
- Inner circle discusses.
- Outer circle listens and takes notes.
- If a student in the outer circle wants to switch into the inner circle to speak, he/she will need to raise his/her hand.
- If a student in the inner circle wants to switch out, he/she will need to find a student in the outer circle with their hand raised. Once this occurs, they make eye contact and switch without interrupting the discussion.

Socratic Seminar Rubric

Criteria	Excellent	Good	Average	Poor
Participation	Presents 2-3 original claims, poses at least one original question, and responds at least once to a peer's question or claim. 10	Presents at least one original claim and responds at least once to a peer's question or claim. 9, 8	Presents claims, but they may not be fully original. 7, 6	Does participate in the seminar. 5 and below
Depth of Arguments	Most arguments are fact-based and supported. Very few responses are based on opinion. 10	Some arguments are fact-based and supported. Some responses are based on opinion. 9, 8	Most responses are supported using only opinions. 7, 6	Most responses are not supported at all. 5 and below
Peer Relations	Respectfully listens to peer's arguments and responses, and presents own arguments in a polite manner. Listens quietly when in the outer circle, and quietly seeks opportunity to switch back and forth. Helps elicit participation from peers by posing own questions 10	Respectfully listens to peers' arguments and responses, and presents own arguments in a polite manner. Listens quietly when in the outer circle, and quietly seeks opportunity to switch to the center. 9, 8	Usually listens to peers' arguments, but may cut people off at some points. Presents own arguments in a polite manner. Listens quietly when in the outer circle, and seeks opportunity to switch to the center. 7, 6	Is disrespectful toward someone in the group. **And/Or** Presents own arguments in a rude or aggressive manner. **And/Or** Has side conversations in the outer circle. **And/Or** Does not seek to switch to the center. 5 and below

Teacher Resource 8.1: Short Scenarios on Ethical Issues

Case Scenarios Source: Vlek, R., Steines, D., Szibbo, D., Kubler, A., Schneider, M., Haselager, P., & Nijboer, F. (2012). Ethical issues in brain-computer interface research, development, and dissemination. *Journal of Neurologic Physical Therapy*, 36(2), 94-99. Retrieved August 11, 2014, from http://eprints.eemcs.utwente.nl/21870/01/Vlek_Nijboer_2012.pdf

"Jane"

Jane is a 46-year-old housewife who has had the neurodegenerative disease ALS for 10 years. She lives at home and has a full-time staff of caregivers. Since the onset of locked-in syndrome 1 year ago, she has not been able to communicate in any way.

She has a legal representative who enrolled her in tests with noninvasive brain-computer interfaces. The researchers using noninvasive BCI say they can see that Jane is making an effort but that they are unable to reliably decode Jane's brain activity. Jane's husband, who is eager to communicate with his wife again, has read about invasive BCIs in the media and would like to try this method. He asks the BCI team whether his wife could be considered for brain surgery.

"Nigel"

Nigel is a 51-year-old research scientist who has had ALS for 11 years. He has used a P300 BCI home system for 4 years to communicate with his family members and for professional purposes with his laboratory colleagues. In recent months, he has dramatically reduced his use of the system and appears to be losing the capability to control it. The BCI team has noticed the decline and is trying hard to determine whether the algorithms need to be adapted.

“Ben”

Nine months ago Ben had a stroke, resulting in paralysis of his right arm. He has regained some function in his arm after months of extensive motor rehabilitation, and Ben’s doctor asked him to enroll in a study that investigates whether BCI neurofeedback could accelerate Ben’s recovery. Ben has difficulty understanding what the doctor is asking of him (he has minor cognitive impairment), but he trusts his doctor.

“Thomas”

Thomas is a 30-year-old air traffic controller who was told by his boss that starting this month he would have to undergo attention training by wearing a new neurotechnological tool that provides him with neurofeedback. Thomas does not know exactly what the device does, but he feels that his attention has somewhat improved since he started training. The explanation that Thomas was given about the new tool was that it somehow reads his brain, so he is sometimes afraid the tool can also read his thoughts. Also, last Monday Thomas got a lecture from his boss, who said he could see that Thomas most likely had been drinking alcohol on Sunday night.

Lesson Nine: Getting to Know the Arduino Uno

Center for Sensorimotor Neural Engineering
Lesson Plan Authors: Angelica Sauceda, TAF Academy, Federal Way, WA
and Steve Pratt, Cleveland High School, Seattle, WA

LESSON OVERVIEW

Activity Time: Three 50 minute class periods.

Lesson Plan Summary: In this lesson, students will be introduced to circuits using a breadboard, the Arduino Uno, and the Arduino Uno programming language. They will use this knowledge to create and modify simple sketches. In addition, they will design and evaluate a systems model for a neuroprosthetic that includes descriptions of the sensors, the input and output mechanism, and possible feedback loops.

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:

Students will understand that…

- **Systems:** A system is a network of sub-systems that contains inputs, outputs, and feedback mechanisms in order to control/regulate a specific outcome. Disturbances affect the outcome of the system.
- **Circuit:** A circuit consists of a power source, wires, and a resistor/s.

Essential Questions:

- How can you program a robot to do something that you want it to do based on your instructions?

Learning Objectives:

Students will know…

- That a system consists of inputs, outputs, and feedback.
- The function of the sensory and motor neurons within the nervous system.
- The basic sensorimotor feedback loop that is required for neural engineering.
- The Arduino Uno programming language consists of declaration of variables, void setup, and void loop.

Students will be able to…

- Design and evaluate a systems model for a neural prosthetic that includes a description of the role of the sensors, output mechanism, and possible feedback loops.
- Write and make sense of programming sketches.
- Describe the input, output, and explain if feedback is established

Vocabulary:

- Neuroprosthetic
- Input
- Output
- System
- Sketch
- Arduino Uno
- Circuit
- Breadboard
- LED
- Motor
- Feedback

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

- **MS-ETS1-1 Engineering Design:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **HS-PS3-3 Energy:** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- **HS-ETS1-1 Engineering Design:** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **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.

Common Preconceptions & Misconceptions:

- Robotic systems and the human brain operate using two completely different systems.
- All neural prosthetics are “good” so there’s nothing really ethically debatable about them.
- Robots can “think for themselves” with an artificial intelligence (i.e., they don’t need human input/programming).
- Every problem has one “perfect” solution.

- Matter and energy are two completely different things and do not interact with one another.

MATERIALS

Note: For portions of this lesson, students will be working in groups of four students each.

Material	Quantity
Wire, C battery, and a mini light bulb	1 per group
Universal solderless breadboard, available from RadioShack, http://www.radioshack.com/product/index.jsp?productId=2882885	1 per group
Arduino Uno R3, available from http://store.ArduinoUno.cc/product/A000066	1 per group
9 V battery	1 per group
AmazonBasics Hi-Speed USB 2.0 A-Male to B-Male Cable, 6 feet, available from Amazon http://www.amazon.com/AmazonBasics-Hi-Speed--Male-B-Male-Cable/dp/B001TH7GUA/ref=sr_1_1?s=electronics&ie=UTF8&qid=1407518205&sr=1-1&keywords=usb+cable	1 per group
LED, 3 mm, 3 V, 20 mA	2 per group
Wire for solderless breadboard, 22 gauge, ~10 cm long, minimum of three different colors	4 per group
Wire cutters/strippers. Optional, only needed if students need to cut and strip their wires.	As needed
Resistor, anything between 1 k – 10 k Ohms	1 per group
Mini push button switch, available from Spark Fun https://www.sparkfun.com/products/97	1 per group
5 V Stepper Motor, 5VDC 2-Step 1/16 Gearing, available from AdaFruit http://www.adafruit.com/products/858	1 per group
ULN2803 8 Channel Darlington driver (solenoid/unipolar stepper), available from AdaFruit http://www.adafruit.com/products/970	1 per group

Force sensor, available from Pololu http://www.pololu.com/product/1645	1 per group
Student Handout 9.1: Day One Exit Ticket	1 per student
Student Handout 9.2: Day Two Exit Ticket	1 per student
Teacher Resource 9.1: Arduino Sketches	1 copy (teacher resource)
Circuits and Arduino Uno PowerPoint presentation	1 PPT file
Laptop or computer for programming the Arduino Uno software. Arduino Uno software must be installed on each computer; available from: http://www.ArduinoUno.cc/en/Main/Software	1 per student group (ideally 1 per student)
Classroom computer with speakers and internet connection, connected to projector	As needed

TEACHER PREPARATION

1. Make copies of ***Student Handouts 9.1*** and ***9.2***, one per student.
2. Prepare a bin with all of the materials needed for each part of this lesson (this will help manage each part of the lesson smoothly).
3. Familiarize yourself with all the materials listed above.
4. Download the Arduino Uno software on all computers that will be used by students.
5. Preview the videos included in the PowerPoint presentation.
6. Familiarize yourself with the pHet simulation (link in the PowerPoint presentation).
7. **To be best prepared for work with the Arduino Uno, it is recommended that the teacher either take time to work through the "Getting Started with Arduino Uno" pdf guide OR watch a few of Jeremy Blum's Arduino Uno tutorials on YouTube (see the *Teacher Background & Resources* section for the links).** Both are helpful for learning the basics of connecting the hardware as well as programming within the Arduino Uno environment.

PROCEDURE

Note: The slide numbers mentioned in the *Procedure* are from the ***Circuits and Arduino Uno*** PowerPoint Presentation.

DAY ONE

Engage/Explore

1. Show challenge *Slide #2* as a warm-up that asks students to illuminate the light bulb using a piece of wire, 1.5 V battery, and a mini-light bulb incandescent or LED—just be careful to watch the voltage requirements for certain light bulbs. Hand out the required materials and allow time for students to work on the challenge in small groups. If students complete the challenge, ask them to make observations and explain why their design is a closed circuit.

Explain

2. Teach the components of a closed circuit using *Slide #3* and referencing the designs students did at the beginning of class.

3. Use *Slides #4* and *#5* to check for understanding.

4. Use *Slides #6-8* to teach students about current. *Slide #6* will give you the definition and *Slides #7* and *#8* puts the definition into perspective.

5. Show *Slide #9* and *#10*. Ask the class the following questions:

   - What would happen if we removed the light bulb from your circuit and connected just the wires to both terminals of the battery?
   - What would happen if a wire was connected between the battery and the bulb?

6. Use the pHet simulation to show students what happens during a short circuit by clicking on the Circuit Construction Link on the slides. (Available directly from http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc).

7. Follow the hyperlink on *Slide #11* to show the "Introduction to Breadboard" video. Before showing the video, preview the video discussion questions on *Slide #12*. The purpose of this is to show primarily the setup of the breadboard so that students can create closed circuits on a breadboard.

Introduction to Breadboard (Protoboards)
Electroninstructor, September 2007, (8:08 minutes)
https://www.youtube.com/watch?v=oiqNaSPTI7w

8. Have students discuss the answers to the Discussion Questions on *Slide #12* in their groups, and then share out the results.

9. Because the purpose of understanding **I vs V vs R** is to understand how to use a circuit board correctly, review the two diagrams on *Slides #13* and *#14* that relate these three concepts to water. Then show how you would use them in a circuit drawing.

10. ***OPTIONAL SLIDES (Slides #17-20):*** These slides offer more detailed definitions of current, resistance, and voltage.

Elaborate

11. Introduce the Breadboard Challenge on Slide #15. Students are to create three functioning closed circuits with the listed materials. The challenge asks them both take a photo for each of the three closed circuits they will create, as well as to draw a circuit diagram for each one. **Tell students that they should *not* hook up an LED to a power source without a resistor because a LED is not a strong enough resistor.**

Evaluate

12. Check off student work as they finish. Then pass out copies of ***Student Handout 9.2: Day One Exit Ticket*** to assess student knowledge of circuits.

DAY TWO

Note: Students will need their laptops with the Arduino Uno software installed for the Day Two activities.

Explain

13. Use *Slide #21* to introduce Day Two and the Arduino Uno. Explain that now that students understand the basics of circuits, it is now time to learn how to program the Arduino Uno. The purpose of today's lesson is to learn the basics of programming, practice some code manipulation, and show how systems can be "programmed" with different variables, inputs, and outputs.

14. Distribute the Arduino Uno kits (Arduino Uno, USB cable, a LED, a resistor, a breadboard, a button, and 3 wires) to the student groups.

15. Show students *Slide #22* which describes each part of the Arduino Uno. Ask students to place a piece of paper underneath their Arduino Uno. Then, they can draw arrows and write labels on the paper for the major components of the Arduino Uno.

16. Have students open up the Arduino Uno program. They should open up the same sketch called "Blink" as shown on *Slide #23* (File → Examples → Basics → Blink). **Note:** The other two Arduino Uno sketches can be copied and pasted from ***Teacher Handout 9.1***.

17. Use *Slide #23* to show students the three main sections of a sketch: declaration, setup, and loop. Remind the students that computers are essentially "stupid" and need to be told explicitly what things are and what they need to do with them. Be sure to point out the different types of declarations (int vs float vs char), the relevant methods (pinMode, etc.) and the point of a loop function. Also show students how a program is read from top-down, with semi-colons serving as "periods" that tell the computer to go to the next line to receive the next direction.

18. Then, use the same *Slide #23* to explain the step-by-step mechanics of the code using the //comments on the right hand side. Students can write their own comments to describe what each line means. Be sure to tell the students that they will need to do this on future sketches, even though you are modeling what to do on the first one.

19. Have students set up the LED and USB cable connected to the Arduino Uno according to the diagram on *Slide #24*. (Basically, put the short lead of the LED into the GND, the long into pin 13). This diagram is based off the "Getting Started with Arduino Uno" pdf (See *Resources* section below).

Explore/Elaborate

20. Get students to start on Arduino Challenge #1 using *Slide #25*. Make sure that they identify the system inputs, outputs, and any subsystems, and also state whether there is feedback.

21. When students feel like they are ready to test out their sketch, have them set up a breadboard circuit, upload the sketch to the Arduino Uno, and test it out.

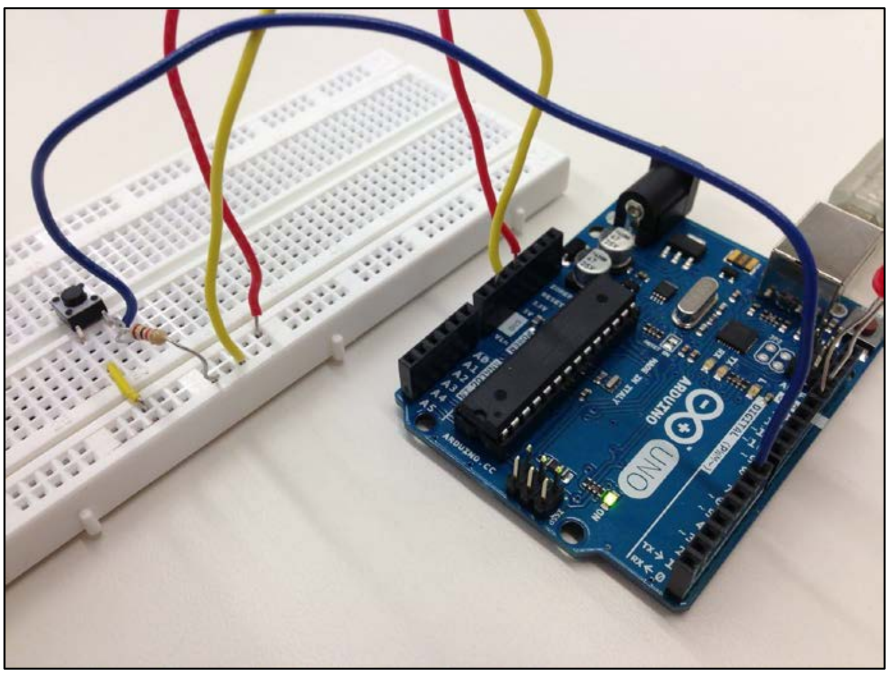
22. Next, students are challenged to change the code in two completely different ways to affect the outcome of the blinking LED. (**Hints:** Time delay duration, on vs off, adding

extra lines to make a pattern, etc.) Ask students to document the different ways that they changed the output.

23. When students have completed Arduino Uno Challenge #1, ask them to start Arduino Challenge Uno #2 on *Slide #26* by asking students to copy and paste the "button" sketch into their module (the sketch is included in the Notes section of *Slide #26* and on ***Teacher Handout 9.1***).

24. Explain the serial.println function, and how a serial monitor works by relaying information that is outputted to a serial screen on their computer. It can output text, numbers, or any kind of information that is inputted into the Arduino Uno.

25. Have students add //comments to each line of code. Then, have students complete Arduino Uno Challenge #2 by setting up a breadboard circuit, uploading the sketch to the Arduino, and testing it out. A photo of the correct connections is included below.



Correct set-up for Arduino Uno Challenge #2

26. Students will need to paste the "fading light" sketch into their module to see the sketch function. Introduce the "for" function, which will cause a light bulb to increase in brightness in small increments and then decrease similarly, like the light on a sleeping Apple computer.

27. Students will complete Arduino Uno Challenge #3 on *Slide #27*. **Note:** The setup is the *same* as the above photo...the only thing that changes is that one of the LED pins should be in the 9 pin (because 13 is not capable of pulse width modulation signals). See if the students can notice that the LED pin has changed based on the code...don't tell them right away...see if they can see the change!

Evaluate

28. Have students complete ***Student Handout 9.2: Day Two Exit Ticket*** for today's lesson.

DAY THREE

Note: This lesson is highly recommended. The Arduino Uno is used to create systems with various inputs and outputs. These inputs / outputs are various types of sensors, which can be purchased online rather cheaply. Use the hyperlinks below to purchase.

Force sensors, light sensor, temperature sensor, small buzzer, speaker, etc.

Inputs and Outputs Explored in this Activity

Inputs	Outputs
force sensor	light sensor
temperature sensor	mini speaker
light sensor	
color sensor	Stepper motor

Elaborate/Evaluate

29. Give each group one of the input sensors and one of output sensors (choosing from the table above)

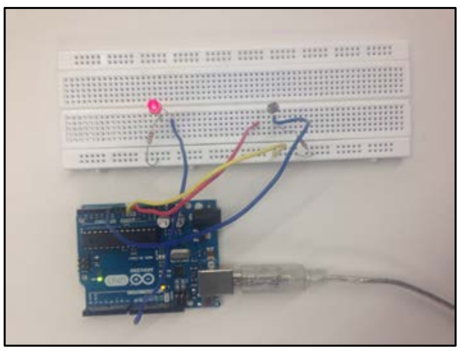
30. Ask the students to copy and paste the sketch that correlates with their input sensor to the Arduino program screen. (Code is provided on ***Teacher Handout 9.1***).

31. The students may need to modify the sketches based on their output. Students will also need to setup the breadboard circuit. Pictures are included below for each one if you want to give the actual instructions to students (as opposed to letting them create the circuit themselves).

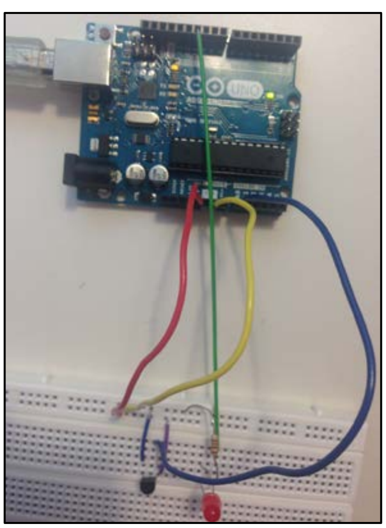
32. It is highly recommend to have all students work with the force sensor input and speaker output (they will find it really fun). See if students can figure out how to adjust the code to affect the input and output. Students can adjust the sensitivity (or, in engineering speak, “gain”) of the sensors/outputs by adjusting the “if” statements in the code.

33. Lastly, once students have configured two or three different “systems”, have them draw out on a piece of paper the system they created using the systems language they’ve learned from this unit. Words to include are: *node, edge, input, output, sub-system, feedback.*

Light Input & LED Output Circuit:
Code is provided on ***Teacher Handout 9.1***.



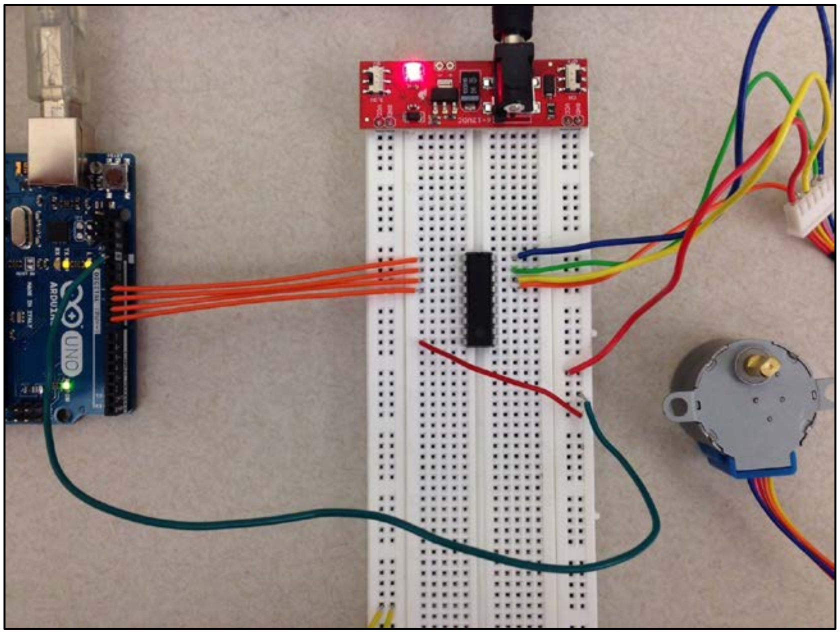
Temperature Input & LED Output Circuit:
(**Safety Warning:** Make sure the sensor is facing the right way in the circuit...otherwise, a build of charge will result in a ***very hot*** sensor.)



Force Input & Step Motor Output:

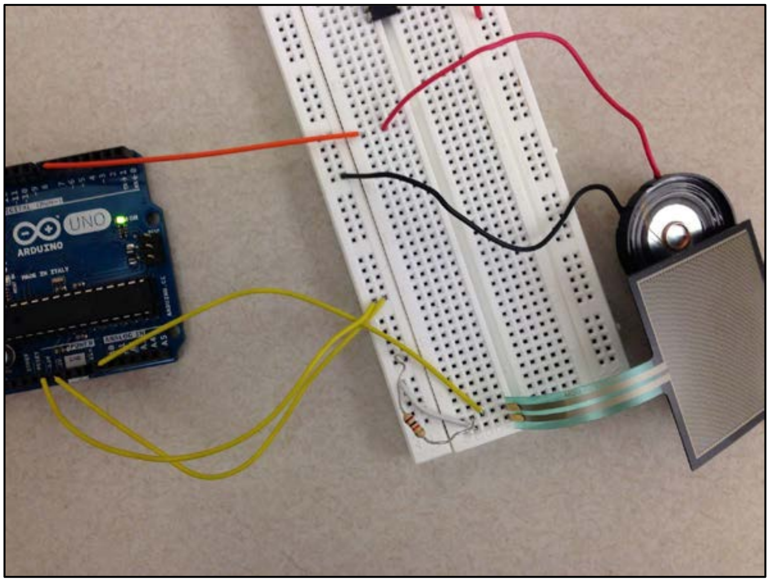
To setup the motor: This is a more complicated setup and requires an extra 5V source (like this one at https://www.sparkfun.com/products/114, or just a few batteries hooked up together with some wires going into the breadboard will work) as well as a 8-channel DIP (like the ULN2803 Darlington from https://www.sparkfun.com/products/312). Basically, the program is ***complicated***, but the program will turn the motor clockwise and then counter-clockwise ***if*** a certain input is detected. So, it becomes a great if/else lesson. Follow the schematic from this Arduino forum (at http://forum.arduino.cc/index.php?topic=1011) for connecting everything, which is also included in the photo below. Be sure the Arduino, transistor array, and motor share a common ground, as seen by the red wire in this photo coming out of the 9th pin to the ground side of the breadboard.

Motor setup:

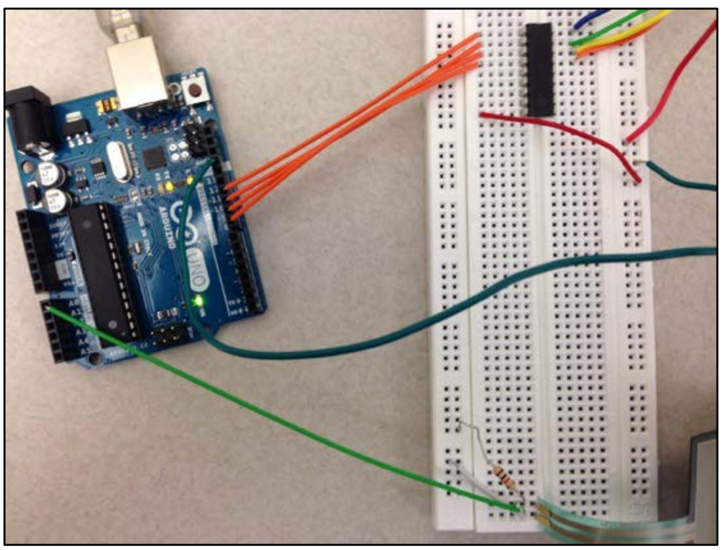


To setup the force sensor: Feel free to use this site (http://bildr.org/2012/11/force-sensitive-resistor-arduino/) to find a basic schematic of how the force sensor connects to the Arduino. It follows a basic power in → analog out and resistor to ground setup that most sensors use. The resistance can vary. In the photo, a speaker is also hooked up (no resistance is needed since it provides enough resistance) to a digital pin #7 for its output signal and then routed back to ground. This way, a force sensor can have a MUSIC OUTPUT or a MOTOR OUPUT or a LIGHT OUTPUT.

Force Sensor Setup:



Force Sensor & Motor Setup:



34. Ask the student to add //comments to each line of code indicating what each step means.

35. Next ask the students to upload the sketch to the Arduino and test it out.

36. Once a group has their system up and running, ask them to take a photo of the setup and label the pictures inputs and outputs.

37. Lastly ask the students to compare their system to the system of a BCI. How are they similar and how are they different?

STUDENT ASSESSMENT

Assessment Opportunities

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

- The students will be formatively assessed after Day One and Day Two of the lesson with the use of Exit Tickets (***Student Handouts 9.1*** and ***9.2***).
- The students will be assessed further by challenging them to apply the knowledge they gained from Day One and Day Two of this lesson to inform their program and setup for Day Three of the lesson (please see the *Procedure* section).

Student Metacognition

Students will be able to reflect on the progress they made in each lesson by reviewing the feedback they receive on their Exit Tickets (***Student Handouts 9.1*** and ***9.2***).

Scoring Guide

- Refer to ***Teacher Handout 9.1*** for the sketches. Use the sketches to determine whether students were able to meet the challenges they were given throughout the lessons.
- In addition, use this section to ensure that student comments on the sketches met standards.

EXTENSION ACTIVITIES

Extension Activities:

The knowledge gained in this three part lesson will be put to the test with the neuroprosthetic project at the end of this unit. See *Project Rubric*.

For students who need more challenge during the BUTTON sketch or want to go farther, direct them towards the tutorial listed below, specifically (5:49-16:00), where they can save the inputs/outputs associated with the button.

> **Tutorial 2 for Arduino: Buttons, PWM, and Functions**
> Jeremy Blum, January 2011 (5:49 – 16:00 minutes)
> https://www.youtube.com/watch?v=_LCCGFSMOr4&list=PLA567CE235D39FA84

Adaptations:

- If a student is not comfortable with the programming language, you can provide all the sketches. In addition they can watch Jeremy Blum's Tutorials, provided in the *Background Information* section, for further assistance.

- If a student needs more of a challenge then you can ask them to come up with their own sketches.

TEACHER BACKGROUND & RESOURCES

Background Information

It will be helpful to familiarize yourself with the Arduino Uno (http://www.arduino.cc/), the Arduino Uno software, and the Arduino Uno programming language by doing one of two things:

1. Watch Jeremy Blum's Arduino Uno Tutorials 1 - 4
   https://www.youtube.com/results?search_query=jeremy+blum+arduino+tutorial

2. Work through the "Getting Started with Arduino, 2nd edition" (Download the free e-book using the following URL http://www.it-ebooks.info/book/1338/) to understand the hardware and programming language.

Resources

Getting Started with Arduino Uno, 2nd edition
Massimo Banzi, free downloadable e-book
http://it-ebooks.info/book/1338/

Getting Started with Arduino
Step-by-step guide from the Arduino company
http://arduino.cc/en/Guide/HomePage

Arduino Uno Tutorials
Jeremy Blum offers a series of five tutorials on his YouTube channel
https://www.youtube.com/channel/UC4KXPjmKwPutGjwFZsEXB5g

Citations

PhET Interactive Simulations. PhET Circuit Construction Kit (DC Only). Retrieved from http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc

Banzi, M. (2011). *Getting Started with Arduino, 2nd edition* [PDF]. O'Reilly Media. Retrieved from http://it-ebooks.info/book/1338/

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.

Image Credits

Breadboard Picture on ***Student Handout 9.1*** is from
http://www.backward-workshop.com/electronics/breadboard-curriculum/breadboard/

Voltage vs Current vs Resistance Water Diagram is from Sparkfun, https://cdn.sparkfun.com/assets/learn_tutorials/1/9/3/water-analogy.png

Voltage vs Current vs Resistance Diagram is from Wikimedia Commons, http://upload.wikimedia.org/wikipedia/commons/thumb/d/de/OhmsLaw.svg/220px-OhmsLaw.svg.png

Arduino Uno Intro Photo is from Arduino, http://ardunio.cc

Parts of an Arduino Uno Diagram is from Adafruit (original author Nick Gammon), http://www.adafruit.com/blog/2012/05/25/handy-arduino-r3-pinout-diagram/

Student Handout 9.1: Day One Exit Ticket

Name:__________________________________ Date:___________________ Period:___________

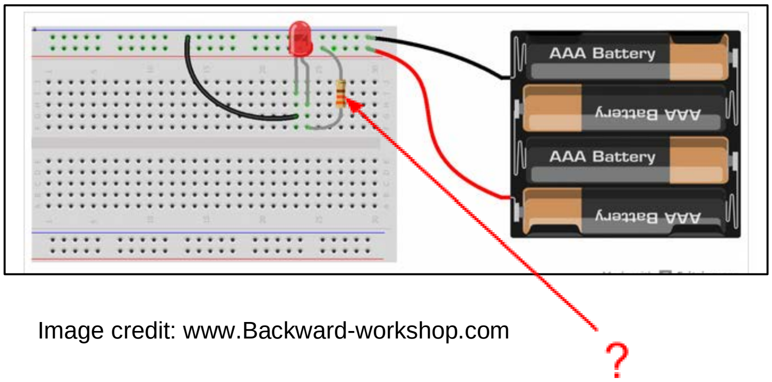
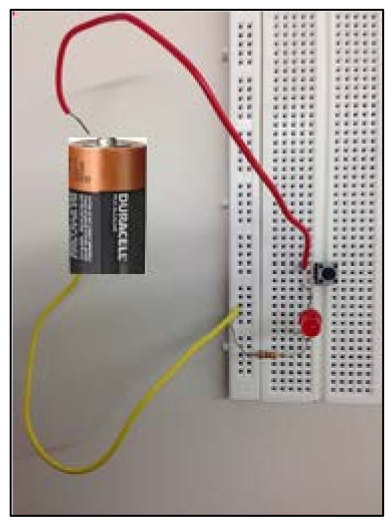


Image credit: www.Backward-workshop.com

1. Name and describe the item indicated by the red arrow in the picture above. What is its role within the circuit and what do you think would happen if it were to be removed?



2. Using the picture to the right, indicate which component represents the ***input*** function. How do you know?

3. Using the picture to the right, indicate which component represents the ***output*** function. How do you know?

Student Handout 9.2: Day Two Exit Ticket

Name:__________________________________ Date:___________________ Period:__________

1. Describe the three main sections of an Arduino sketch.

2. How confident would you feel if you were asked to write your own Arduino sketch. Explain.

Teacher Resource 9.1: Sketches

Button Sketch, Challenge #2 (copy and paste into Arduino Uno)

```
//Button Sketch

//Declarations

int buttonPin = 7;
int ledPin = 13;

//Setup to Determine which Pins are Input vs Output

void setup()
{
 Serial.begin(9600);
 pinMode (buttonPin, INPUT);
 pinMode (ledPin, OUTPUT);
}

//Sketch that will keep looping and looping
void loop()
{

 if(digitalRead(buttonPin) == HIGH)
 {
  digitalWrite(ledPin, HIGH);
 }
 else
 {
  digitalWrite(ledPin, LOW);
 }
}
```

Fading Light Sketch, Challenge #3 (copy and paste into Arduino Uno)

```
//Fading Light Sketch

//Declarations

int button = 7;
int LED = 9;
int i = 0;


//Setup

void setup()
{
 pinMode(button, INPUT);
 pinMode(LED, OUTPUT);
```

```
}

//Loop function

void loop ()
{
 if (digitalRead(button) == HIGH)
 {

  for(i = 0; i < 100; i++)
  {
  analogWrite(LED, i);
  delay(10);
  }

 for (i = 100; i > 0; i--)
  {
  analogWrite(LED, i);
  delay(10);
  }
 }

 else
 {
  digitalWrite(LED, LOW);
 }

}
```

SENSOR code SKETCHES

Color Sensor Sketch (from Sparkfun)
http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/LightImaging/HDJD_S822_QR999_Color_Sensor.pde

Light Sensor Sketch

(as the light on the sensor decreases, the LED increases in brightness...like a night light)

```
// Light sensor

int led = 10;
int photoPin = 0;
int reading = 0;

void setup()
{
 Serial.begin(9600);
 pinMode(led, OUTPUT);
 pinMode(photoPin, INPUT);
}

void loop()
```

```
{
 reading = analogRead(photoPin);

 reading = map(reading, 0, 1023, 0, 255);

 reading = 255 - reading;

 analogWrite(led, reading);

 Serial.println(reading);

 delay(10);
}
```

Force Sensor Sketch:

```
// Force Sensor Sketch

int forceReading = 0;
int ledLight = 11;
int ledBrightness = 0;

void setup()
{
 Serial.begin(9600);
}

void loop()
{
 forceReading = analogRead(A0);
 Serial.println("Analog Reading = ");
 Serial.println(forceReading);

 ledBrightness = map(forceReading, 0, 1023, 0, 255);
 analogWrite(ledLight, ledBrightness);

 delay(10);
}
```

Temperature Sensor
(as temperature increases, the brightness of a LED increases and vice versa)

```
//TMP36 Pin Sensor

int sensorPin = 0;
int ledPin = 11;

void setup()
{
 Serial.begin(9600);
```

```
 pinMode(ledPin, OUTPUT);
}

void loop()
{
 int brightness;
 int reading = brightness = analogRead(sensorPin);

 float voltage = reading * 5.0; //converts analog to voltage
 voltage /= 1024.0;       // float makes the number a decimal, not an integer, which works for calculations

 Serial.print(voltage);
 Serial.println(" volts");

 float temperatureC = (voltage - 0.5) * 100 ; //uses 10 mv / degree conversion factor with -0.5 V offset (to
allow for negative temperatures)
                      //bascially, converts voltage to degrees Celcius
 Serial.print(temperatureC); Serial.println(" degrees C");

 float temperatureF = (temperatureC * 9.0 / 5.0) + 32.0; //converts Celcius to Fahrenheit
 Serial.print(temperatureF); Serial.println(" degrees F");
 Serial.println("\n");

 brightness = map(brightness, 0, 1023, 200, 255); //converts sensor reading to a voltage for LED for an
output
 analogWrite(ledPin, brightness);

 delay(1000);
}
```

Force Sensor to Playing a C Scale on a Speaker

(Note: Students can modify the notes, the force sensitivity, or something else to adjust the code. Picture is below).

```
// This sketch plays a C scale based on how hard you press the force sensor. Harder input -->> higher note
// the #define lines below basically define each note and how many Hz the note is. Ex: A is 440 Hz

#define NOTE_B0 31
#define NOTE_C1 33
#define NOTE_CS1 35
#define NOTE_D1 37
#define NOTE_DS1 39
#define NOTE_E1 41
#define NOTE_F1 44
#define NOTE_FS1 46
#define NOTE_G1 49
#define NOTE_GS1 52
#define NOTE_A1 55
#define NOTE_AS1 58
#define NOTE_B1 62
```

```
#define NOTE_C2 65
#define NOTE_CS2 69
#define NOTE_D2 73
#define NOTE_DS2 78
#define NOTE_E2 82
#define NOTE_F2 87
#define NOTE_FS2 93
#define NOTE_G2 98
#define NOTE_GS2 104
#define NOTE_A2 110
#define NOTE_AS2 117
#define NOTE_B2 123
#define NOTE_C3 131
#define NOTE_CS3 139
#define NOTE_D3 147
#define NOTE_DS3 156
#define NOTE_E3 165
#define NOTE_F3 175
#define NOTE_FS3 185
#define NOTE_G3 196
#define NOTE_GS3 208
#define NOTE_A3 220
#define NOTE_AS3 233
#define NOTE_B3 247
#define NOTE_C4 262
#define NOTE_CS4 277
#define NOTE_D4 294
#define NOTE_DS4 311
#define NOTE_E4 330
#define NOTE_F4 349
#define NOTE_FS4 370
#define NOTE_G4 392
#define NOTE_GS4 415
#define NOTE_A4 440
#define NOTE_AS4 466
#define NOTE_B4 494
#define NOTE_C5 523
#define NOTE_CS5 554
#define NOTE_D5 587
#define NOTE_DS5 622
#define NOTE_E5 659
#define NOTE_F5 698
#define NOTE_FS5 740
#define NOTE_G5 784
#define NOTE_GS5 831
#define NOTE_A5 880
#define NOTE_AS5 932
#define NOTE_B5 988
#define NOTE_C6 1047
#define NOTE_CS6 1109
#define NOTE_D6 1175
```

```
#define NOTE_DS6 1245
#define NOTE_E6 1319
#define NOTE_F6 1397
#define NOTE_FS6 1480
#define NOTE_G6 1568
#define NOTE_GS6 1661
#define NOTE_A6 1760
#define NOTE_AS6 1865
#define NOTE_B6 1976
#define NOTE_C7 2093
#define NOTE_CS7 2217
#define NOTE_D7 2349
#define NOTE_DS7 2489
#define NOTE_E7 2637
#define NOTE_F7 2794
#define NOTE_FS7 2960
#define NOTE_G7 3136
#define NOTE_GS7 3322
#define NOTE_A7 3520
#define NOTE_AS7 3729
#define NOTE_B7 3951
#define NOTE_C8 4186
#define NOTE_CS8 4435
#define NOTE_D8 4699
#define NOTE_DS8 4978

int force = 0;

void setup() {
 pinMode(0, INPUT);
 Serial.begin(9600);
}

void loop(){

 force = analogRead(0);
 Serial.print("Reading = ");
 Serial.println(force);

 if (force < 30 && force > 0)
 {
  tone(7, NOTE_C4, 100);
 }
 else if (force >= 30 && force < 60)
 {
  tone(7, NOTE_D4, 100);
 }
 else if (force >= 60 && force < 90)
 {
  tone(7, NOTE_E4, 100);
 }
```

```
 else if (force >= 90 && force < 120)
 {
  tone(7, NOTE_F4, 100);
 }
 else if (force >= 120 && force < 150)
 {
  tone(7, NOTE_G4, 100);
 }
 else if (force >=150 && force < 180)
 {
  tone(7, NOTE_A4, 100);
 }
 else if (force >= 180 && force < 210)
 {
  tone(7, NOTE_B4, 100);
 }
 else if (force >= 210)
 {
  tone(7, NOTE_C5, 100);
 }
 else
 {
  delay(10);
 }
 delay(10);
}
```

Force Sensor to Moving the Motor:

```
// This Arduino example demonstrates bidirectional operation of a
// 28BYJ-48, using a ULN2003 interface board to drive the stepper.
// The 28BYJ-48 motor is a 4-phase, 8-beat motor, geared down by
// a factor of 68. One bipolar winding is on motor pins 1 & 3 and
// the other on motor pins 2 & 4. The step angle is 5.625/64 and the
// operating Frequency is 100pps. Current draw is 92mA.
////////////////////////////////////////////////

#include <Servo.h>
#include <Stepper.h>

//declare variables for the motor pins
int motorPin1 = 8;  // Blue  - 28BYJ48 pin 1
int motorPin2 = 9;  // Pink  - 28BYJ48 pin 2
int motorPin3 = 10;  // Yellow - 28BYJ48 pin 3
int motorPin4 = 11;  // Orange - 28BYJ48 pin 4
            // Red  - 28BYJ48 pin 5 (VCC)

int motorSpeed = 1200; //variable to set stepper speed
int count = 0;      // count of steps made
int countsperrev = 512; // number of steps per full revolution
int lookup[8] = {B01000, B01100, B00100, B00110, B00010, B00011, B00001, B01001};
```

```
int force = 0;
/////////////////////////////////////////////////////////////////////////////
void setup() {
 //declare the motor pins as outputs
 pinMode(motorPin1, OUTPUT);
 pinMode(motorPin2, OUTPUT);
 pinMode(motorPin3, OUTPUT);
 pinMode(motorPin4, OUTPUT);
 pinMode(0, INPUT); //added
 Serial.begin(9600);
}

/////////////////////////////////////////////////////////////////////////////
void loop(){
 force = analogRead(0);

 if (force > 20)
 {
  run();
  Serial.print("Force reading is ");
  Serial.println(force);
 }
 else
 {
  Serial.println("No significant force detected.");
 }
 delay(10);
}

void run(){
 if(count < countsperrev )
  clockwise();
 else if (count == countsperrev * 2)
  count = 0;
 else
  anticlockwise();
 count++;
}

/////////////////////////////////////////////////////////////////////////////
//set pins to ULN2003 high in sequence from 1 to 4
//delay "motorSpeed" between each pin setting (to determine speed)
void anticlockwise()
{
 for(int i = 0; i < 8; i++)
 {
  setOutput(i);
  delayMicroseconds(motorSpeed);
 }
}
```

```
void clockwise()
{
 for(int i = 7; i >= 0; i--)
 {
  setOutput(i);
  delayMicroseconds(motorSpeed);
 }
}

void setOutput(int out)
{
 digitalWrite(motorPin1, bitRead(lookup[out], 0));
 digitalWrite(motorPin2, bitRead(lookup[out], 1));
 digitalWrite(motorPin3, bitRead(lookup[out], 2));
 digitalWrite(motorPin4, bitRead(lookup[out], 3));
}
```

Lesson Ten: Pugh Charts & Peer Review

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Renee Poitras, Kent-Meridian High School, Kent, WA

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary: In this lesson, students will be introduced to Pugh charts through a few examples and then make one with their team. Also, students will be introduced to the Compliments, Suggestions, and Corrections (CSC) method of peer review which they will use to critique a teammate's Pugh chart.

STUDENT UNDERSTANDINGS

Big Ideas & Understandings:

Students will understand that…

- **Engineering Design Process:** Engineers use Pugh charts to analyze solutions and design plans. Peer reviews, a fundamental part of science and engineering, need to provide useable critiques to improve work. These reviews often include Compliments, Suggestions, and Corrections.

Essential Questions:

- How can a Pugh chart be used to rank solutions and design plans?
- How can peer review be used to improve a model?

Learning Objectives:

Students will know…

- Engineers use Pugh charts to rank solutions and design plans.
- Pugh charts have solutions and design plans as column headings while the rows are made of criteria to rank the solutions.
- Although a Pugh chart might rank a specific solution better then another, one might choose a different solution/design plan as a specific criteria might be the focus of the decision.
- Peer review is fundamental to science and engineering.
- Peer review should be clear, simple, and detailed so that the review may be used to improve models.
- Peer reviews should include Compliments, Suggestions, and Corrections (CSC).

When reading a Pugh chart, students will be able to…

- State the solutions (or design plans) and criteria used to rank them when shown a completed Pugh chart.
- State which solution (or design plan) had the highest total on a completed Pugh chart.
- Rationalize why an individual may not use the highest ranking solution using data from the Pugh chart.
- Fill in a Pugh chart when given solutions (or design plans) and criteria. After filling in the Pugh chart, students should be to rank the solutions.
- Justify why they may not use the highest ranking solution using data from the Pugh chart.

When conducting a peer edit/review, students will be able to…

- State that peer editing allows for more productive and sound data for their peers.
- Explain that peer edits/reviews should include Compliments, Suggestions, and Corrections (CSC).
- Peer edit a classmate's work in an appropriate way using CSC.

Vocabulary:

- Data
- Solutions
- Design Plans
- Rank
- Evaluate
- Peer

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

- **MS-ETS1-1 Engineering Design:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **MS-ETS1-2 Engineering Design:** Evaluate competing design solutions using a systemic process to determine how well they meet the criteria and constraints of the problem.
- **HS-ETS1-1 Engineering Design:** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **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.

Common Preconceptions & Misconceptions:

- There is one “perfect” solution to every problem (no room for improvement).
- Peer reviews are not beneficial.
- When giving peer reviews, you should only include how to improve the work, not what is good about it.

MATERIALS

Material	Quantity
Blank white paper (scratch paper is fine if one side is blank), for peer review intro and drawings	1 per student
Exit Ticket (blank paper, sticky-note, or weekly sheet; whatever is normally used for Exit Tickets)	1 per student
Pencils	1 per student
Timer (computer program, cell phone, or stopwatch)	1 per student
Student lab notebooks, for note taking	1 per student
Student Handout 10.1: Pugh Chart Practice	1 per student
Analyzing Solutions PowerPoint presentation	1 PPT file
Classroom computer connected to projector	As needed

TEACHER PREPARATION

1. Make copies of ***Student Handout 10.1***, one per student.

2. Pre-read the ***Analyzing Solutions*** PowerPoint as it gives directions for the students and for you (there are hidden slides with teacher instructions, so make sure to also view it in “outline view”).

3. This lesson includes group/team activities, so you may need to adjust class seating arrangement (heterogeneous seating is recommended).

PROCEDURE

Note: The slide numbers mentioned in the *Procedure* are from the ***Analyzing Solutions*** PowerPoint Presentation.

Engage: Slides #2-3

1. While projecting *Slide #2*, ask students "How do they make tough decisions?"

2. Give students three minutes to share in their teams, and then call on each team to give their ideas. (1^{st} bullet on slide)

3. Keep track of their ideas on the board.

4. Ask students to get their lab notebooks out for note taking.

5. Continue with *Slide #2*, making sure students are taking notes on Pugh charts.

6. *Slide #3*: Continue to give students information, make sure students are adding info to their notes.

Explore/Explain: Slides #4-5

7. *Slide #4:* Pass out ***Student Handout 10.1***.

8. Give students time to pre-read the activity with their neighbor. The amount of allotted time will depend upon the reading needs of your students.

9. *Slide #5:* Answer any questions the teams might have about the handout.

10. Give students seven to ten minutes to work through *Parts I-IV* of the handout. Set the timer and begin.

11. When time is up or students are ready, review the handout. Ask students about their vehicle choice and what criteria was highest for them.

12. Have the students begin *Part V*, the Team Design Pugh Chart for a good place to study. Set timer for seven to ten minutes and begin. When time is up or students are finished, have them place the completed handout off to the side.

Elaborate: Slides #6-9

13. Show *Slide #6*.

14. After students have picked a writer, pass out a piece of paper to that person (along with pencil if needed). Reinforce to writers that their group members will only have three minutes to sketch based on their directions, so they do need to pick a simple object. Set timer for five minutes for writers to write their instructions.

15. As writers are working on their instructions, this is a good time for their other teammates to review what they have for their neuroprosthetics problem. How is their design going? See PowerPoint for discussion ideas. If writers are getting distracted by their group members' discussion, feel free to move the writers to a separate table for a few minutes.

16. When time is up, show *Slide #7*. Set clock for three to five minutes (depending on needs of writers). Have writers share their instructions while the rest of the group members are drawing the object.

17. When time goes off, lead a quick discussion based on the discussion questions.

18. Have students get their notebooks back out and take notes on *Slides #8* and *#9*.

19. Show *Slide #10*. Have students switch their handouts with another student and peer review the Team Design Pugh Chart (*Part V* of handout). Make sure the original owner gets to see the comments (if not enough time, you can always pass back the next day for students to review).

Evaluate: Slide #10

20. Have students get out their Exit Tickets (or you pass out sticky-note or whatever you use in your classroom) and complete the "1 to 1 to 1" task presented in *Slide #10*.

21. Collect the Student Handouts and the Exit Tickets.

STUDENT ASSESSMENT

Assessment Opportunities

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

- **Formative:** During discussions during class.
- **Formative:** ***Student Handout 10.1***—students begin by analyzing a filled-in Pugh chart, and then fill one in, finally constructing one with their team. They also need to use CSC to review a peer's Pugh chart.
- **Formative:** Exit Ticket 1 to 1 to 1—addresses use of Pugh charts and peer review as relates to their neuroprosthetic problem.

Student Metacognition

- Pre-assessment.
- How do you make Tough Decisions discussion with their teams.
- Being able to fill in the handout.
- Will have to eventually use Pugh Chart in their neuroprosthetic project.

- Peer Review Intro: Students should think about how to improve/give feedback about the instructions they were given.
- At end of lesson students should be able to give CSC review to another student's Pugh chart.
- During neuroprosthetic problem model development, later in the unit, students should provide CSC feedback to another team.

Scoring Guide

As the assessments are formative, some recommendations for scoring are provided below. Feel free to change based on the needs of the classroom (see *Slide #11*).

1. Review the Student Handout for Pugh Chart:
   - Just do a simple check. Could the students create a Pugh chart with their team? If not, you will need to re-teach.
2. Review the Student Handout for Peer Review:
   - Just do a simple check to see that all comments are appropriate. Address any inappropriate comments the next day.
3. Exit Ticket: 1-1-1
   - Could the students relate Pugh charts and peer review to their overall problem? If not, do some direct instruction the next day.
4. The importance is to observe student understanding as these skills will be used later on in the unit.

EXTENSION ACTIVITIES

Extension Activities:

- Have students create a Pugh chart on a topic of their own choice, and then review each other's.
- Have students do a CSC review of the instructions given for the Peer Review Intro.
- Have students do a CSC for any of the labs/assignments given in this unit.

Adaptations:

- Print out the PowerPoint slides for students that need a copy so that they are focused on understanding verses taking notes.
- Have students work with a partner to complete the Student Handout.
- Have a transcriber for the Peer Review so that students are vocalizing their CSC and another person is writing their response. The same should be done for the 1 to 1 to 1 Exit Ticket.

TEACHER BACKGROUND & RESOURCES

Background Information

The following background knowledge is needed to successfully deliver this lesson:

- Although Pugh charts are used are new to teaching, they have been used for decades in engineering.

- Pugh charts allow for engineers to concentrate on constraints when designing solutions and then rank solutions based on criteria.
- Peer review allows for students to become better writers and thinkers.
- CSC allows students to think more deeply on their peer reviews.
- If you need more information on Pugh Charts and CSC peer review, check out the *Resources* section below.

Resources

Pugh Chart Worksheet
A good teacher resource; it is a bit in-depth for students.
University of Michigan
http://www-personal.umich.edu/~bobden/me450_pugh_chart.pdf

Peer Edit with Perfection: Effective Strategies
ReadWriteThink
http://www.readwritethink.org/classroom-resources/lesson-plans/peer-edit-with-perfection-786.html?tab=4

Citations

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.

Student Handout 10.1: Pugh Chart Practice
Name:________________________________ Date:__________________ Period:__________

Part I: Choosing a Car

You came into some money….and have decided to buy a car! There are many different cars which you can buy. The problem is that each car has some things you like and some things that you don't. As an example, maybe one is the perfect color but has awful gas mileage. Another could have the perfect price but it is a truck and you like 4 door car (sedan). How will you determine which vehicle will meet the majority of your needs?

The answer is, use a **Pugh chart** to evaluate your priorities. With a Pugh chart, the higher the number, the higher your priority. Think of the numbers this way… (see table).

0	Criteria is never met (HATE it)
1	Criteria is rarely met (can handle it)
2	Criteria is sometimes met (good with it)
3	Criteria is always met (LOVE it)

Part II: Coffee Example from Class

When I woke up this morning, I realized that my coffee machine had broken. Thus, I needed to go buy coffee on my way to work. I used a Pugh chart to show the best option.

Best place for Coffee	**Starbucks**	**McDonalds**	**Gas Station**
Cost	0	2	3
Taste	3	2	2
Strength of Caffeine	3	2	3
Wait Time	1	2	3
Total:	**7**	**10**	**11**

1. According to the Pugh chart, where should your teacher get coffee?

2. Why would your teacher go to Starbucks instead (which criterion was most important to your teacher)?

Part III: Back to your Car

There are three vehicles available to you. Which should you buy? Fill in the Pugh chart (using the same numbers discussed at the top of this sheet). (*MPG=miles per gallon)

Characteristics of Vehicle	**Vehicle #1:** • Green • 4 door sedan • 35 MPG* • $19,000	**Vehicle #2:** • Silver • Truck • 15 MPG • $7,000	**Vehicle #3:** • Black • 2 door sports car • 20 MPG • $44,000
Color			
Type			
Gas Mileage			
Cost			
Total:			

3. Which vehicle does the Pugh chart suggest you buy?

4. Would you have picked a different car? Why?

Part IV

Team Design: Your team needs to design your own Pugh chart for a good study location. You have a big test coming and need to find a good place to study.

- ☐ Discuss and decide on 4 locations that are **commonly** used as places to study. Add them to the **column** headings on the Pugh Chart below.
- ☐ Discuss and decide on 3 criteria that make a location a good place to study **productively.** Add them to the **row** headings on the Pugh chart below.
- ☐ (Don't complete the chart, just set it up.)

Good Location to Study for a Test				
Total:				

Part V: Peer Review

Using what you have learned today, you are going to review another person's Good Location to Study for a Test Pugh Chart.

- ☐ Trade paper's with someone from another team.
- ☐ Fill in the Pugh chart.

Peer Review's Name: ___________________

5. According to the Pugh chart, which location would work best for you? Do you agree with the Pugh chart?

6. Review the Good Location to Study for a Test Pugh Chart.

C:

S:

C:

Pass back this sheet to its original owner

Lesson Eleven: Online Research & Writing an Abstract

Center for Sensorimotor Neural Engineering

Lesson Plan Author: Steve Pratt, Cleveland High School, Seattle, WA

LESSON OVERVIEW

Activity Time: Varies. As written, two 50 minute class periods (100 minutes total). Lesson could be truncated to a block-period (~85 minutes). Extension activities could allow this to be longer (see *Extension Activities* and *Teacher Background* sections for explanation).

Lesson Plan Summary: In this lesson, students will learn how to use Google searching more effectively to research the characteristics of a neuroprosethic for their project. After practicing how to research, they will also have a lesson on how to articulate their research in writing by following a science abstract structure. Students will use this structure to describe their neuroprosthetic model they have developed in terms of being an active system.

STUDENT UNDERSTANDINGS

Big Ideas & Enduring Understandings:

Students will understand that…

- **Online Research:** Online search engines, when employed effectively, are powerful tools for the researcher.
- **Scientific Communication:** Engineers and scientists are challenge to communicate their research findings to a variety of technical and non-technical audiences. A scientific abstract is a commonly used method for summarizing a research project.

Essential Questions:

- What is the most efficient way to write about your work in science?
- What is the best way to use Google to conduct research?
- How can you describe the model you have created for the neuroprosthetic project?

Learning Objectives:

Students will know…

- An abstract is a method commonly used by scientists for summarizing a research project; it is also a useful way of reporting about their neuroprosthetic model project.
- When researching a topic, online search databases such as Google or Bing can be used to find relevant, helpful, and reliable resources.

Students will be able to…

- Use the five-step process for writing a scientific abstract.
- Use better search terms to find relevant sources for their project.
- Write an abstract that summarizes the purpose, procedure, data, and conclusions related to the neuroprosthetic model.

- Use Google to do searches that narrow the number of responses to provide research for an answer

Vocabulary:

- Abstract
- Search engine

Standards Alignment: This lesson addresses the following Common Core State Standards in Science & Technical Subjects:

- **WHST.6-8.7 Writing:** Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.
- **WHST.6-8.8 Writing:** Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard form for citation.
- **RST.6-8.4, RST.9-10.4 & RST.11-12.4 Craft & Structure:** 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 6-12 texts and topics*.
- **WHST.9-10.7 & WHST.11-12.7 Writing:** 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 Writing:** 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.11-12.8 Writing:** 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 citations.
- **RST.11-12.7 Integration of Knowledge & Ideas:** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

Common Preconceptions & Misconceptions:

- Scientists don't need to worry about writing in their profession—they have other people that do that for them.
- Written communication is not important in the field of science.
- Typing any question into Google and clicking on the top result is the fastest and best way to do research.

MATERIALS

Note: Paper copies can be replaced with digital copies if students have access to EduModo, Google Drive, or any other social learning platform you may use in your classroom.

Material	Quantity
Copy of "How to Write an Abstract" (available from http://users.ece.cmu.edu/~koopman/essays/abstract.html)	1 per student
Copy of Student Example Abstracts (available from http://www.sciencefairofiowa.org/forms/abstract.html)	1 per student
SpikerBox Lab student data (handouts from *Lesson Four* and *Lesson Six*); each student should have their completed handouts from previous lessons	1 set per student
Colored pencils or highlighters (optional)	As needed
Computers or laptops, for online research	1 per student or 1 per pair
Classroom computer connected to internet and projector	As needed

TEACHER PREPARATION

1. Make copies of the two readings, one per student.

2. Gain an understanding of the Google search process by reviewing the websites listed in the *Teacher Background* and *Resources* sections.

3. Preview the Google lesson plan, *Picking the Right Search Terms*, and accompanying PowerPoint presentation (see *Procedure* section for URL).

PROCEDURE

Day One: Google Searching

Engage

1. Begin class by asking students how they would figure out the answer to a question. (Most students will say use Google, Bing, research, etc.) Explain that today we will be learning how to more effectively use Google to help find relevant research so that students can make their neuroprosthetic model as research-based as possible.

Explore/Explain

2. **For the core of the lesson, use Google's Beginner Lesson on Picking the Right Search Terms.** The lesson uses a PowerPoint presentation, too, if you want to supplement your instruction with it as well. This lesson is wonderfully thorough with details, prompting questions, and demonstrations to show how effective a Google search can be.

    Google Lesson: Picking the Right Search Terms
    https://docs.google.com/a/uw.edu/document/d/1l4pS26nZLUok_-rx2_w5qu5aYy40p5gXX58l6dgE4_c/edit?pli=1

    PowerPoint: Picking the Right Search Terms
    https://docs.google.com/a/uw.edu/presentation/d/1JFaDwf3_mHVe-O0lqlGRibCD_Hv6zle58YsbUcanzDM/present#slide=id.i0

Elaborate

3. Here are some "extras" to include with the Google lesson:
    a. As part of the lesson, include the main points from this infographic to show the different terms and parameters a student can use when doing a Google search. Examples include: using quotations, searching within a site, the "-" function, AND vs OR.

        How to Use Google Search More Effectively [Infographic]
        http://mashable.com/2011/11/24/google-search-infographic/

    b. Because students will be doing research relevant to their neuroprosthetic project, show the students the different types of searches that would be relevant to their topic:
        i. "Prosthetic" vs "Neuroprosthetic"
        ii. "Neuroprothetic" vs "Neural prosthetic"

iii. "Neural prosthetic" vs "Smart prosthetic"
iv. "Neuroprosthetic design" vs Neuroprosthetic AND design

c. Also, show students the Advanced Search tab, and show them how to use a filter that separates based on reading level. This will help them find sources that are more intelligible for them to understand.

Evaluate

4. At the end of the lesson, students will be using their newfound knowledge to conduct research relevant to their project. The following is an excerpt taken from the Google lesson:

   Have students use one of the three methods introduced in this lesson to arrive at key search terms and then queries for their research task. Have them submit their queries along with the work showing how they used one of these methods to assist them in developing queries: (1) parsing, (2) web, and (3) word list based on prior experience. Students will read the results of these queries in the following Foundational Lesson #2 to choose what sources they want to examine.

   Note: Google's Foundational Lesson #2 is an extension activity that is not required but, if time allows, could be a great supplement to learning how to evaluate sources.

5. There is an opportunity to check-in with students and assess their submitted research queries and methods.

Day Two: How to Write an Abstract
Engage

6. Ask the class if a scientist needs to have good communication skills. What would be the purpose? What could be the downfall of not having good communication skills?

Explain

7. Discuss with the class how universities are able to get money for research (which funds for positions, departments, equipment, essentially their livelihood) based on their ability to write grants applications. This includes both science as well as non-scientific disciplines.

8. Since communication is vital, and being able to summarize well is also important, explain to students that they will be completing an abstract. A research abstract is an executive summary of any relevant research or prototyping that has occurred.

9. Pass out copies of the "How to Write an Abstract" article. Also project the website using the classroom computer and projector. The checklist is especially helpful. Explain the five parts of the abstract.

    How to Write an Abstract
    Philip Koopman, Carnegies Mellon University, 1997
    http://users.ece.cmu.edu/~koopman/essays/abstract.html

Explore

10. Pass out the example abstracts taken from the Iowa State Science Fair (see *Materials* section for URL). Ask students to read the abstracts closely and evaluate if they examples include all five parts in the checklist. Allow ten minutes for this activity. Students can use colored pencils, highlighters, ***or*** annotations to "find" the five different parts in the abstracts.

11. Ask students to turn and talk with a neighbor, comparing their annotation. Then debrief as a class.

Elaborate

12. With an example compared, students will now write their own abstract in pairs or solo (your choice) using the SpikerBox Lab student data (handouts from *Lesson Four* and *Lesson Six)*. This data can be very useful, and with the background knowledge that students now have with neural engineering, they should be able to write a compelling abstract. Allow 20 - 25 minutes for this activity.

13. As students are working on their abstracts, walk around the classroom to provide individual help or just to check-in with students.

Evaluate

14. At the end, students can read and compare their abstracts with one another. The final abstracts will be turned in by the end of class (or for homework, if you prefer) so that you can provide feedback to your students.

STUDENT ASSESSMENT

Assessment Opportunities

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

- **Online Searching:** Students will submit their research queries and methods used for conducting online research related to their neuroprosthetic model.
- **Sample Abstract:** Students will evaluate an example abstract to practice scientific writing using the five-part scientific abstract
- **Project Abstract:** Students will complete an abstract either in pairs or individually (based on your classroom) that describes their neuroprosthetic model. This is one of the final products of their project.

Student Metacognition

- Students will have opportunities to share their abstracts with one another, which will allow them to think critically about their own writing by considering the writing of others.
- Students could be allowed the opportunity to respond to instructor feedback on their abstracts to improve them.

Scoring Guide

- Use the abstract checklist on the "How to Write an Abstract" website to provide formative, written feedback on student's abstracts. This is their "practice" abstract, so providing feedback is key. Grade should be done on completion.

  How to Write an Abstract
  Philip Koopman, Carnegies Mellon University, 1997
  http://users.ece.cmu.edu/~koopman/essays/abstract.html

EXTENSION ACTIVITIES

Extension Activities:

- The great thing about Google's lessons on searches is that they are scaffolded at different levels (Beginner, Intermediate, Advanced). If your students are far enough along that they understand the basics of a search query, you can use a different lesson or even allow more advanced students to work their way through one of the advanced lessons.

  Google Search Education: Lesson Plans
  http://www.google.com/insidesearch/searcheducation/lessons.html

Adaptations:

- Boolify is a "Web 2.0" search tool that can be used to teach younger students to use online search engines effectively. Boolify offers a middle-school-friendly lesson that involves a lot more direct instruction and call-and-response feedback to explain how a search engine works. The lesson can be found at the following website:

  Boolify Lesson One: Introduction to Search
  https://docs.google.com/a/uw.edu/document/d/1ebthehQ0ETWzmonLDNe-ul6WioTvMJJbbB87CNi5Q4g/edit?pli=1

TEACHER BACKGROUND & RESOURCES

Background Information

General information on web searches:

How to Search the Web: Steps to Success
KY Virtual Library
http://www.kyvl.org/html/tutorial/research/howweb.shtml

Use Google Scholar Effectively for Research
Univeristy of Illinois at Urbana-Champaign
http://www.library.illinois.edu/ugl/howdoi/use_google_scholar.html

Google Search Lesson Plans
These were created by folks at Google with students in mind. Lessons include extension activities, pre-made powerpoints, differentiation suggestions, and lesson flow with standards.
http://www.google.com/insidesearch/searcheducation/lessons.html

- **Google Search Lesson Plan Map**
  A one-page overview of all the lessons available on Google Searches
  http://www.google.com/insidesearch/searcheducation/lesson-map.html

- **Beginner Lesson**
  Picking the right search query terms.
  https://docs.google.com/a/uw.edu/document/d/1l4pS26nZLUok_-rx2_w5qu5aYy40p5gXX58l6dgE4_c/edit?pli=1

- **Beginner Lesson PowerPoint Presentation**
  https://docs.google.com/a/uw.edu/presentation/d/1JFaDwf3_mHVe-O0lqlGRibCD_Hv6zle58YsbUcanzDM/present#slide=id.i163

- **Intermediate Lesson**
  Definitely more advanced, but focuses on choosing more precise words when doing a search. Honestly, the beginner lesson has more room for growth and more structure to it. But, you could consider combing both.
  https://docs.google.com/a/uw.edu/document/d/1zZ6C6CN_51L9_TUIUjMJWf_yWfzAJzi8koZWVTuXxb0/edit?pli=1

- **Searching for Evidence in Research Tasks**
  Teaches the "stepping stone" approach to research (on page four) which should be modeled to the students to show how neuroprosthetic research is difficult but possible.
  https://docs.google.com/a/uw.edu/document/d/1uOeFnjh2DiUrAx6EHItFvD_3o2VSzMZv0MdH3QhC0Lo/edit?pli=1

Information about the Google search process:

How Search Works: From Algorithms to Answers (Animation)
http://www.google.com/insidesearch/howsearchworks/thestory/index.html

How Search Works Video
Google, 2010, 3:14 minutes
http://www.youtube.com/watch?v=BNHR6IQJGZs

Tips & Tricks for Doing an Effective Google Search
Google
http://www.google.com/insidesearch/tipstricks/all.html#numbers

Google Advanced Search
Become familiar with the Advanced Search function on Google. Teaching students that they can distinguish between sources based on website type, reading level, file type, date, etc. can be very helpful.
http://www.google.com/advanced_search

Resources
Print this helpful infographic and post it in your classroom.

How to Use Google Search More Effectively [Infographic]
http://rack.0.mshcdn.com/media/ZgkyMDEyLzA0LzI0LzAyXzIwXzEzXzI5M19maWxlCnAJdGh1bWIJMTIwMHg5NjAwPg/0ac922b6

Share this fun and informative animation with your students to provide an understanding of how a Google search works

How Search Works: From Algorithms to Answers (Animation)
http://www.google.com/insidesearch/howsearchworks/thestory/index.html

Citations

Catone/Mashable, J. (2011). *How to Use Google Search More Effectively [INFOGRAPHIC]*. Retrieved August 14, 2014, from http://mashable.com/2011/11/24/google-search-infographic/

Google in Education. (2014). *Lesson Plans – Search Education – Google*. Retrieved August 14, 2014, from http://www.google.com/insidesearch/searcheducation/lessons.html

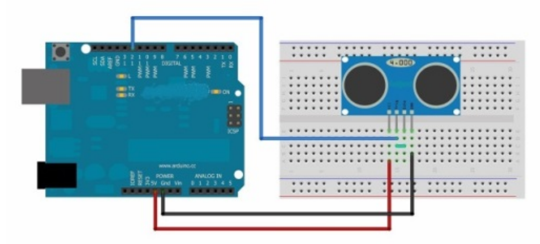
Iowa State University. (2010). *Abstract | Science Fair of Iowa*. Retrieved August 14, 2014, from http://www.sciencefairofiowa.org/forms/abstract.html

Koopman/Carnegie Mellon University, P. (1997, October). *How to Write an Abstract*. Retrieved August 14, 2014, from http://users.ece.cmu.edu/~koopman/essays/abstract.html

Public Learning Media Laboratory. (2013, April). *Boolify L1 - Introduction to Search - Google Docs*. Retrieved August 14, 2014, from https://docs.google.com/document/d/1ebthehQ0ETWzmonLDNe-ul6WioTvMJJbbB87CNi5Q4g/edit

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.

Systems Vocab Terms
- Disruption/disturbance
- Dynamic
- Edges
- Equilibrium feedback
- Inputs
- Networks
- Nodes
- Outputs
- Positive feedback
- Subsystem
- System



Neural Engineering Project Rubric

Criteria	4	3	2	1
Presentation	Group effectively uses technology to clearly and thoroughly describe the engineering design cycle they went through in learning, researching about, designing, and improving upon neuroprosthetic devices and systems.	Group uses a technology tool to describe the engineering design cycle they went through in learning, researching about, designing, and improving upon neuroprosthetic devices and systems.	Group attempts to describe the engineering design cycle they went through in learning, researching about, designing, and improving upon neuroprosthetic devices and systems.	Group minimally or does not attempt to describe the engineering design cycle they went through in learning, researching about, and improving upon neuroprosthetic devices and systems.
Improved Design	There is a clear description of an existing neuroprosthetic, and a detailed explanation of specific aspects of the device that the group would improve. Specific modifications and their subsequent impacts on users' experience are clearly described.	There is a description of an existing neuroprosthetic, and an explanation of specific aspects of the device that the group would improve. The impact on users' experience is outlined.	An existing neuroprosthetic is identified, and there is a description of how the group would improve upon the design.	An existing neuroprosthetic is not identified Or There is minimal or no description of how the group would improve upon the design.
Connection to System	There is a detailed description of an Arduino input/output system and a clear connection to how the system would operate within the improved neuroprosthetic device. The system clearly incorporates feedback into the design. Uses at least 9 of the 11 systems vocab terms from the unit.	There is a description of an Arduino input/output system and a connection to how the system would operate within the improved neuroprosthetic device. The system incorporates feedback into the design. Uses 6-8 of the 11 systems vocab terms from the unit.	An Arduino input/output system is outlined and somewhat of a connection is made to how the system would operate within the improved neuroprosthetic device. Uses 3-5 of the 11 systems vocab terms from the unit.	An Arduino input/output system is not present or minimally outlined Or There is no connection between the system and the improved neuroprosthetic device. Uses fewer than 3 of the systems vocab terms from the unit.
Neuroethics Considerations	Group clearly describes ethical issues that surround the existing neuroprosthetic as well as the modifications they designed. Presentation includes a thoughtful reflection on how these ethical issues could be addressed.	Group describes ethical issues that surround the existing neuroprosthetic as well as the modifications they designed. Presentation includes a reflection on how these ethical issues could be addressed.	Group identifies ethical issues that surround the existing neuroprosthetic and/or the modifications they designed. A reflection on how these ethical issues could be addressed is attempted.	Ethical issues surrounding the existing neuroprosthetic of the modifications of it are minimally or not identified. Or A reflection on how these ethical issues could be addressed is missing.