Computer Science Arduino-Based Neural Network: An Engineering Design Challenge

A Curriculum Unit for High School

Computer Science Classes

CENTER FOR

SENSORIMOTOR NEURAL

ENGINEERING

Research Experience for Teachers (RET) Program

Draft *for Piloting, September 2015*

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About the RET Program & the CSNE

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

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

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

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

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NSF

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Unit Description

In this unit, students will design, construct and test a six to eight node Arduino network as a model of a neural network as they explore introductory programming, computer engineering, and system design. The engineering design challenge is placed within the context of sensorimotor neural engineering.

Learning Outcomes

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

Big Ideas & Enduring Understandings:

- **Technology Solves Global Problems**: Computing is a creative activity that has global impact. Technology enables problem solving, human expression and creation of knowledge. All technology has benefits and drawbacks
- **Tools of Computer Science:** Within the field of computer science, abstraction reduces information and detail to facilitate focus on relevant concepts. Algorithms are used to develop and express solutions to computational problems. Computer scientists use specific terminology and formats to communicate information.

Essential Questions:

- How are innovative computer programs developed to help people, organizations, or society solve problems, such as those problems encountered within the field of neural engineering?
- How are physical phenomena and mathematical concepts represented on a computer?
- How does abstraction help us in writing programs, creating computational artifacts, and solving problems?
- How are algorithms implemented and executed on computers and computational devices?

Knowledge and Skills (Outcomes):

Students will know…

- A Brain-Computer Interface connects a technological device to the brain through electrodes.
- A neural network is constructed of neurons and their synaptic connections and can be modeled using a connectome.
- Computer programs can simulate the brain's decision making processes.

- An abstraction is a simplified model of a problem that reduces the system to nodes (objects, inputs, or outputs) and edges (connections or processes) to help make the problem more manageable.
- An Arduino is a microcontroller that can be used to input information from sensors, modify that information, and produce an output.
- Arduinos use simple programs called sketches that can be written from scratch or downloaded from the creative commons and modified.

Students will be able to…

- Identify potential beneficial and harmful effects of Artificial Intelligence and Brain-Computer Interface technology.
- Identify and name the important components of a circuit.
- Use Ohm’s Law to calculate the size of resistor needed in a circuit.
- Construct a network of Arduino controlled circuits that integrate a variety of sensor inputs and output devices.
- Explain the transfers and transformations of energy as it flows through the circuit/network.
- Break a complex system into smaller more manageable subsystems.
- Identify and prioritize constraints to solving a problem.
- Use abstraction to simplify a problem.
- Use the engineering design process to solve a problem.
- Work collaboratively to solve a complex problem.
- Evaluate strengths and weaknesses of an engineering design/model.
- Communicate ideas orally and in writing.
- Read and extract useful information from a technical or science based text and use text based details as evidence.

Knowledge and Skills (Prerequisite):

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

Helpful prerequisite knowledge includes:

- Basic understanding and familiarity with the engineering design process.

- Basic understanding of the human nervous system including reflex arcs and neural networks.
- Basic understanding of the structure and function of a simple circuit.

Helpful prerequisite skills include:

- Basic familiarity with programming and running Arduinos.

Key Vocabulary:

- Abstraction
- Arduino
- Circuit
- Constraint
- Criteria
- Debug
- Energy transfer
- Energy transformation
- Microcontroller
- Neural network
- Neuron
- Reflex Arc
- Resistor
- Sensor
- Sketch
- Subsystem
- User based design
- User story

Alignment to National Learning Standards

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

Next Generation Science Standards: Performance Expectations

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

	1: Introduction to BCIs	2: Introduction to Neural Networks	3: Abstraction	4: Design/Construction of Neural Networks	5: Reflection and Evaluation
Engineering Design					
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.					
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.

Next Generation Science Standards: Crosscutting Concepts

	1: Introduction to BCIs	2: Introduction to Neural Networks	3: Abstraction	4: Design/ Construction of Neural Networks	5: Reflection and Evaluation
Cause and Effect—Mechanism and Explanation: Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.					
Systems and System Models: Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.					
Energy and Matter—Flows, Cycles, and Conservation: Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.					
Structure and Function: The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.					

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

Next Generation Science Standards: Science & Engineering Practices

	1: Introduction to BCIs	2: Introduction to Neural Networks	3: Abstraction	4: Design/ Construction of Neural Networks	5: Reflection and Evaluation
Asking questions and defining problems.					
Developing and using models.					
Using mathematics and computational thinking.					
Constructing explanations and designing solutions.					
Engaging in argument from evidence.					
Obtaining, evaluating, and communicating information.					

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

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

	1: Introduction to BCIs	2: Introduction to Neural Networks	3: Abstraction	4: Design/ Construction of Neural Networks	5: Reflection and Evaluation
RST.11-12.1: Cite specific textual evidence to support analysis of science texts.					
RST.11-12.2: Determine the central ideas or conclusions of a text; summarize complex concepts, processes or information presented in a text.					
RST.11-12.8: Determine the meaning of symbols, key terms, and other domain specific words and phrases as they are used in a specific scientific context.					
RST.11-12.9: Synthesize information from a range of sources into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.					
WHST.11-12.1: Write arguments focused on discipline specific content.					
WHST.11-12.2: Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.					
WHST.11-12.7: Conduct research projects to answer a question or solve a problem.					
WHST.11-12.9: Draw evidence from informational texts to support analysis, reflection and research.					

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: Introduction to Brain-Computer Interfaces

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

LESSON OVERVIEW

Activity Time: Two 50 minute class periods.

Lesson Plan Summary: In this lesson, students will explore Brain-Computer Interfaces through a user centered design lens. After watching an introductory video, students will assume the persona of a hypothetical BCI user and flow chart a design for a BCI based device. Students will then share their designs as a class and discuss potential benefits and drawbacks for each design.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- Technology Solves Global Problems: Technology enables problem solving, human expression and creation of knowledge. All technology has benefits and drawbacks.

Essential Questions:

- How can a creative development process affect the creation of computational artifacts?
- What are some potential beneficial and harmful effects of technology?

Learning Objectives:

Students will know…

- A Brain-Computer Interface connects a technological device to the brain through electrodes.
- All technology has benefits and drawbacks.

Students will be able to…

- List several examples of BCIs.
- Identify potential beneficial and harmful effects of Brain-Computer Interface technology.
- Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- Communicate ideas orally and in writing.
- Write informative/explanatory texts, including the narration of technical processes.

Vocabulary:

- Benefit
- Brain-Computer Interface (BCI)
- Drawback

- Ethics/ethical
- User centered design

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

NGSS High School Disciplinary Core Ideas (DCIs)

- **HS-ETS1-2:** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

NGSS Crosscutting Concepts

- System and system models
- Structure and function

NGSS Science & Engineering Practices

- Developing and using models
- Using computational thinking
- Designing solutions
- Obtaining, evaluating and communicating information

Common Core State Standards:

- **WHST.11-12.2:** Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes

MATERIALS

Material	Description	Quantity
60 Minutes video	"Breakthrough: Robotic Limbs Moved by the Mind", 13:05 minutes. Available at https://www.youtube.com/watch?v=Z3a5u6djGnE	1
Student Handout 1.1	*BCI Exit Ticket*, used to assess student understanding	1 per student
Teacher Resource 1.1	*User Identity Cards*	1 set per class
Teacher Resource 1.2	*Abstraction Success Criteria*	1 per class or team
Teacher Resource 1.3	*Robotic Arm Abstraction*	1 per class or team

Teacher Resource 1.4	*BCI Exit Ticket—Answer Key*	1
Benefit /Drawback T-charts for each design	List the device on top and then one column for benefits and one for drawbacks	1 per design
Presentation supplies	Poster paper, white board space, markers or other presentation medium that enables text and sketches	1 set of supplies per team
Science Notebooks	Students' science notebooks or journals	1 per student
Media Center	Classroom media equipment including computer with internet connection, speakers, and projector, for showing the introductory video.	1 media center

TEACHER PREPARATION

1. Print and cut out end user identity cards on Teacher Resource 1.1. Make copies of ***Teacher Resource 1.2*** and ***1.3***.

2. Pre-test the video to make sure that there are no technological issues.

3. Gather abstraction and presentation materials.

4. For day two, construct T charts on the whiteboard or on poster paper for each design.

PROCEDURE

DAY ONE

Engage: Warm-up (10 minutes)

1. When students enter the classroom they should begin thinking about Brain-Computer Interfaces (BCIs) by answering the questions "What is a Brain-Computer Interface? and "What are some examples of BCI?" Adapt this step to your normal classroom routine whether students are expected to write in their science notebook as an entry task, use a graphic tracking organizer, or use table talk. Do not spend too much time on this step as the point is just to get students thinking on the topic.

2. Select several students to share-out ideas with the class. It is fine if students are only listing sci-fi examples. Not every student has been exposed to cutting edge technology and many devices are not commercially available.

3. Explain to students that BCIs will be the topic of today's activity.

Explore: Watch Video (13 minutes)

4. Play the "Breakthrough: Robotic Limbs Moved by the Mind" video for students. You may want to encourage students to take notes in their science notebooks.

Explain: Discuss BCI as Portrayed in the Video (7-10 minutes)

5. Have students revisit the warm-up questions using a quick two minute turn and talk.

6. Select several students to share-out. Focus discussion on ideas that revise or refine the warm-up discussion. Students should be left with the idea that BCI connects some sort of technology to the brain such as the robotic arm in the video. Other examples include controlling a wheelchair, moving a cursor on a computer screen to spell out words for communication, and changing environmental controls such as heat and light settings. For a more in depth description of BCI see the *Teacher Background & Resources* section of this lesson plan.

Elaborate: User Design Activity (20 minutes)

7. Break the class into teams of three to five students.

8. Assign each team an end user by having one team member come forward to pick a random card from a pile or making several copies of each card and passing them out randomly to students. All students with the same card then form a team.

9. Students will then assume the role of that user and "design" a BCI-based device that would serve that type of user.

10. Students should simply abstract the major components of their device using a "high level block diagram" and create some type of flowchart, annotation, or narration that

explains how the device will function. An example abstraction with annotation of the robotic arm has been provided in ***Teacher Resource 1.3***, however students should be encouraged to use creativity when recording their ideas and not just copy the format of the example. Students' abstractions should contain enough information to stand on its own.

11. Explain to students that they will be sharing out their ideas using their abstraction as a visual aid at the beginning of the next class period.

DAY TWO

Evaluate: Share Out Designs and Discuss Benefits/Drawbacks (50 minutes)

13. Allow each team three minutes (or less) to concisely share their design. As students share, post their artifacts in the classroom for future reference and write the name of a device on a T-chart next to the artifact. (These materials could also be spread around the room on tables as well. The key is to make them accessible to students.)

14. When all teams have shared, instruct students to rotate through each device and record at least one benefit or drawback on each T-chart. If an idea is already present, the student should come up with a new different idea to record. Give students about five minutes to complete this step.

15. When most students have recorded their ideas, discuss some of the patterns or unique suggestions with a mindframe of ethics. **Note:** For a great background of ethics related CBI issues see the *Teacher Background & Resources* section of this lesson.

    Some suggested question starters:

    - What common benefits did you notice?
    - What common drawbacks?
    - Would you consider getting a BCI? Why or why not?
    - When should BCIs be allowed and when should they not be permitted?
    - Should BCIs be accessible wirelessly?
    - Who should have control of/ access to data recorded using a BCI (i.e., video, audio, movement records, GPS history, etc.)

16. During the last ten minutes of class, have students complete and turn in ***Student Handout 1.1: BCI Exit Ticket.***

STUDENT ASSESSMENT

Assessment Opportunities:

- Team abstractions can be assessed for demonstration of success criteria.
- Students' individual knowledge can be assessed using the provided Exit Ticket.

Student Metacognition:

- Students start with discussing and sharing pre-conceptual ideas during the warm-up activity on Day One.
- Following the video students continue to modify their ideas.
- Finally, students reflect upon what they have learned during an exit ticket closing activity.

Scoring Guide:

- For Success Criteria for the Abstraction, see ***Teacher Resources 1.2***.
- For an answer key for the BCI Exit Ticket, see ***Teacher Resources 1.4***.

EXTENSION ACTIVITIES

Extension Activities:

- Additional Research: Students can each research an example of a BCI and share with the class.

- Debate or Socratic Seminar: Students can debate an ethical issue related to BCIs such as "Who should own the data produced by a BCI?"or "Should BCIs be accessible wirelessly?" Another possibility is to read and discuss the article "Did I Do That? Brain-Computer Interface and the Sense of Agency" listed in the *Teacher Background & Resources* section of this lesson plan.

- Compare and Contrast: Students can be charged with defining how BCIs are similar to and different from other neuroprosthetic devices such as Deep Brain Stimulators, retinal implants, and cochlear implants.

Adaptations:

- Students can pretty much self-adapt this lesson based on the detail that they include in their abstraction and how elaborately they develop their design.
- ELL students can depend more on illustrations to share ideas and use an online dictionary or translator to help with vocabulary.

TEACHER BACKGROUND & RESOURCES

Background Information:

- A fairly indepth background of BCIs can be found on Wikipedia https://en.wikipedia.org/wiki/Brain%E2%80%93computer_interface and contains many links for further investigation.

- A great general primer on Brain Computer Interface written by one of the CSNE partners is "App Stores for the Brain: Privacy and Security in Brain-Computer Interfaces." Available from: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6893415&openedRefinements%3D*%26filter%3DAND(AND(NOT(4283010803))%2CAND(NOT(4283010803)))%26pageNumber%3D8%26rowsPerPage%3D50%26queryText%3D(brain-computer+interfaces+)

- If you would like to facilitate a lively discussion that is sure to engage your students, start with the article "Did I Do That? Brain-Computer Interface and the Sense of Agency." Use this article as a starting point for students to decide who should be held accountable for accidents involving BCIs.

Resources:

CBS News. "Breakthrough: Robotic limbs moved by the mind." *60 Minutes.* 30 Dec. 2012. Web https://www.youtube.com/watch?v=Z3a5u6djGnE

Citations:

Content Credits

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Student Handout 1.1: BCI Exit Ticket

Name:______________________________ Date:__________________ Period:__________

1. How has your understanding of BCIs changed during this activity?

2. How can BCIs be used to solve problems? What are some benefits of BCIs?

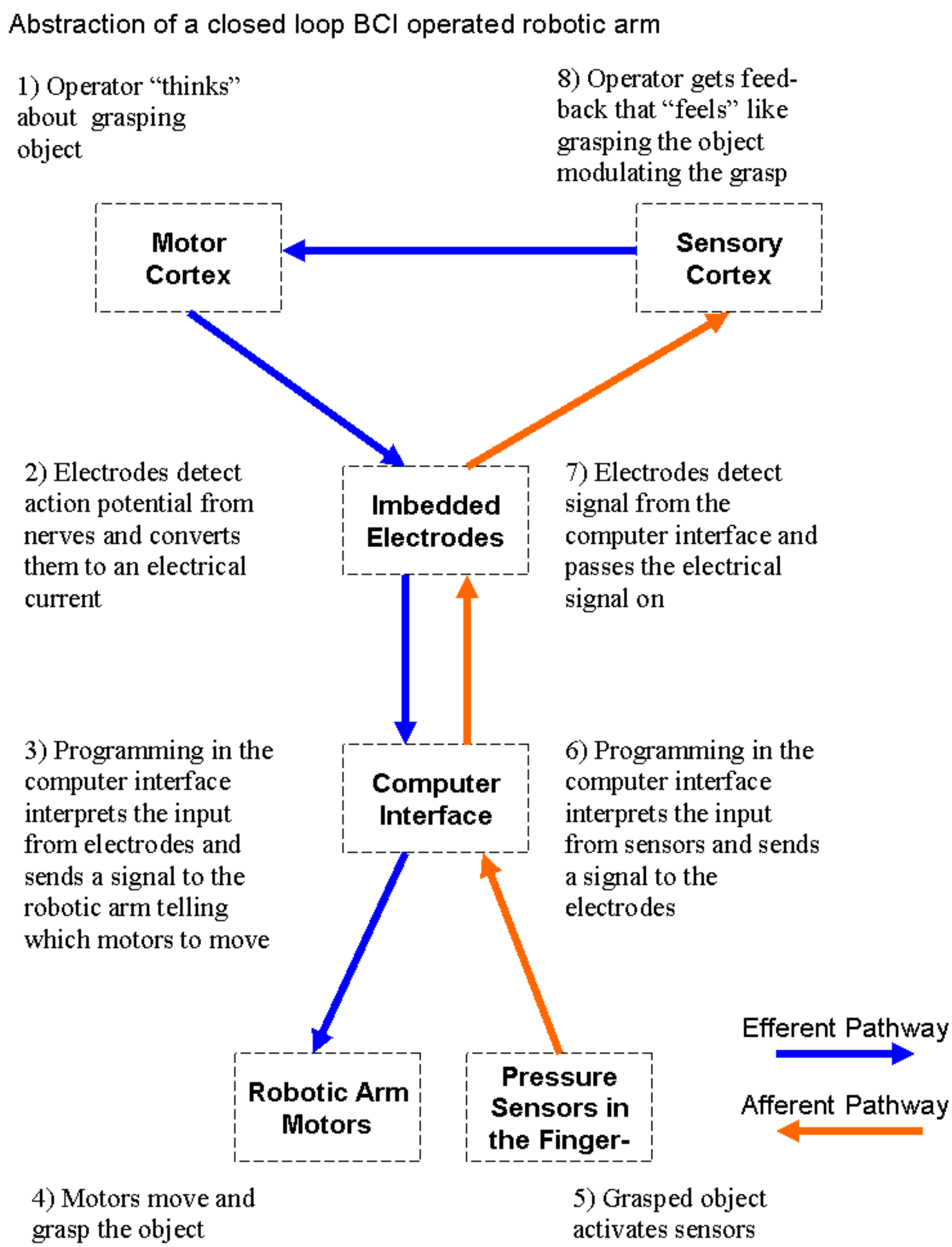
3. What are some potential drawbacks or harmful outcomes of BCIs?

4. If you were offered an opportunity for a BCI, would you accept it? Why or why not?

Teacher Resource 1.2: Abstraction Success Criteria

- Represents the operation of a BCI-based device.
- Clearly reflects the end user in its design.
- Filters out unnecessary details to focus on general patterns.
- Uses nodes to represent “objects” and “values”.
- Uses edges to represent “connections” and “processes”.
- Enough detail is provided to allow the artifact to stand on its own.
- Neat and well organized, easy to interpret and understand.
- Creative, stands out as an original design.

Teacher Resource 1.3: Robotic Arm Abstraction



Teacher Resource 1.4: BCI Exit Ticket--Answer Key

1. How has your understanding of BCIs changed during this activity?
   Accept any reasonable answer.

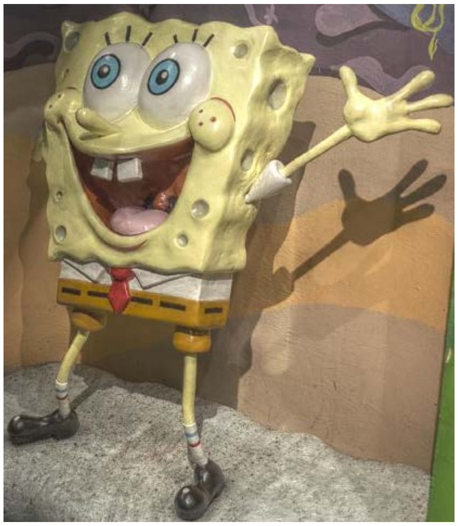
2. How can BCIs be used to solve problems? What are some benefits of BCIs?
   - BCIs can help people with disabilities gain more independence.
   - BCI devices could be used in situations that are too dangerous for people.
   - BCI devices could be used in places that people can't get to such as in a mine after a collapse.
   - BCI devices could be used to protect the environment such as monitoring oil pipelines or nuclear reactors.

3. What are some potential drawbacks or harmful outcomes of BCI?
   - BCIs could be weaponized.
   - BCIs have many ethical issues to consider such as privacy and security.
   - We don't know all of the potential consequences or side effects of long-term neurological implants.
   - Some might use BCIs for enhancement.

4. If you were offered an opportunity for a BCI, would you accept it?
   Why or why not?
   Accept any reasonable answer supported with evidence.

Teacher Resource 1.1: User Identity Cards

Hi, I'm SpongeBob! I love working as a fry cook at the Krusty Krab, catching jellyfish, and practicing karate. I am very active and prone to suffering cartoon levels of violence.



Hello, my name is Sherlock Holmes. I am a high-functioning sociopath who uses his wit to catch criminal masterminds. I love mysteries, playing the violin, and smoking tobacco heavily from my pipe.

I'm Batman. I am an expert in martial arts, gadgets, and inheriting fortunes. I fight crime in Gotham while battling the darkness within my own brooding soul.

Greetings, I am King Henry VIII of England. I am having a great degree of difficulty producing a son and heir with the half dozen wives whom I have cycled through. To make things worse, all of these divorces and consequent battles with the Pope have elevated my stress and food intake. I now find myself losing my athletic physique and time to produce a son. It is not always great to be king.

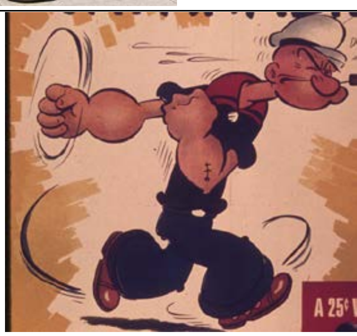
Hello, my name is Poseidon and I've recently left the pantheon to become an extreme scuba instructor. I teach my students how to perform difficult tasks such as welding and pipeline repair while underwater. It is important that I can see all of my students, communicate with them underwater and operate equipment in a safe manner.

Hey, I'm the Pink Panther. I am mute, sophisticated, mischievous, and inventive. I enjoy playing hijinks on The Detective, adventuring around the world (and even through time!), as well as strutting to jazzy rhythms.

Teacher Resource 1.1: User Identity Cards

It's a-me, Mario! I love Peach, but rescuing her exposes me to fire, lava, ice, and intense physical exertion. From impossibly high altitudes to the depths of the ocean, my surroundings pose a serious challenge to my resolve to remain agile, alive, and devoted to my sweetheart.

Hello, my name is Alice. I enjoy napping and talking to my cat, Dina. I am very confident and adventurous, even though my anxiety-inducing undertakings are nothing more than inventions of my own mind. Some people say that I suffer from mental illness, but I say that I just have a vivid, sometimes hallucinogenic, imagination.



I'm Popeye the sailor man
I'm strong to the fin-ich
'Cause I eats me spin-ach
I'm Popeye the sailor man

Nutrition is important to me in order to keep my muscles in top form to protect Olive. Still, life on the sea exposes me to harsh conditions and scurvy. Speaking of which, I may or may not be suffering from exposure to radioactive spinach.

I am Smaug. While I enjoy my cave where I live among all the gold from the once mighty Dwarf kingdom of Erebor, I find the lifestyle to be cramped and lonely. The threat of someone stealing my treasures leaves me constantly anxious and furious, which leads to unbearable headaches and distress.

Lesson Two: Introduction to the Neural Network
Reading Assignment

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

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary:
In this lesson, students will explore the idea of modeling a neural network using content based reading strategies. Students will read an article about a model of the worm nervous system and evaluate different pictorial abstractions present in the model.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- **Scientific Communication:** Scientists use specific terminology and formats to communicate information

Essential Question:

- How can computational models and simulations help generate new understanding and knowledge?

Learning Objectives:
Students will know…

- That a neural network is constructed of neurons and their synaptic connections and can be modeled using a connectome.
- That computer programs can simulate the brain's decision making processes.

Students will be able to…

- Read and extract useful information from a technical or science based text and use text based details as evidence.
- Use images and diagrams to support reading comprehension.

Vocabulary:

- AI (Artificial Intelligence)
- Connectome
- Effectors
- Excitatory
- Inhibitory
- IP and Port Number

- Motor Neuron
- Sensors
- UDP packets

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

NGSS Disciplinary Core Ideas (DCIs)
- **ETS1-3:** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints.

NGSS Crosscutting Concepts
- System and system models

Science & Engineering Practices
- Engaging in argument from evidence
- Obtaining, evaluating and communicating information

Common Core State Standards
- **RST.11-12.1:** Cite specific textual evidence to support analysis of science texts.
- **RST.11-12.2:** Determine the central ideas or conclusions of a text; summarize complex concepts, processes or information presented in a text.
- **RST.11-12.8:** Determine the meaning of symbols, key terms, and other domain specific words and phrases as they are used in a specific scientific context.
- **WHST.11-12.9:** Draw evidence from informational texts to support analysis, reflection and research.

MATERIALS

Material	Description	Quantity
Robot Thinks It's a Worm video	The Know, 2014, 2:23 minutes. Available from https://www.youtube.com/watch?v=fRC6xjU1XRg	1
Student Handout 2.1	*Worm's Mind in a Lego Body Article*. A two-page article describing the "Open Worm" project, http://www.i-programmer.info/news/105-artificial-intelligence/7985-a-worms-mind-in-a-lego-body.html	1 copy per student
Student Handout 2.2	*Worm's Mind in a Lego Body Article—Analysis Questions.* Uses CCSS questions threads.	1 copy per student

Timer	Used to manage segments of activity	1 per classroom
Science Notebooks	Students' science notebooks or journals	1 per student
Media Center	Classroom media equipment including computer with internet connection, speakers, and projector, for showing the introductory video.	1 media center

TEACHER PREPARATION

Preparation:
1. Pre-check video and multimedia equipment.

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

3. Gather supplies.

PROCEDURE

Engage: Worm's Mind in a Lego Body Video *(10 minutes)*

1. Play video for students.

2. Give students three minutes of Private Think Time (PTT) to make a list of at least five questions raised from the video.

3. Give students two minutes to turn and talk and share their list of questions with a partner.

4. Select two or three students to share questions with the class. You might want to write the questions on a whiteboard or poster as an artifact to return to later in the unit.

Explore: Pre-read (5 minutes)

5. Handout copies of ***Student Handout 2.1*** to each student. Allow students three minutes of PTT to "pre-read" or scan the article for the theme. **Note:** This isn't enough time to thoroughly read the article on purpose. It forces students to take a moment to preview the headings and images before reading the article for details. DO NOT PASS OUT THE QUESTIONS YET, otherwise students will just jump to answering the questions and ignore the pre-read steps.

6. Give students 60 seconds to turn and talk about what they identified as the theme. Then have several students share with the class.

Explain: Deep Read (20 minutes)

7. Handout a copy of ***Student Handout 2.1*** to each student.

8. Allow students 20 minutes of PPT to deeply read the article and answer the questions.

Elaborate and Evaluate: Share and Revise (15 minutes)

9. Assign students to groups of three or four to share out responses and supporting evidence using text based details.

10. One student in each group should lead by reading the first question followed by his or her response. Each student in the group should then add his or her details to the response or ask a clarifying question until all students have shared.

11. The next student should lead question #2 and continue rotating until all questions have been discussed.

12. Students should be encouraged to edit or revise responses as new ideas are shared.

13. Either remind students to save the article for the next class's lesson or collect the articles from students and redistribute at a later date when needed.

STUDENT ASSESSMENT

Assessment Opportunities:

- Student understanding of the article can be evaluated by collecting and evaluating their written responses to the question stems. (See ***Teacher Resource 2.1*** for potential responses).
- Evaluation of student conversations during the discussion portion may be used as well.

Student Metacognition:

- Students will complete the reading activity individually and then will discuss each question in a small group. As students talk through their ideas and evidence, students will revise and edit responses to include new information and understanding.
- While discussing the article, students may choose to add details to the answer, or ask a clarifying question providing an opportunity for students to evaluate their own responses.

Scoring Guide:

- See ***Teacher Resource 2-1: Worm's Mind in a Lego Body Analysis Questions—Answer Key***.

EXTENSION ACTIVITIES

Extension Activities:

- Advanced Research: Students can find more information about this project including open source code at www.openworm.org.

- Math Connection: Students can use math to calculate the number of nodes and edges required to model different animal brains and assign the problem the appropriate "O notation".

- Reflection: Re-visit questions from the warm-up and see if any have been answered through this reading exercise. Have students find answers to the others and report back to the class.

- Connect to Prior Learning: Revisit the previous lesson's discussion of ethics. Apply those same questions to this new topic.

Adaptations:

There is a less technical version of an article from Smithsonian magazine found here that may be useful for younger audiences or for students requiring a less technical vocabulary.

> **We've Put a Worm's Mind in a Lego Robot's Body**
> November 19, 2014, Smithsonian.com
> http://www.smithsonianmag.com/smart-news/weve-put-worms-mind-lego-robot-body-180953399/

TEACHER BACKGROUND & RESOURCES

Background Information:

Wikipedia gives a pretty detailed overview of Artificial Neural Networks https://en.wikipedia.org/wiki/Artificial_neural_network

Resources:

The Know. *Robot Thinks it's a Worm.* YouTube. November 18, 2014. Available online at https://www.youtube.com/watch?v=fRC6xjU1XRg

Citations:

Black, Lucy. *Worm's Mind in a Lego Body.* i-Programmer. November 16, 2014. Available online at http://www.i-programmer.info/news/105-artificial-intelligence/7985-a-worms-mind-in-a-lego-body.html

Fessenden, M. "We've Put a Worm's Mind in a Lego Robot Body." Smithsonian Magazine. 19 Nov. 2014. Available online at http://www.smithsonianmag.com/smart-news/weve-put-worms-mind-lego-robot-body-180953399/#Vgyfi5OWDJVp0DLY.99

Massachusetts Institute of Technology. “OpenWorm website” 2011. Available online at www.openworm.org

The Know. *Robot thinks it’s a worm.* YouTube. November 18, 2014. Available online at https://www.youtube.com/watch?v=fRC6xjU1XRg

Wikipedia contributors. "Artificial neural network." *Wikipedia, The Free Encyclopedia*. Wikipedia, The Free Encyclopedia, 31 Jul. 2015. Web. 3 Aug. 2015. https://en.wikipedia.org/wiki/Artificial_neural_network

Student Handout 2.2: Worm's Mind in a Lego Body—Analysis Questions

Name:______________________________ Date:__________________ Period:__________

1. Briefly summarize the theme of this article.

2. What evidence from the article supports the idea that "computational models and simulations help generate new understanding and knowledge" especially related to our topic of brain-computer interface? Use text based details to support your ideas.

3. How was the worm's neural network modeled by the robot in the article? What did each of the following parts represent?

   a. Sensors

   b. Wires

   c. Computer programming

   d. Motors

4. The word "connectome" is used several times in the article. Using text based details, write a definition of connectome.

5. Describe several strengths and weaknesses of this model's design.

Teacher Resource 2.1: Worm's Mind in a Lego Body—Analysis Questions—Answer Key

1. Briefly summarize the theme of this article.
   This article is about a project that used a Lego robot to represent a worm and its neural network. It explains the basics of how the robot was designed and works.

2. What evidence from the article supports the idea that "computational models and simulations help generate new understanding and knowledge" especially related to our topic of brain-computer interface? Use text based details to support your ideas.
   It is helping researchers answer the question "are we just the sum of our neural networks?" and provides an opportunity to see what happens when a physical model of a neural network is developed for a worm. The worm is used as it has a much smaller network than a human since it only has 302 neurons.

3. How was the worm's neural network modeled by the robot in the article? What did each of the following parts represent?

   e. Sensors- senses such as touch, taste and site
   f. Wires- neural connections, synapse, nerves
   g. Computer programming- the worm's brain, ganglion, processing center, decision making
   h. Motors- muscles, reflexes

4. The word connectome is used several times in the article. Using text based details, write a definition of connectome.
   Connectome is another word for the worm's neural network. The article says "take the connectome of a worm and transplant it as software", so it has to be what is being modeled by the software—which is all of the neurons in the worm's body.

5. Describe several strengths and weaknesses of this models design.
   Accept any reasonable response.
   Strength: The robot reacts to stimulus, somehow represents all 302 neurons of the worm, input leads to similar output, helps make predictions
   Weakness: "Food sensor" doesn't actually sense food, motor neurons all attach to one motor on each side instead of many different muscles that have to work together to move the worm. Worm has other types of senses such as heat/cold...not in the article, too simple to model a human connectome

Student Handout 2.1: Worm's Mind in a Lego Body Article

Name:______________________________ Date:__________________ Period:__________

A Worm's Mind In A Lego Body

Written by Lucy Black, i-Programmer Sunday, 16 November 2014

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Take the **connectome** of a worm and transplant it as software in a Lego Mindstorms EV3 robot - what happens next?

It is a deep and long standing philosophical question. Are we just the sum of our neural networks? Of course, if you work in AI you take the answer mostly for granted, but until someone builds a human brain and switches it on we really don't have a concrete example of the principle in action.

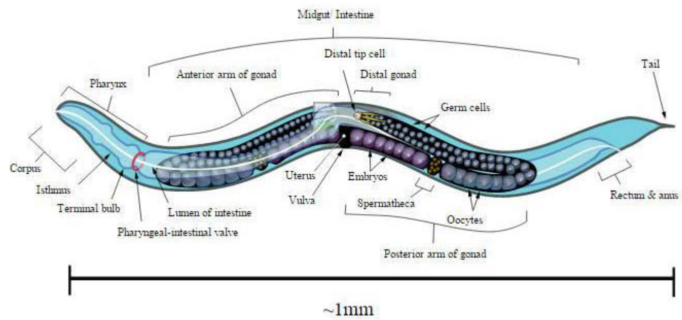


Figure 1: *C. elegans* anatomy

The nematode worm *Caenorhabditis elegans* (*C. elegans*) is tiny and only has 302 neurons. These have been completely mapped and the OpenWorm project is working to build a complete simulation of the worm in software. One of the founders of the OpenWorm project, Timothy Busbice, has taken the **connectome** and implemented an object oriented neuron program.

The model is accurate in its connections and makes use of UDP packets to fire neurons. If two neurons have three synaptic connections then when the first neuron fires a UDP packet is sent to the second neuron with the payload "3". The neurons are addressed by IP and port number. The system uses an "Integrate and fire" algorithm. Each neuron sums the weights and fires if it exceeds a threshold. The accumulator is zeroed if no message arrives in a 200ms window or if the neuron fires. This is similar to what happens in the real neural network, but not exact.

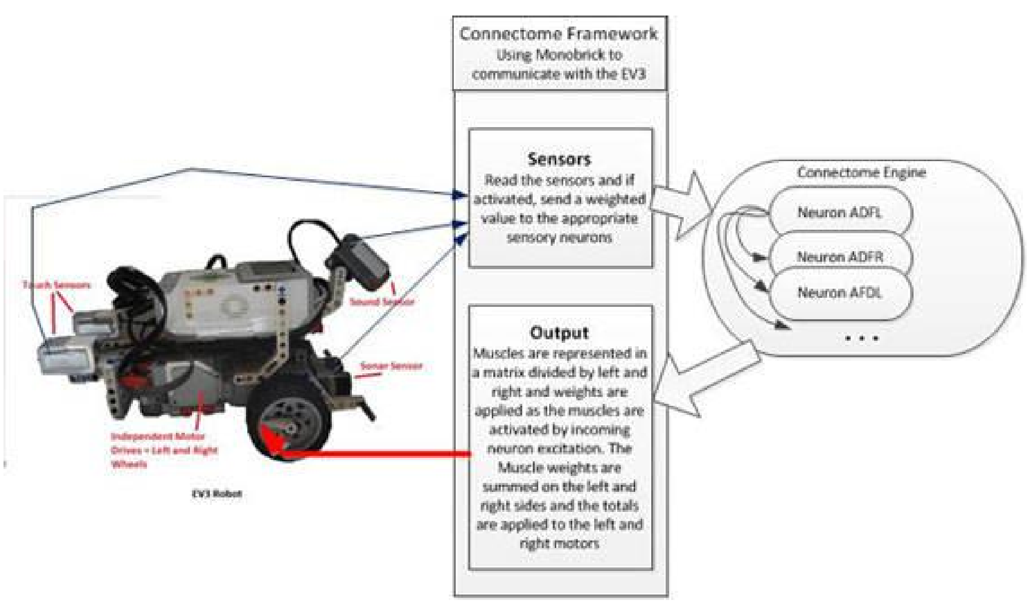


Figure 2: High-level block diagram of Connectome Framework

The software works with sensors and effectors provided by a simple LEGO robot. The sensors are sampled every 100ms. For example, the sonar sensor on the robot is wired as the worm's nose. If anything comes within 20cm of the "nose" then UDP packets are sent to the sensory neurons in the network.

The same idea is applied to the 95 motor neurons but these are mapped from the two rows of muscles on the left and right to the left and right motors on the robot.

The motor signals are accumulated and applied to control the speed of each motor. The motor neurons can be **excitatory or inhibitory** and positive and negative weights are used.

And the result?

It is claimed that the robot behaved in ways that are similar to observed *C. elegans*. Stimulation of the nose stopped forward motion. Touching the anterior and posterior touch sensors made the robot move forward and back accordingly. Stimulating the food sensor made the robot move forward.

The key point is that there was no programming or learning involved to create the behaviors. The **connectome** of the worm was mapped and implemented as a software system and the behaviors emerge.
The **conectome** may only consist of 302 neurons but it is self-stimulating and it is difficult to understand how it works - but it does.

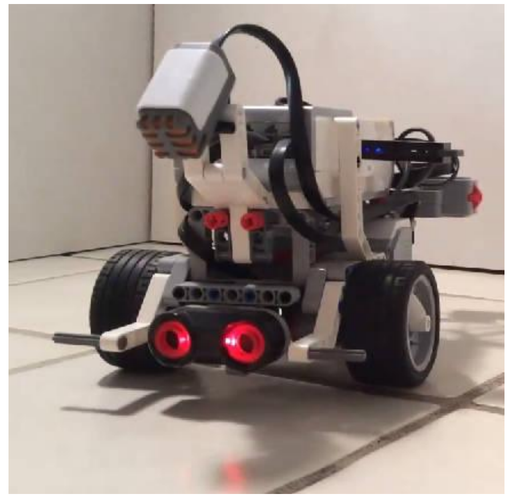
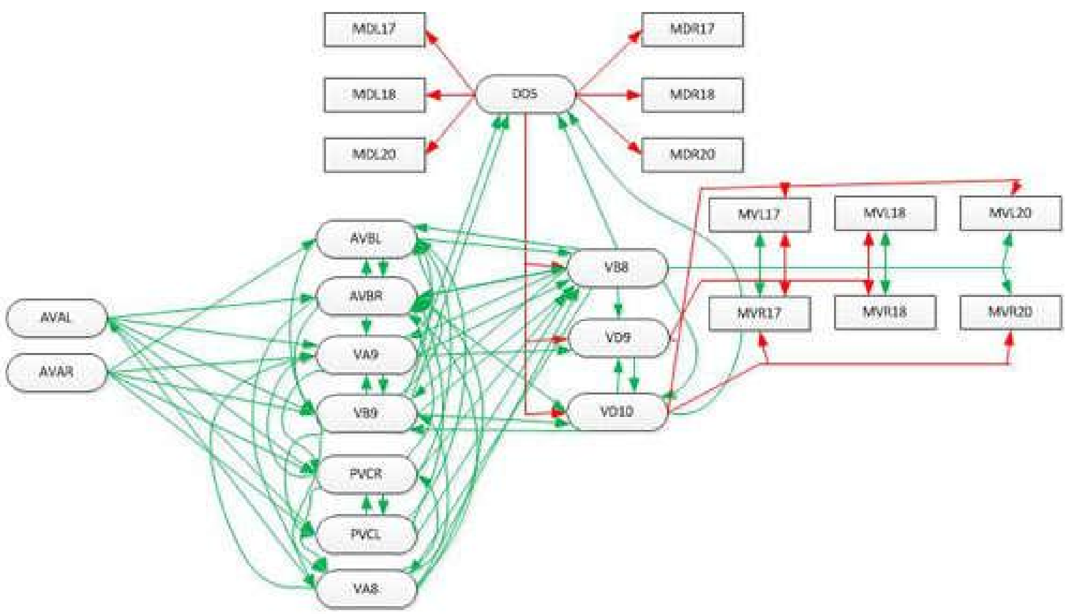


Figure 3: Completed robot model



Currently the **connectome model** (modeled above) is being transferred to a Raspberry Pi and a self-contained Pi robot is being constructed. It is suggested that it might have practical application as some sort of mobile sensor - exploring its environment and reporting back results. Given its limited range of behaviors, it seems unlikely to be of practical value, but given more neurons this might change.

Is the robot a *C. elegans* in a different body or is it something quite new?

Is it alive?

These are questions for philosophers, but it does suggest that the ghost in the machine is just the machine.

For us AI researchers, we still need to know if the principle of implementing a **connectome** scales at the levels needed to model more advanced organisms such as humans.

Lesson Three: Abstraction

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

LESSON OVERVIEW

Activity Time: Two 50 minute class periods.

Lesson Plan Summary: In this lesson, students will practice abstraction skills as a class by using ideas from the "Worm's Brain in a Lego Body" article (introduced in *Lesson Two*) to abstract their design challenge problem and refine constraints. In addition, students will define and prioritize "success criteria" for the project to evaluate their designs.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- **Abstraction:** Abstraction reduces information and detail to facilitate focus on relevant concepts.

Essential Question:

- How does abstraction help us in writing programs, creating computational artifacts, and solving problems?

Learning Objectives:

Students will know…

- An abstraction is a simplified model of a problem that reduces the system to nodes (objects, inputs, or outputs) and edges (connections or processes) to help make the problem more manageable.
- Abstractions should focus on general patterns needed to solve the problem and not specific details.

Students will be able to…

- Identify and prioritize constraints to solving a problem.
- Use abstraction to simplify a problem.

Vocabulary:

- Abstraction
- Constraint
- Criteria
- Edge
- Input
- Motor
- Node

- Output
- Processor
- Sensor

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

NGSS Disciplinary Core Ideas (DCIs)

- **HS-ETS1-1:** 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:** 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:** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints**.**

Crosscutting Concepts

- System and system models

Science & Engineering Practices

- Asking questions and defining problems
- Developing and using models

Common Core State Standards

- **RST.11-12.9:** Synthesize information from a range of sources into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

MATERIALS

Material	Description	Quantity
Materials for brainstorming	White boards, markers, poster paper or other brainstorming materials.	1 per group
Scissors and glue/tape	To add graphics to graphic organizer.	1 per group
Examples of abstractions	Robotic arm abstraction from *Lesson One*, computer science text, Worm article, or see *Teacher Background & Resources* section for additional sources.	Several different examples per class
SparkFun Inventor's Kit Handbook	Should be included with Arduino kits but can also be downloaded from Sparkfun.com.	1 per team

Student Handout 2.1	*Worm's Brain in a Lego Body Article*, from *Lesson Two*	1 per student
Student Handout 3.1	*Abstraction Graphic Organizer*. Resource to scaffold abstraction activity.	1 per student
Student Handout 3.2	*Engineering Design Challenge.* Provides the context and problem for the challenge	1 per student
Teacher Resource 3.1	*Abstraction Graphic Organizer—Answer Key*	1

TEACHER PREPARATION

1. Locate copies of ***Student Handout 2.1:*** *Worm's Brain in a Lego Body Article* from *Lesson* Two if you collected them at the end of the lesson.

2. Make copies of ***Student Handout 3.1:*** *Abstraction Graphic Organizer*, one per student. These two pages can be printed front and back or on two different sheets of paper.

3. Also make copies of ***Student Handout 3.2:*** *Engineering Design Challenge*, one per student. You may want to provide additional constraints such as the number of Arduino nodes available or a time constraint as the "CEO has already booked a flight for your team to pitch your design on ________"

4. Gather supplies.

5. Post artifacts from prior abstracting activities (assuming that this is not the first attempt at abstraction in the computer science class); otherwise post the robotic arm abstraction from *Lesson One* and point out the two different abstractions in the "Worm's Brain in a Lego Body" article.

PROCEDURE

Engage: (2 minutes)

1. Either return copies of ***Student Handout 2.1:*** *Worm's Brain in a Lego Body* Article or have students locate their copy from *Lesson Two*. Distribute copies of ***Student Handout 3.1:*** *Abstraction Graphic Organizer.*

2. Inform students that today they will be preparing for an Engineering Design Challenge where they will be designing their own model of a neural network. To prepare for that, they need to understand the Lego Worm model with more detail than in the previous lesson.

Explore: (10 minutes)

3. Instruct students that they have five minutes of Private Think Time (PTT) to scan the article and identify **inputs, outputs, and computational processes** present in the Lego worm model to complete the first question on the graphic organizer. Remind students to not only review the text, but also the figures.

4. After five minutes have passed, ask students for a fist of five to show how close they are to completing the task. (0 = done and 5 = need 5 more minutes). Allow a few more minutes if students need more time.

5. As students work, monitor student progress while walking around the room. Select students to record specific ideas on a larger version of the graphic organizer posted in the classroom such as on a whiteboard, elmo projector, or poster paper. Be sure to select a variety of general patterns and specific details.

Explain: (15 minutes)

6. Once most the students are finished and more importantly when you have a diverse set of ideas on the class organizer, call students' attention to the classroom artifact.

7. Remind students that abstraction is used to define a problem by focusing on the most important patterns and ignoring specific details until later.

8. Read through each of the ideas that are present in the class version of the graphic organizer. Have students identify if the idea is a "specific detail" or a "general pattern" by raising hands to vote. If there is a split vote, call on one or more students from each perspective to explain how they made the decision to categorize the idea as a pattern or detail. Clarify any misconceptions and then re-vote. (See ***Teacher Resource 3.1:*** *Abstraction Graphic Organizer—Answer Key* for ideas).

9. Cross out the specific details and circle the general patterns on the classroom organizer. Have students return to their own lists and do the same.

10. The "Worm Mind in a Lego Body" article illustrates two different types of "high level" abstractions. *Figure 2* is a block diagram (like the abstractions that were made is Lesson #1) and *Figure 4* uses nodes and edges to represent the same information.

11. Instruct students to cut out and glue *Figure 4* into the abstraction step of their graphic organizer. This will provide an example to refer to as students construct their own abstraction. Students should identify and circle the nodes that represent each of the different components identified in Step 1. (The direction of the arrows will help.)

12. Explain to students that abstraction of a neural network often contains three layers: an input layer, a hidden "decision" layer, and an output layer. We will be using this format to abstract our own neural network design. (For examples of three-layer abstractions

see the wikipedia article mentioned in the *Teacher Background & Resources* section.) You should provide students with a visual example on the whiteboard, poster paper, or other visual aid.

Elaborate: (20 minutes)

13. Explain to students that they now have the background information needed to design their own neural network. Provide each student with a copy of ***Student Handout 3.2:*** *Engineering Design Challenge*. Allow students three to five minutes of PTT to read about the Engineering Design Challenge and write a one or two sentence summary of the problem on the second copy of the ***Student Handout 3.1:*** *Abstraction Graphic Organizer*.

14. Give students an additional five minutes of PTT to thoughtfully consider the problem and make a list of inputs, outputs, and computational processes just as we completed before for the worm model. Tell students to include both general patterns and specific details just like before. You may want to provide students with copies of the Arduino Inventor's kit handbook or a copy of the inventory list so that they have an idea of what components are available.

15. Next have students take turns in small groups or pairs sharing their lists with each other. Ask a few students to share out for the class to ensure that all the important components have been mentioned. For ideas, see ***Teacher Resource 3.1:*** *Abstraction Graphic Organizer—Answer Key.*

16. Again, just as before with the worm model, have students filter their list to just the most general components of the design challenge. This can be accomplished individually, in pairs, or small groups. Allow students three to five minutes to identify the key components and circle them on their copy of the organizer.

17. Select a few students/groups to share-out their list. As students make suggestions, record them on the whiteboard or other visual aid. Ask the rest of the class for feedback—additions? edits? revisions?—until as a class they reach a consensus. You may want to tell them that since each group will be designing one of the components of the system, they all need to agree on what the final product will look like.

18. Depending on your students experience with node and edges abstraction and your time constraints, this step can be handled at a variety of levels of support.

    - For **experienced students** or those with flexible time: Have small groups draft abstractions and then share with the class. Facilitate a discussion that integrates the strengths of each design into one abstraction for the class.
    - For **less experienced students** or those who have more constrained time limits: Provide an empty three level abstraction such as provided in the Wikipedia article

and have students annotate the illustration. Followed by a discussion that integrates the strengths of each design into one abstraction for the class.

- In the case that this is your student's **first attempt at abstraction**: You can start by facilitating a class discussion and making an abstraction on the whiteboard or other visual aid and then have students copy it onto their graphic organizer. See ***Teacher Resource 3.1:*** *Abstraction Graphic Organizer—Answer Key* for ideas.

19. Remind students that nodes should include all of the "objects" like inputs, outputs, and computational processes and edges would be simulating wires that form all of the connections. Also remind them that each node in the hidden layer should connect to all the inputs, but only two outputs; this requires decision making at each node. The initial abstraction should be fairly simple framework. Additional detail and annotation can be added after determining the criteria and constraints.

Evaluate: (50 minutes)

20. Allow students ten minutes of PTT to review ***Student Handout 3.2:*** *Engineering Design Challenge* and make a list of potential criteria and constraints. Remind students that criteria establish guidelines for judging the success of their design and that constraints provide boundaries that set limits on the design. Encourage students to think beyond what is written on the handout. You might provide one of the examples from ***Teacher Resource 3.1:*** *Abstraction Graphic Organizer—Answer Key* to get them started.

21. As students work monitor them for interesting and unique ideas. Send individual students to the whiteboard (or other such visual aide) to record one of his or her ideas on a class version of the Criteria/Constraints table.

22. When you have acquired a diverse variety of ideas on the class table, draw everyone's attention to the visual aid. Give each student five small dot stickers or a whiteboard marker. Instruct students to pick their top five criteria and place a dot next to that criteria on the whiteboard. Explain that we will be using their votes to prioritize which criteria are most important. Spend a few minutes reading and clarifying each criteria and then give students a few minutes to vote.

23. Once all students have voted, count the number of votes received by each criteria. Number the top five starting with 1= greatest number of votes. Have students record this list in order on their graphic organizer or keep the artifact posted in the classroom to refer to during the evaluation and reflection portion of the lesson.

24. Now that the class has agreed on the criteria that will be used to judge their design, students will need to add some details to their abstraction such as what sensors will trigger which outputs, what "signal" will be sent from inputs to the hidden layer and from the hidden layer to outputs. See ***Teacher Resource 3.1:*** *Abstraction Graphic Organizer—Answer Key* for ideas. Remind students that each team will be picking one

node to design and construct, so it is very important for every team to understand how the network will work together.

25. Don't be too worried about getting every detail annotated; remember that students need to practice communicating with each other and working in teams. Missing details will show up during design and testing and students can address them at that time. You just want to make sure that there is enough information that teams have an idea of how each node interacts with the others. As problems arise, have teams go back to the class abstraction and refine the information presented there, that way when a similar issue arises from other teams, they can be referred to the abstraction just like these types of problems are solved in real life.

STUDENT ASSESSMENT

Assessment Opportunities:

- Student graphic organizers can be evaluated for completion and accuracy.
- Students may also be assessed based on classroom observations of engagement and participating in discussions.

Student Metacognition:

- In this lesson, students are working together to construct an abstract for the Engineering Design Challenge. Students have many opportunities to think about and share ideas during the process.
- Students record ideas on a graphic organizer and are encouraged to make changes, revisions and edits throughout the lesson as they evaluate their own understanding.

Scoring Guide:

- See ***Teacher Resource 3.1:*** *Abstraction Graphic Organizer Answer Key*.

EXTENSION ACTIVITIES

Extension Activities:

- More Networking Activities: Teach Engineering has a Networking unit https://www.teachengineering.org/view_curricularunit.php?url=collection/jhu_/curricular_units/jhu_cnetworks_unit.xml

- Modify the Challenge: Depending on the time constraints, available materials, and student skill level, add complexity to the design challenge such as requiring weighted inputs, modeling excitatory and inhibitory neurons, or adding additional tasks requiring additional sensors or responses**.**

- Class Discussion: Facilitate a discussion or Socratic seminar addressing the questions raised at the end of the "Worm in a Lego Body" article. Is the robot a *C. elegans* in a different body or is it something quite new? Is it alive?

Adaptations:

- Abstraction is great at reducing a complex problem to a manageable level so that every student can identify the core components and interconnections of the system.
- Reduce the vocabulary so that younger or ELL students can understand the concepts using a thesaurus or translation app.
- Have students draw sketches of each component (as the node instead of just a circle) to clearly communicate understanding.
- A translated version of the Wikipedia article can also be provided to ELL students by selecting the appropriate language from the Wikipedia home page.

TEACHER BACKGROUND & RESOURCES

Background Information:

- Wikipedia gives a pretty detailed overview of Artificial Neural Networks with some great images of abstractions that would be useful as examples for students. https://en.wikipedia.org/wiki/Artificial_neural_network

- This activity focuses on the "high-level" abstraction necessary to break down a complex system into more manageable subsystems that can be designed independently of each other and then integrated together. "Low-level" abstraction of algorithms or within programming is not a focus, however could be included. A more in-depth and academic background with examples of abstractions can be found in this Foundations of Computer Science text available free online. http://infolab.stanford.edu/~ullman/focs.html

- For a great explanation of how to set up an engineering design challenge of your own, check out the It's About Time's blog by Cary Sneider. http://blog.iat.com/2014/03/12/science-vs-engineering-expert-untangles-curriculum-conundrum/

Resources:

- Examples of abstractions from https://en.wikipedia.org/wiki/Artificial_neural_network

- Electronic version of the SparkFun Inventor's Kit handbook is available at https://cdn.sparkfun.com/datasheets/Kits/RedBoard_SIK_3.2.pdf

Citations:

Aho, A. and Ullman, J. "Foundations of Computer Science." Out of Print. Available online at http://infolab.stanford.edu/~ullman/focs.html

Black, Lucy. *Worm's Mind in a Lego Body.* I Programmer. November 16, 2014. Available online at http://www.i-programmer.info/news/105-artificial-intelligence/7985-a-worms-mind-in-a-lego-body.html

Brain-Controlled Prosthetic Arm Photograph. FDA (https://flic.kr/p/9gFr4x) [Public domain], via Wikimedia Commons.

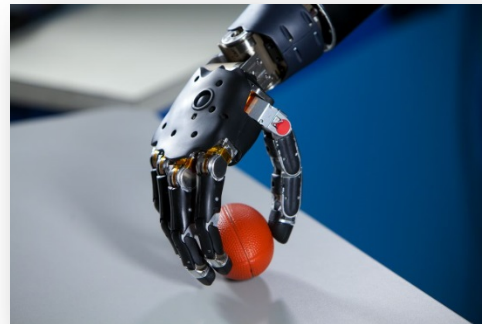
Burnett. C.M.L. as published by Wikipedia contributors. "Artificial neural network." *Wikipedia, The Free Encyclopedia*. 31 Jul. 2015. Web. 3 Aug. 2015. https://en.wikipedia.org/wiki/Artificial_neural_network under GNU Free Documentation License

Sneider, C. *Science vs. Engineering: An Expert Untangles a Curriculum Conundrum.* It's About Time. 12, Mar. 2014. Available online at http://blog.iat.com/2014/03/12/science-vs-engineering-expert-untangles-curriculum-conundrum/

Wikipedia contributors. "Artificial neural network." *Wikipedia, The Free Encyclopedia*. Wikipedia, 31 Jul. 2015. Web. 3 Aug. 2015. https://en.wikipedia.org/wiki/Artificial_neural_network

Student Handout 3.2: Engineering Design Problem

Name:______________________________ Date:__________________ Period:__________



Your client, a neuro-prosthetic designer, has hired your team to help improve the safety features of their BCI-controlled robotic arm. They would like to improve their customers' independence to include daily tasks such as cooking, cleaning, and other household chores but are concerned that a lack of environmental feedback may cause their customers physical harm from accidents such as spilling boiling water on themselves or catching the arm on fire.

Challenge:
Construct a three-level model neural network that will detect a dangerous condition such as a hot or burning object and respond with a warning and releasing the object or moving away from the source of danger. The network needs to be able to determine when a situation is truly dangerous by integrating information from more than one sensor at a time.

Constraints:
Your client has provided a toolkit of sensors and other components that they currently use in their neuro-prosthetic devices that they would like you to work from as they already have a reliable and quality controlled manufacturing source, however they warn that the BCI can only support up to three inputs and outputs at a time due to the wiring already in the equipment.

They further state that for the purpose of this model, you don't have to actually move a robotic arm as they have another team of experts working on that, you just need to get a signal to a single motor for the gripper and a single motor for the elbow in order for them to integrate your design into their current hardware.

Image credit: FDA (https://flic.kr/p/9gFr4x) [Public domain], via Wikimedia Commons.

Student Handout 3.1: Abstraction Graphic Organizer

Name:______________________________ Date:__________________ Period:__________

Problem: Model the neural network of a *C. elegans* worm using a Lego robot.

Step 1: Identify components of the problem

Inputs	Computational Processes	Outputs

Step 2: Filter out specific details to highlight the general patterns needed to solve the problem

Cross out the specific details in your lists from step 1

Circle or highlight the general patterns

Step 3: Abstract the identified components

Abstraction Graphic Organizer

State the Problem:

Step 1: Identify components of the problem

Inputs	Computational Processes	Outputs

Step 2: Filter out specific details to highlight the general patterns needed to solve the problem

Cross out the specific details in your lists from step 1

Circle or highlight the general patterns

Step 3: Abstract the identified components (attach a separate diagram if needed)

Step 4: Identify Criteria and Constraints

Criteria	Constraints

Teacher Resource 3.1: Abstraction Graphic Organizer—Answer Key

Name:_______________________________ Date:__________________ Period:__________

Abstraction Graphic Organizer

<u>Problem: Model the neural network of a *C. elegans* worm using a Lego robot.</u>

Step 1: Identify components of the problem

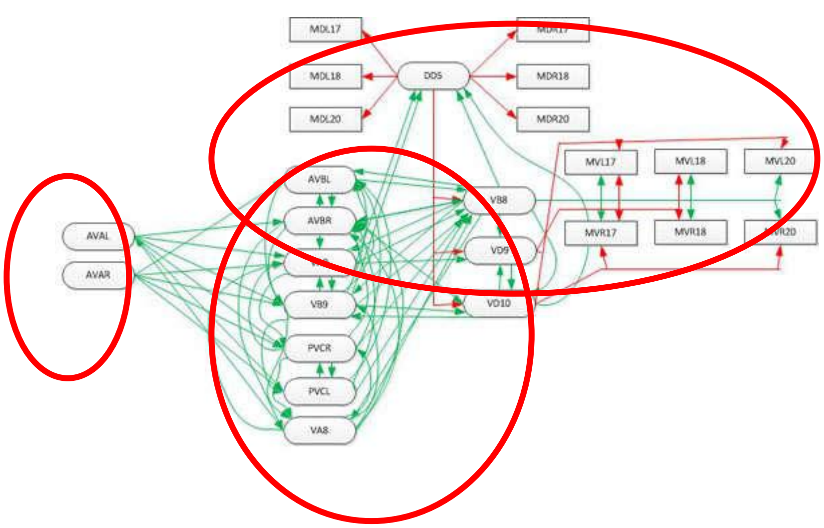
Inputs	Processes	Outputs
Sensors ~~Touch Sensor~~ ~~Food Sensor~~ ~~Sonar~~ ~~Sample every 100ms~~ ~~Sensory neurons~~	~~Object oriented neuron program~~ ~~Integrate and Fire Algorithm~~ Connectome Engine ~~Accumulator~~ Software system	~~effectors~~ ~~95 motor neurons~~ ~~R and L motors~~ ~~"behaviors"~~ Speed up/slow down motors

Step 2: Filter out specific details to highlight the general patterns needed to solve the problem

Cross out the specific details in your lists from step 1

Circle or highlight the general patterns

Step 3: Abstract the identified components



Abstraction Graphic Organizer

Problem: Construct a three- layered neural network that improves the safety of a prosthetic robotic arm by using sensors to identify dangerous conditions in the environment.

Step 1: Identify components of the problem

Inputs	Processes	Outputs
Sensors	~~Decide if it is hot~~	~~Yelping~~
~~Touch sensor~~	~~Decide if it is grasped~~	~~Drop the cup~~
~~Pressure sensor~~	~~Decide if it is burning~~	Sound/speaker
~~Temperature sensor~~	Programs	Moving /motor
~~Flex sensor~~	software	~~Move arm away~~
~~Heat, Light~~	hidden layer	

Step 2: Filter out specific details to highlight the general patterns needed to solve the problem

Cross out the specific details in your lists from step 1

Circle or highlight the general patterns

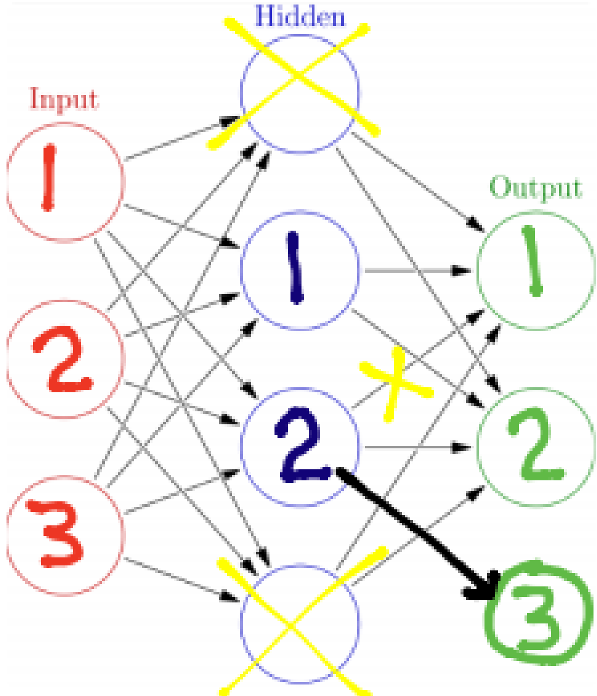
Step 3: Abstract the identified components

See sample annotated abstraction

Step 4: Identify Criteria and Constraints

Criteria	Constraints
Uses a different tone for hot vs. fire Elbow motor moves faster if fire present than just a hot object Gripper motor only activates if hot/burning object is in the "hand" Not triggered by every hot object or bright light (trigger threshold)	Use sensors from kit No more than three inputs Need to detect dangerous situations (hot, burning) Need to output movement and warning buzzer

Sample abstraction with annotations:



If temp and pressure sensor reach threshold, hidden layer #1 activates buzzer with a low tone (hot) and #2 activates gripper motor

If temp, pressure and light sensors reach threshold, hidden layer #1 activates buzzer with a high tone (fire) and elbow motor and #2 activates elbow and gripper motor

If only one sensor is activated, then no output occurs

If light and temp sensors reach threshold, hidden layer #1 activates buzzer with a high tone (fire) and both #1 and #2 activate the elbow motor

NOTE:

Hidden layer receives input from all sensors but can only output to two. The number of nodes can be modified based on the number of teams or Aruduino kits available.

Three-level diagram modified from Burnett. C.M.L. as published by Wikipedia contributors. "Artificial neural network." *Wikipedia, The Free Encyclopedia*. 31 Jul. 2015. Web. 3 Aug. 2015. https://en.wikipedia.org/wiki/Artificial_neural_network under GNU Free Documentation License

Lesson Four: Design and Construction of Neural Network

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

LESSON OVERVIEW

Activity Time: Depending on student skill and background knowledge two or three-50 minute class periods.

Lesson Plan Summary: In this lesson, teams of students will each select a subsystem from the previous lesson's abstraction to design using Arduino microcontrollers and then to test. As individual teams complete their assigned subsystem, they will begin networking with other groups to complete the model neural network, debugging and iterating their designs as they go along.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- **Collaboration:** Scientists build on and extend the work of others.

Essential Question:

- How are physical phenomena and mathematical concepts represented on a computer?

Learning Objectives:

Students will know…

- That an Arduino is a microcontroller that can be used to input information from sensors, modify that information, and produce an output.
- That Arduino use simple programs called sketches that can be written from scratch or downloaded from the creative commons and modified.

Students will be able to…

- Construct a network of Arduino controlled circuits that integrate a variety of sensor inputs and output devices.
- Explain the transfers and transformations of energy as it flows through the circuit/network.
- Use the engineering design process to solve a problem.
- Work collaboratively to solve a complex problem.

Vocabulary:

- Arduino
- Circuit
- Debug
- Feedback

- Input
- Microcontroller
- Network
- Output
- Resistor
- Sketch

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

NGSS Disciplinary Core Ideas (DCIs)
- **HS-PS3-3:** 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:** 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:** 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:** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints**.**

Crosscutting Concepts
- Cause and Effect
- Energy and Matter: Flows, Cycles, and Conservation

Basic Understandings of the Nature of Science & Crosscutting Concepts
- Science is a Way of Knowing
- Science is a Human Endeavor

Science & Engineering Practices
- Designing solutions
- Using mathematical and computational thinking

Common Core State Standards
- **WHST.11-12.7:** Conduct research projects to answer a question or solve a problem.

MATERIALS

Material	Description	Quantity
Arduino based SparkFun Inventor's Kit V3.2	SparkFun Electronics, https://www.sparkfun.com/products/12060	1 per team
Computer or laptop with Arduino drivers and Fritzing app downloaded and internet access	For downloading, modifying, and uploading Arduino sketches	1 or more per team or access to wireless for personal electronic devices
Artifacts from *Lesson Three*	For students to constrain their designs	1 per class
Student Handout 4.1	*What? So What? Now What?* Used at the end of each day to keep track of student progress.	1 per team per day
Student Handout 4.2	*Group Roles.* Holds each student accountable for a specific role within the group	1 per team
Student Handout 4.3	*Getting Started Checklist.* Instructions to get each team started	1 per team
Student Handout 4.4	*Resistors*. Brief background for using resistors in circuits.	1 per team
Student Handout 4.5	*Final Checklist.* Instructions to make sure that each team completes the challenge	1 per team

TEACHER PREPARATION

1. Make copies of ***Student Handout 4.1:*** *What? So What? Now What?,* ***Student Handout 4.2:*** *Group roles*, ***Student Handout 4.3:*** *Getting Started Checklist*, ***Student Handout 4.4:*** *Resistors* and ***Student Handout 4.5:*** *Final Checklist*, one of each per team.

2. Download Arduino drivers and Fritzing app to student laptops or computers (see the *Teacher Background & Resources* section of this lesson plan for more information).

3. Depending on experience, set up some sample circuits and familiarize yourself with the Arduino microcontroller.

4. Collect and organize materials.

5. Thoughtfully assign students to teams of four or five students.

PROCEDURE

Note: Students without prior experience with Arduino may want to work through some introductory circuits or complete the "Introduction to the Arduino Uno" lesson plan in the *Introduction to Neural Engineering: Neuroprosthetics & Brain-Computer Interfaces* curriculum unit listed in the *Teacher Background & Resources* section. This step will add at least a day to the unit's timeline.

DAY ONE
Engage: (10 minutes)

1. Divide students up into teams. There should be one team for each of the nodes outlined in the abstraction from *Lesson Three*. See *Adaptations* for grouping suggestions.

2. Distribute a copy of ***Handout 4.2:*** *Group Roles* to each team. Give teams five minutes to read and select group roles.

3. Explain to students that frequently in industry, different teams each work on a subsystem of a larger system. As each team works to complete their individual design, teams are going to have to communicate with each other in order for all the components to work when they are networked together.

Explore: (5 minutes for Project Leader meeting and 35 minutes of work time)

4. Instruct all of the Project Leaders to meet with you at a specified place in the room for the first "Check In". Ask them to bring ***Student Handout 4.2:*** *Group Roles* with them and post these prominently in the classroom so that other teams can access them if needed. Have the Project Leader select a node from the abstract to design or assign each team a node.

5. Give the Project Leader a copy of ***Student Handout 4.3:*** *Getting Started Checklist,* a copy of ***Student Handout 4.1***, a SparkFun Inventor's Kit, and a copy of the *SIK Handbook*. The Project Leader should then return to his or her team and get started on the checklist.

6. The checklist outlines a starting point for each team member to contribute to the completion of the task.

Explain: (Timing depends on students' background experience)

7. As team members complete their exploratory tasks, they should naturally move into construction of their assigned subsystem. This step is highly unpredictable based on

students' level of experience, clarity of abstraction, and communication with other groups. It is important to check in with each set of group roles each day to answer questions and provide support until they are all progressing forward AND closely monitor groups for stuck-points or frustration.

8. As students work through debugging their designs use the "What?, So What?, Now What?" protocol on ***Student Handout 4.1*** to help them think through next steps. All members of the team should contribute ideas but the Communications Specialist will complete the Exit Ticket and turn it in at the end of each class period. (More information about this activity can be found in the *Resources* section.) The instructor should read and provide feedback on the Exit Ticket and return it to the team at the start of the next class period or use them as a touch point for the next day's Project Leader Check In.

DAY TWO
Elaborate: (Timing depends on completion of subsystems)
10. As teams complete their subsystem (You should know which teams are close based on your daily check ins with the Project Leaders) begin pairing teams to start networking their subsystems together.

11. Designate a specific space in the room to network the components as you will not want to start over every day until the network is completed.

DAY TWO OR THREE
Evaluate: (50 minutes)
12. Students will daily evaluate and iterate their designs until they work together to meet the design challenge. Continue to have teams complete ***Student Handout 4.2*** daily until their portion of the project is complete and debugged.

13. As teams finish, some members can be reassigned as consultants to other teams as support if needed.

14. Meet again with the Project Leaders and distribute ***Student Handout 4.5:*** *Final Checklist*. This step should happen as teams seem to be nearing completion to remind team members that everyone has a product due at the end.

STUDENT ASSESSMENT

Assessment Opportunities:

- Since students are working in groups, summative evaluation of the group's product is discouraged. Students could be asked to self-evaluate their own contributions to the final product, however if students are completing the tasks assigned to their group role, everyone should be actively engaged. Instead, evaluate the thoughtfulness of students' reflections and evaluations in *Lesson Five*.

Student Metacognition:

- Students will keep track of their learning and modifications to their designs using a "What? So What? Now What?" protocol.

Scoring Guide:

- See *Lesson Five* for scoring guidance.

EXTENSION ACTIVITIES

Extension Activities:

- Add Complexity: As groups complete their subsystem and begin networking the subsystems together add complexity such as weighting inputs, adding additional sensors or problems to solve, including inhibitory and excitatory feedback.

Adaptations:

- Be thoughtful with your grouping strategies when making the teams. I suggest placing the students with the most coding experience or interest in coding in the two groups designing the hidden layer and adding complexity as needed such as weighted inputs.
- Students that are likely to struggle can be distributed among the remaining groups or clumped together and assigned one of the easier circuits such as the pressure sensor or buzzer. I prefer the latter option to ensure that stronger students in the group don't take over allowing struggling students to disengage. However, such a group will need support so be sure to check in with them frequently.

TEACHER BACKGROUND & RESOURCES

Background Information:

- The SparkFun Inventor's Curriculum has many useful resources for the teacher and students. Especially useful is Chapter 2 of the Teacher's Binder which provides a one page description of each sensor with a schematic diagram and model sketch. https://learn.sparkfun.com/resources/39 and Chapter 7 which provides an overview for using the Fritzing app for schematic diagrams.

- The kit also comes with a handbook that is also available electronically at https://cdn.sparkfun.com/datasheets/Kits/RedBoard_SIK_3.2.pdf

- More information about the “What? So What? Now What?” protocols can be found at http://teachingcommons.depaul.edu/Classroom_Activities/metacognition-activities.html

Resources:

- “Lesson Nine: Getting to Know the Arduino Uno,” from *Introduction to Neural Engineering: Neuroprosthetics & Brain-Computer Interfaces,* Center for Sensorimotor Neural Engineering's Research Experience for Teachers Program, 2014. Available online at http://www.csne-erc.org/content/lesson-plans

- Arduino Playground is a useful resource for starting sketches which are all available through Creative Commons http://playground.arduino.cc/Main/GeneralCodeLibrary

- Download web pages for the Fritzing app for use in making schematic diagrams of each team’s circuit available online at http://fritzing.org/download/

- Arduino drivers are available online at https://www.arduino.cc/en/main/software

- Arduino kits and a variety of sensors and motors can be purchased through SparkFun Electronics (www.sparkfun.com).

Citations:

Craig, L., “SparkFun Inventor’s Kit Curriculum.” SparkFun Website. 28, Mar. 2014. Available online at https://learn.sparkfun.com/resources/39

DePaul University. “Activities for Metacognition.” Teaching Commons. 2014. Available online at http://teachingcommons.depaul.edu/Classroom_Activities/metacognition-activities.html

JimbO SparkFun Contributor. “Resistors.” SparkFun Tutorials. N. D. Available online at https://learn.sparkfun.com/tutorials/resistors

Student Handout 4.1: What? So What? Now What?

Name:______________________________ Date:__________________ Period:__________

What?

Describe what your group accomplished today or what issues you ran into.

So what?

Explain why those accomplishments or issues are important to reaching your group's goal.

Now what?

Describe what you will do for your next steps. Is there anything that you need from me to execute your next steps?

Student Handout 4.2: Group Roles

Name:______________________________ Date:__________________ Period:__________

Note: *Remember all members of the group have to be able to explain the components of the team's subsystem and how it works.*

Role	Student
Computer Science Specialist: This student is responsible for identifying resources needed for completion of the project which includes downloading, modifying, annotating, and uploading the Arduino sketch. This student will have to work closely with the Electrical Engineer to ensure that the sketch works with the hardware. Final product is a printed copy of the annotated sketch used in the final design.	
Electrical Engineer: This student is responsible for construction and modification of the Arduino circuit. This student will need to work closely with the Communication Specialist to document the layout of the circuit. Final product is a printed copy of the circuit schematic.	
Communication Specialist: This student is responsible for keeping records for the team such as Exit Passes, schematics, and communication with other teams. This student will need to monitor what everyone else is doing in order to keep accurate records. Final product is a printed copy of the circuit using the Fritzing app.	
Project Leader: This student is responsible for keeping the group on task, adhering to the goal, and working efficiently. This student will represent his or her team at daily team meetings to check in. The PL will need to know what every member is doing and assign additional tasks as needed to complete the project. The PL should call a team meeting within the last 5 minutes of each class period to assist the Communication Specialist with completing the day's Exit Pass. Final Product is a summary of the team's design process including stuck points and strategies used to reach a solution.	
Inventory Control Specialist: This student will be in charge of all the materials needed to complete the project. The ICS will inventory and keep track of the supplies checked out and ensure that the workspace is cleaned up at the end of class each day. This student will need to work closely with the Electrical Engineer to ensure that all needed components are available. Final product is a detailed materials list that identifies all components used in the final design including sizes, numbers and uses for each component.	

Student Handout 4.3: Getting Started Checklist

Name:______________________________ Date:__________________ Period:__________

As the Project Leader you are responsible for assigning the following tasks to your team. Don't forget to tell your team which node of the system they are working on. Once you have your team started, help manage time and troubleshoot problems as they arise.

Computer Science Specialist:

- Open the Arduino software and practice downloading the needed sketches for your circuit. Read through the notes within the sketch to build an understanding of the purpose for major blocks of code.

Inventory Control Specialist:

- Inventory the Inventor's Kit and make sure all components are identified and present.
- When the Electrical Engineer has his/her list of needed components complete, supply him/her with everything on the list.
- If anything is missing or broken, inform your teacher for a replacement.

Electrical Engineer:

- Use the *SIK Handbook* to identify the circuit needed to complete your team's design and make a list of materials needed for the Inventory Control Specialist.
- Review the instructions for calculating the correct resistor for your circuit.

Communications Specialist:

- Begin reviewing the Fritzing utility for recording the schematic for your circuit.
- Review ***Student Handout 4-1***. A copy of the handout will need completed and turned at the end of every class period.
- Identify the CS for each of the other teams for communication and coordination—especially the teams whose nodes attach to yours.

Student Handout 4.4: Resistors

Name:________________________________ Date:___________________ Period:___________

Use the SparkFun Resistors Tutorial (www.learn.sparkfun.com/tutorials/resisors) to answer the following questions:

1. What is the purpose of a resistor in a circuit?

2. What units and symbols are used to represent resistance or resistors in a circuit?

3. Ask the Inventory Control Specialist for one of each resistor contained in the SparkFun kit. Use the color table to decode the size of each resistor.

Band 1	+ **Band 2**	**X Band 3**	**= Total**	**+/- Band 4 tolerance**

4. Explain why some types of circuits require resistors. List some examples.

5. Explain how to determine the size of resistor needed in a circuit. Describe the equation and variables involved.

Student Handout 4.5: Final Checklist

Name:______________________________ Date:__________________ Period:__________

Computer Science Specialist:

- Add notes using # explaining all the components of the sketch and what modifications were made. Make sure that you include a Title # note identifying your group and node.
- Print the entire sketch used and give it to the Project Leader.

Inventory Control Specialist:

- Work with the Electrical Engineer to make a complete materials list (including sizes and numbers of components and their use) and give it to the Project Leader.

Electrical Engineer:

- Work with the Communication Specialist to draw an accurate schematic for your circuit.

Communications Specialist:

- Print a copy of the circuit schematic and give it to the Project Leader.

Project Leader:

- Construct a 1-2 paragraph summary of your team's design process. Describe any stuck points and what strategies you used to move beyond them to find a solution (your daily exit passes should help guide you).
- Collect the sketch, material's list, and schematic for your team's design from the appropriate team members.
- Staple them together with the team's ***Student Handout 4-2: Group Roles*** and your summary and turn the entire packet into your instructor.

Lesson Five: Reflection and Evaluation

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

LESSON OVERVIEW

Activity Time: One 50 minute class period.

Lesson Plan Summary: In this lesson, students will use the success criteria to evaluate their designs, reflect upon strengths and weaknesses, and propose improvements. Lastly, students will make comparisons between their model and living neural networks.

STUDENT UNDERSTANDINGS

Big Idea & Enduring Understanding:

- **Technology Solves Global Problems**: Computing is a creative activity that has global impact. Technology enables problem solving, human expression and creation of knowledge. All technology has benefits and drawbacks

Essential Question:

- How do scientists communicate and evaluate information?

Learning Objectives:

Students will know…

- All models have strengths and weaknesses.

Students will be able to…

- Evaluate strengths and weaknesses of an engineering design/model.
- Communicate ideas orally and in writing

Vocabulary:

- Energy transfer
- Energy transformation

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

NGSS Disciplinary Core Ideas (DCIs)

- **HS-ETS1-3:** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints**.**

NGSS Crosscutting Concepts:

- Energy and Matter: Flows, Cycles, and Conservation

NGSS Science & Engineering Practices:

- Developing and using models
- Engaging in argument from evidence

Common Core State Standards:

- **WHST.11-12.1:** Write arguments focused on discipline specific content.

MATERIALS

Material	Description	Quantity
Student Handout 5.1	*Design Reflection and Evaluation*	1 per student

TEACHER PREPARATION

1. 1. Make copies of ***Student Handout 5.1:*** *Reflection and Evaluation*, one per student.

PROCEDURE

2. This lesson is intended to provide the time and structure for students to reflect upon their team's designs and the processes that they undertook.

3. Distribute copies of ***Student Handout 5.1***, one per student.

4. Allow students the class period to thoughtfully reflect upon their designs. Students may want access to their graphic organizers and other artifacts from the project.

STUDENT ASSESSMENT

Assessment Opportunities:

- ***Student Handout 5.1*** can be used as a summative assessment for the unit. Paired with each team's group project and assignments, the handout will allow the instructor to assess each student's acquisition of new content knowledge (neural networks, energy transfer, energy transformations, etc.) and skills (abstractions, modifications, Arduino programming, engineering design process, evidence-based reasoning, communication, etc.)

Student Metacognition:

- ***Student Handout 5.1*** provides opportunities for students to demonstrate and reflect on what they have learned (knowledge and skills) during this unit. This includes challenging student's thinking about the engineering design process, including criteria, constraints, testing, and iterations.

Scoring Guide:

- The instructor may develop their own scoring rubric or answer key for ***Student Handout 5.1*** which reflects his/her own learning goals for this unit.

Student Handout 5.1: Design Challenge Evaluation and Reflection

Name:_______________________________ Date:__________________ Period:__________

1. Draw an abstraction of your final design. You may use any format that we have practiced.

2. Describe two energy transfers and two energy transformations that take place in your design. Remember to state the type of energy(s), where the change is taking place AND whether it is a transfer or transformation of energy.

3. Describe at least one modification that you made to your design over the course of this activity. Explain why this modification necessary?

4. Describe at least one modification that you made to the Arduino sketch over the course of this activity. Explain why this modification necessary?

5. Describe how your design was tested?

6. What were the strengths and weaknesses of your final design?

7. Should your design be considered a success? Give evidence to support your claim?

8. In what ways is your Arduino model similar to and different from a biological neural network such as exists in the worm or a human?

9. What did you learn from this activity? List several examples.