Why dread a bump on the head?

The neuroscience of traumatic brain injury

Lesson 4: How to build a neuron

I. Overview
After identifying the structures and functions of the brain, students move to the cellular and molecular levels to explore the neuron, the fundamental cellular building block of the nervous system. Students begin by discussing the versatile roles of the nervous system. The first activity in the lesson has student groups design their own neuron, or “Neuron,” from scratch, based on knowledge learned in previous lessons and a series of guided questions. The students are then introduced to the anatomy and physiology of an actual mammalian neuron and asked to compare their design to a real neuron. Finally, the students are introduced to the ways in which traumatic brain injury manifests at the level of neurons and glial cells.

Connection to the driving question
This lesson brings students to the cellular level in answering the question “why dread a bump on the head?” In order for students to understand the consequences of TBI at a cellular level, they must first learn the normal structure and function of neurons, the primary cells in the brain.

Connections to previous lessons
Thus far in the unit, students focus on the macro level of defining and identifying traumatic brain injury. In this lesson students shift over to the micro, or cellular, level by learning about the structure of a neuron and how neurons communicate by sending signals.

II. Standards

National Science Education Standards
Content Standard C: The Cell
- Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells. In the development of these multicellular organisms, the progeny from a single cell form an embryo in which the cells multiply and differentiate to form an embryo in which the cells multiply and differentiate to form the many specialized cells, tissues and organs that comprise the organism. This differentiation is regulated through the expression of differentiated genes. (9-12 C: 1/6)

Content Standard C: The Behavior of Organisms
- Multicellular animals have nervous systems that generate behavior. Nervous systems are formed from specialized cells that conduct signals rapidly through the long cell extensions that
make up nerves. The nerve cells communicate with each other by secreting specific excitatory and inhibitory molecules. In sense organs, specialized cells detect light, sound, and specific chemicals and enable animals to monitor what is going on in the world around them. (9-12: C 6/1)

Benchmarks for Science Literacy
The Living Environment: Cells
- Every cell is covered by a membrane that controls what can enter and leave the cell. (5C/H1a)
- Within the cells are specialized parts for the transport of materials, energy capture and release, protein building, waste disposal, passing information, and even movement. (5C/H2a)
- In addition to the basic cellular functions common to all cells, most cells in multicellular organisms perform some special functions that others do not. (5C/H2b)

III. Learning Objectives

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<th>Learning Objective</th>
<th>Assessment Criteria</th>
<th>Location in Lesson</th>
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<tr>
<td>List several important roles of the nervous system.</td>
<td>Students need to be able to identify roles such as: Communication, Synthesize sensory input, Sense surroundings, Emotion</td>
<td>Throughout lesson</td>
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<td>Develop a hypothetical cell from first principles and evaluate its design.</td>
<td>After developing a hypothetical cell based on their prior knowledge and reasoning, students critically evaluate their model’s design through comparisons with an actual neuron cell.</td>
<td>Activity 1</td>
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<td>Identify the major anatomical components of the neuron.</td>
<td>Students must be able to label the following major components of a neuron: Soma, Dendrites, Axon</td>
<td>Activity 2</td>
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<td>Explain in basic terms how neurons communicate with each other.</td>
<td>Students explain neuron communication using the following terms: action potential, synapse, synaptic vesicles, and neurotransmitters.</td>
<td>Activity 2</td>
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<tr>
<td>Articulate how the differences between neurons and other</td>
<td>Students explain that TBI can affect billions of neurons, upsetting or even eliminating important</td>
<td>Activity 2</td>
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IV. Adaptations/Accommodations
Consider student ability during the design of the “Newron.” Students work within groups during this activity so they may take different roles. A student may contribute ideas and feedback while other students complete the drawing. You may also consider accepting the “Newron” drawing in other formats such as designed on a computer.

The guiding questions for the “Newron” activity may be read aloud to students individually or in small groups, if needed.

The “Meet an Actual Neuron” activity relies on students reading at grade level. For below-level readers, the passage may be read aloud. Students may need to use a specific literacy strategy to help them make sense of the reading. This reading is also vocabulary-intensive so students who need more support may need to paraphrase definitions for bolded words prior to reading.

If students need more time to complete the reading and accompanying questions, consider allocating more class time to the activity so that you can specifically provide support to students.

Safety
There are no additional safety concerns associated with this lesson.

V. Timeframe for lesson

Opening of Lesson
- Class Discussion: What does a sheep’s nervous system do? – 10 minutes

Main Part of the Lesson
- Activity 1: Design Your Own Neuron (“Newron”): 30-35 minutes
  - Introduction
  - Group work
  - Presentation
- Activity 2: Meet an Actual Neuron: 30-35 minutes
  - Key Features of Neuroanatomy
  - Neurophysiology: How Neurons Communicate
  - Types of Neurons
  - Neurons and Traumatic Brain Injury
VI. Advance prep and materials

Opening of Lesson

Materials:
- Computer-compatible projector
- “Introduction to Neurons” Presentation (U4_L4_Presentation_IntroductionToNeurons)

Preparation:
- Connect computer to projector and Load the presentation: “Introduction to Neurons”

Activity 1: Design Your Own Neuron (“Newron”)

Materials:
- Student Packet (one copy per student)
  - “Building Your Newron” (U4_L4_StudentPacket_BuildingYourNewron)
- Markers or crayons (several colors per group of 3-4)
- Piece of poster board (1 per group of 3-4)

Preparation:
- Make copies of “Building Your Newron” packet (1 per student)
- Place the markers and poster board in a central location

Activity 2: Meet an Actual Neuron

Materials:
- Student Packet (one copy per student)
  - “Meet an Actual Neuron” (U4_L4_StudentPacket_MeetAnActualNeuron)
- Computer with internet access
- Computer-compatible projector
- “Introduction to Neurons” Presentation (U4_L4_Presentation_IntroductionToNeurons)

Preparation:
- Make copies of “Meet an Actual Neuron” packet (1 per student)
- Connect the projector to the computer
- Load the Powerpoint presentation: “Introduction to Neurons”
- Open a web browser and load the video links found below in teacher resources as needed
Homework

Materials:
- Homework questions on neurons (U4_L4_Homework_QuestionsOnNeurons)

Preparation
- Print one copy per student

VII. Resources and references

Teacher resources
- Center for Brain Science: http://cbs.fas.harvard.edu/science/connectome-project/brainbow#
- Action Potential Video: http://www.youtube.com/watch?v=jcZLtH-Uv8M
- Neurotransmitter video: http://www.youtube.com/watch?v=HXx9qIJetSU
- BrainU: http://brainu.org/synapses
- BrainU-Connect the Neurons Activity: http://brainu.org/connect-neurons

References
Images:
- http://brainstories.wordpress.com/tag/ebbinghaus/
- http://shp.by.ru/spravka/neurosci/
VIII. Lesson Implementation

Opening of Lesson:

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<th>Teacher Pedagogical Knowledge</th>
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<td>The first activity of this lesson involves students designing their own neurons, or “Newrons,” and then comparing their designs to that of an actual neuron. In order to afford students as much creative license as possible, you may wish to refrain from discussing the structure and function of actual neurons at this point in the lesson.</td>
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As a prelude to introducing the first activity of the lesson, ask students to think about all the activities and functions that a brain has to regulate. Possible questions include:

- What key points did you learn during the sheep brain dissection?
- In other words, what does a nervous system do?
  - While facilitating this discussion, make sure that students understand that as in Lesson 2, the sheep brain is being used a *model* for the human brain. This is due to the high degree of anatomical and physiological homology between sheep and human brains.

Begin to solicit ideas from the students about what a nervous system does, making a list on the board. Save this list for later in the lesson.

- Make certain that the following are mentioned by the end of the discussion:
  - Rapid communication between different parts of the body
  - Regulation and coordination of other bodily systems, such as respiration, circulation, reproduction and endocrinial activity
  - Sensing the outside environment (e.g., seeing, hearing, feeling)
    - Processing sensory information
  - Controlling muscular action
    - Computing motor activity

- Throughout the discussion, have students try to group roles together as necessary. For example, control of motor activity could also be thought of as regulation of the skeletomuscular system in certain animals; rapid communication between different parts of the body could include regulation of respiration (communication between the brain and the lungs).

Depending on the level of the class, you may wish to have a discussion about the extent to which the roles carried out by the sheep nervous system generalize to all nervous systems. In fact, the list included above is broadly applicable to all animals possessing a nervous system, although certain specifics vary (e.g., not all animals with nervous systems possess vision, hearing or taste, for example).
Making connections across organisms can help students to understand the conservation of structure and function as a phenomenon seen often in biology.

To get students thinking more about where and how nervous systems occur in nature, consider asking the following questions (display slide 1: “The Tree of Life” slide from the Powerpoint Presentation “Introduction to Neurons” while discussing these):

- **Do all animals possess nervous systems?** No. In fact, there are some very ancient animals such as sponges that possess no nervous system at all. Point to the sponge branch, located off of the larger animal branch. Explain that while coelenterates (more commonly referred to as cnidarians or ctenophores in contemporary literature) like corals and jellyfish have nervous systems, they are very primitive, consisting only of basic nerve nets.

So what abilities does a nervous system impart to most animals that other organisms do not possess?

- **Do other kingdoms and domains of life, such as plants, fungi, protists, archaea and bacteria, possess nervous systems?** No, nervous systems are unique to animals. Point to the animal branch on the tree of life, but emphasize that this is a simplified representation of the animal kingdom; the actual evolutionary relationships between animals are far more complex than what is shown.

If nervous systems are unique to animals, does that mean, for example, that bacteria are incapable of sensing their external environments or plants are altogether incapable of movement? The roles served by a nervous system are often seen in other kingdoms of life; indeed, bacteria can sense their environment in several different manners, and plants are capable of generating limited movement. Rather, nervous systems are unique with respect to the rate and degrees of coordination and complexity with which they facilitate these essential biological roles.

To close the brainstorming session, have students think back to what they learned over the last few lessons. Which among the roles they listed does traumatic brain injury (TBI) impair?

Continue the lesson by asking the students **how** the nervous system is able to accomplish what it does.

- **When the brain or spinal cord is injured, is the injury always apparent at the gross (macroscopic) level?**

Remind students that the fundamental building blocks for all living organisms are cells. From bacteria to mammals such as humans, cells constitute and control every aspect of life. Explain that this is no different with the nervous system.

- **Ask the students if they know what the major cellular building block of the nervous system is?**
  - Neurons.
Teacher Pedagogical Content Knowledge
To capture the students’ interests show them brain images in which fluorescent proteins are used to visualize neurons—the main type of cell in the brain. These are bright, colorful, and artistic images of the brain where students can simultaneously see the larger brain sections (similar to the level of the CT Scans and brain dissection) as well as the neurons that make up the brain tissue. Because, both the macro and the cellular levels can be visualized in some of these images, this would be a good way to transition the students from what they saw in the brain dissection and CT Scan lessons to the neuronal level that will be covered in this lesson and the next.

One site at which these types of images can be seen is:
http://cbs.fas.harvard.edu/science/connectome-project/brainbow#.

Briefly explain that neurons are what allow the brain and other components of the nervous system to function in concert; the nervous system is made from neurons and other specialized support cells. Neurons are therefore what enable animals to generate behavior and interact with their environments.

Main Part of Lesson
Activity 1: Design Your Own Neuron (“Newron”)

Teacher Pedagogical Content Knowledge
The following activity will allow students to make connections across organisms. Students need to understand that that although the structure and function of neurons vary somewhat from animal to animal, their underlying design has been remarkably conserved over hundreds of millions of years of evolution. Thus, what they are learning about here can be viewed as a prototypical neuron and can generalized to humans and other animals. Connections to other organisms should be made in the final discussion of the lesson.

The goal of this activity is to have students extrapolate from their knowledge of biology to develop a novel nerve cell, using descriptions and diagrams. Begin the activity by distributing the lesson’s student packet “Building Your Neuron” (U4_L4_StudentPacket_BuildingYourNewron).

- Explain that today students will design their own generalized nervous system cell, or “Newron”. Tell students that they can pull on their prior knowledge of neuronal structure and function; however, they should endeavor to be creative in designing their Newrons.
• Direct students to turn to their “Building Your ‘Newron’” handout. Explain that in groups of 3-4, students will complete this handout in order to guide their designs. Tell them that the handout is designed to engage students in critically thinking about
  o The roles of the nervous system
  o Newron structure
  o Communication
  o Variety
  o Protection and repair

• To focus their designs, explain to the students that each group will choose an animal, either real or imaginary, for which their Newron will be specially designed.

• Explain that each group will need to sketch their Newron on a poster board, using their replies on the handout and class discussion as a guide. They will need to label any important Newron feature. Each group will present and explain their design. Let the students know that the design and sketching process should take no more than 25-30 minutes.

Emphasize again that this is a creative activity, and as long as students can justify their design decisions, they are welcome to take “artistic licenses.” As a way to make the build a “Newron” more personal, students can use household materials to build their Newron in lieu of drawing one.

Tell students that once the groups have designed their Newrons and presented to one another, they will explore as a class what an actual neuron looks like and how it functions, while drawing comparisons to their own designs. You may need to explain that anatomy deals with biological structure, while physiology deals with biological function.

Ask students if they have any questions about how to do the activity. Assign them to groups of 3-4, and have each group collect a set of markers and a piece of poster board. Allow students to progress through the “Building Your ‘Newron’” handout, providing help as needed.

Students need to consider what sorts of information a nervous system has to communicate (e.g., sensory, motor, central processing, homeostatic, etc.) to ensure the short- and long-term fitness of an animal.

In addition, students will consider the following questions:

• What should a Newron look like? What parts should it have? Students do not have to specify organelles but should think about things like cell shape, energy requirements, etc.
• How do Newrons communicate with each other (i.e., what is their mode of communication)?
• What sorts of varieties would need to be found among Newrons?
• What kinds of protection and repair mechanisms exist for your Newrons?
While students can be encouraged to take creative license in their designs, they should be challenged with any illogical or impractical aspects of the Newrons they are designing.

**Teacher Pedagogical Knowledge**

The degree to which students’ designs are directed away from concepts that may be biologically “impractical” should depend on the extent to which the students have developed an intuition for biological design. For example, a student who has not learned about mitochondria and ATP should not necessarily be dissuaded from developing a Newron that relies on a less plausible source of intracellular energy.

Once each student group has brainstormed different aspects of Newron structure and function and completed the relevant questions in the “Building Your ‘Newron’” handout, groups should begin sketching their Newron.

- Make certain that every student in the group has completed his/her worksheet before the groups begins their drawing.
- Students should be labeling important features in their drawing.
- Make sure that every student is contributing to the drawing in some fashion.
- As the groups are making their posters, remind them that they will be presenting their Newrons to the class in a few minutes. They should therefore consider who within the group will present which aspects of their Newron’s structure and function. The group members should try to divide the presentation responsibilities equally.

When student groups have completed their posters, have the class reconvene. Tell students that each group will take a few minutes to present the Newron they designed. In their presentations, they should address those aspects of their Newron that they were asked to highlight in the handout, namely:

- Structure
- Communication
- Variety
- Protection and repair

Challenge them as necessary on their design, and solicit questions for the presenting group from other students.

**Activity 2: Meet an Actual Neuron**

Once every group has presented their Newron design, tell the class that they will now discuss the anatomy and physiology of an actual neuron.

- Have students turn to the “Evaluate Your Newron” worksheet in their “Build Your Newron” packet. Explain to the students that while they are discussing the structure and function of
actual neurons as a class, they will be periodically stopping to make comparisons between actual neurons and their own Newrons. Emphasize that at these points in the discussion (“STOP AND EVALUATE” bullets in this lesson plan), students should be filling in the relevant portions of the comparison chart on their handout.

- **Optional:** Ask students: does natural selection (or “nature,” if the concept of natural selection is unfamiliar) always produces the “best” biological design? In other words, is the biological neuron inherently “superior” to anything the students could conceive of themselves? “Best” and “superior” are normative terms and are best avoided when discussing empirical science. It is also important to convey that evolution is not a goal-directed process. Rather, if natural selection leads to a design that is conducive to an animal’s fitness, that design is genetically preserved. Accordingly, highlight that the fact that neuronal structure and function are so well-conserved throughout the animal kingdom demonstrates ipso facto that the neuron as it presently exists possesses a versatile and adaptable design, capable of regulating the diverse nervous systems of many animals in a multitude of environments.

- Next, have students turn to the “Meet an Actual Neuron” worksheet in their student packet. Tell students that this worksheet contains a summary of information about actual neurons, and that the questions at the end of this worksheet should be completed as homework.

At this point, set up a web-connected computer with an attached projector. Display the “Introduction to Neurons” presentation. The suggested slides of the PowerPoint file and associated web links are included throughout the lesson plan.

Begin the discussion by reminding the students that a neuron is a specialized cell that mediates communication in the nervous system.

Ask students if they can identify any other specialized cells. **In fact, all cells are specialized in some way or another, but neurons are to the nervous system what lymphocytes are to the immune system, what erythrocytes are to the circulatory system, etc.**

**Key Features of Neuroanatomy**

(Slide 2: “The Neuron”) Point out that the typical neuron can be divided into three major sections: the **soma**, the **dendrites**, and the **axon**. Explain that the **soma** is the body of the cell, containing a nucleus and many of the other organelles found in other animal cells.

Ask the students how large they believe the typical soma is in a vertebrate neuron.

- Vertebrate somata can range in size from 4-100 microns (1 micron=one millionth of a meter). In some invertebrates like sea slugs (from the phylum Mollusca), some somata are known to be as large as a centimeter in diameter, slightly smaller than a dime!
Point out that branching off from the soma are tree-like processes known as **dendrites**, which typically receive inputs from other neurons.

Ask the students why they suppose neurons, like the one shown in the diagram, have so many branches.

- The more dendritic branches a neuron has, the more links it can make to other neurons. In more complex nervous systems, numerous neuronal connections are needed.

Tell students that a neuron will possess at most one **axon**, which is a long, cable-like filament that typically conducts outputs away from the soma to the **axon terminal**, where one neuron synapses (communicates) with another.

Ask the students why axons tend to be long relative to length of the soma.

- Neurons do not always make connections with other nearby neurons. Sometimes they must communicate over relatively long distances. As such, axons can range in length from tens of microns to over a meter!

Explain that in many vertebrate neurons, axons are covered by insulating cell layer known as the **myelin sheath**. In the central nervous system (brain and spinal cord), these insulating cells are called **oligodendrocytes**, while they are known as **Schwann cells** in the peripheral nervous system (tissue and organs).

Ask the students to speculate on what the function of the myelin sheath is.

- The sheath speeds up conduction along the axon by causing passing current to literally jump from Schwann cell to Schwann cell, a phenomenon known as salutatory conduction. The faster neurons are able to communicate with each other, the more immediately an animal is able to send and receive information throughout its body.

(Slide 3 “Actual Neuron”): Show the students what an actual neuron looks like, as highlighted by a chemical method called Golgi staining. Explain that while different neurons vary in shape, size and function, they all possess somata, dendrites and axons.

STOP AND EVALUATE: Ask the students how the structure of actual neurons differs from the structures of the Neurons they designed. What are the relative advantages and disadvantages of each design? Solicit specific points of comparison from several different groups.

**Neurophysiology: How Neurons Communicate**

Explain to the students that neurons use both **electrical** and **chemical** means to communicate with one another.

Ask students if they can think of any forms of electrical and chemical communication.
• There are many possible examples. An ant, for example, can release a trail of chemicals known as pheromones to guide other individuals from their colony to a source of food. Telephones make use of electrical communication, by transmitting signals across long wires.

Ask students to think about what electrochemical communication may involve.

• Neurons communicate electrochemically in the sense that their chemical properties affect their electrical properties and vice versa. In other words, a neuron is able to pass an electrical current because its internal and external concentrations of certain chemicals (ions) can be modified under the right circumstances.

Tell students that a neuron’s electrical state can be described by its voltage. Explain that a voltage is a measurement of electricity’s tendency to flow in one direction or the other. Ask students where they have seen examples of voltage in their own lives.

• Batteries are an excellent example: the higher the voltage rating on the battery, the greater the tendency for electrical current to flow from it.

Tell students that when one or more inputs from one or more neurons excites another neuron above a certain voltage threshold, the neuron being excited will generate an electrochemical pulse known as an action potential.

At this point start the Action Potential Video: http://www.youtube.com/watch?v=jcZLtH-Uv8M. Stress the following details and questions either before or after the video:

• Action potentials are usually generated at the axon hillock, where the soma and axon join, and move like a wave down the axon to the axon terminal.
• Ask the students if the action potential behaves like waves in the ocean.
  o In many ways, yes. However, there is one important difference: action potentials are self-regenerating, meaning that the axon is able to regenerate them fully as they travel along. Once waves in the ocean are initiated by the wind, for example, sometimes they die out along the way.
• The movement of action potentials down the axon is facilitated by the rapid flux (movement) of ions, such as sodium (Na\(^+\)), potassium (K\(^+\)), across the axonal membrane in one direction or the other.

(Slide 4 “The Action Potential”) Wherever the action potential is found in the neuron, it depolarizes (raises the voltage) at that location; once the action potential passes a location, the neuron begins to repolarize (returns to its original voltage) at that location.

When no action potential is traveling through a neuron, that neuron is said to be at its resting potential.

Refer to the action potential diagram on Slide 4. Ask the students what they think it means that the resting potential of the neuron is less than 0 (negative).
- This reflects the fact that at rest, there are more positive ions, such as sodium and potassium, outside the cell than there are inside.
- Stress that the action potential pulse as shown on slide 4 does not itself literally travel down the axon. Rather, this is a graph that shows how the voltage at a single point changes as the action potential passes through it.

Ask students whether the size of the action potential a neuron generates depends on how much input it receives.

- Surprisingly, no. Action potentials are “all-or-nothing” events: no matter how threshold is reached (e.g., through multiple smaller inputs summing vs. one large input), an action potential is created if threshold is reached. If threshold is not reached, the neuron will not generate an action potential, even though it may be receiving inputs. The concept could be likened to a class election: two candidates may each receive about half of their classmates’ votes, but the winner nevertheless “completely” wins, while the loser completely loses; there is no such thing as “half-winning.”
  - While increased input into a neuron will not create stronger action potentials, it may cause the neuron to generate action potentials more frequently.
- Ask the students whether they believe all cells are electrochemical in nature. Yes, in the sense that they all have resting potentials; these simply result from differences in charge, or ionic concentrations, between the internal and external environments. However, only neurons and muscle cells can rapidly change their cellular potentials.

Ask the students what they think happens when an action potential hits the end of the neuron, or the axon terminal. Does it stop? Does it jump to the next neuron?

- Explain that when an action potential has traveled down the length of an axon and reaches the axon terminal, it causes synaptic vesicles, small pockets filled with special chemicals called neurotransmitters, to fuse to the axonal membrane. The action potential itself terminates at this point; it is not directly sent to the next neuron.

At this point, start the Neurotransmitter video: http://www.youtube.com/watch?v=HXx9qJcetSU. Make certain that the following details and questions are discussed either before or after the video:

- (Slide 5 “The Synapse”) When the synaptic vesicles fuse, they release neurotransmitters into the synaptic cleft, the small space between two neurons.
- Neurotransmitters leave the axon terminal of one neuron and then bind to specialized receptors on the dendrites (and sometimes the soma or axon) of another neuron.
- Ask the students what sort of effect they suppose the binding of neurotransmitters has to the receiving neuron. The binding of neurotransmitters to receptors on another neuron can either excite (raise the voltage of) or inhibit (lower the voltage of) the receiving neuron; an excited neuron is more likely to fire, while an inhibited neuron is less likely to fire.
Explain that whether a synapse is excitatory or inhibitory depends on both the type of neurotransmitter secreted and the type of dendritic receptor binding the neurotransmitter on the receiving neuron.

- Common neurotransmitters found in vertebrates include serotonin, dopamine, acetylcholine, glutamate, epinephrine, norepinephrine, glycine and gamma-aminobutyric acid (GABA). Ask the students if they recognize any of these chemicals. Students might recognize epinephrine, also known as adrenaline.

Ask students to recap the several ways in which neurons communicate both electrically and chemically.

- The initiation and transit of an action potential is both electrical and chemical, or electrochemical: 1) an electrical current created by the action potential moves down the axon due to 2) changes in external and internal chemical (ionic) concentrations. Furthermore, 3) the electrical current created by the action potential causes 4) neurotransmitters, which are chemicals, to induce 5) an electrical effect in the receiving neuron by modulating its voltage.

STOP AND EVALUATE: Ask the students how the communication in actual neurons differs from the modes of communication in the Neurons they designed. What are the relative advantages and disadvantages of each design? Solicit specific points of comparison from several different groups.

Teacher Pedagogical Content Knowledge
As a possible extension to the discussion of neuronal communication, you may wish to engage the students in one of the following hands-on activities developed by BrainU, an educational outreach program based out of University of Minnesota: http://brainu.org/synapses. In particular, the “Connect the Neurons!” activity (http://brainu.org/connect-neurons) features a simple, interactive way to simulate synaptic communication by using the students as “neurons”; this may be a particularly instructive activity for less advanced classes.

Types of Neurons
Ask students to think about what different classes of neurons they imagine exist, given the roles played by the nervous system. To help them focus their brainstorming, tell students to refer back to the list of functions mediated by the nervous system; have them think about these roles in terms of how they might be filled at the neuronal level.

Explain that although vertebrate neurons can be categorized in many different ways and exist in many different varieties, they are often grouped based on the direction in which they carry information (Slide 6 “Types of Neurons”):

The Neurotransmitter Secreted
- Excitatory Neurons: Release neurotransmitters that open cation channels, allowing more sodium and calcium to enter the postsynaptic neuron, thereby depolarizing it.
- Inhibitory Neurons: Release neurotransmitters that open Cl− channels, allowing more chloride ions to enter the postsynaptic neuron, thereby hyperpolarizing it.

The Neuronal Receptor Distinctive to the Neurons
- Excitatory Neurons: Have receptors for glutamate, which depolarizes the postsynaptic neuron.
- Inhibitory Neurons: Have receptors for GABA, which hyperpolarizes the postsynaptic neuron.

The Ionophore (Gating) Channel Specific to the Neurons
- Excitatory Neurons: Have specific ionophores (e.g., NMDA, AMPA) that depend on calcium to gate (open and close) the channel.
- Inhibitory Neurons: Have specific ionophores (e.g., GABA receptors) that depend on chloride to gate (open and close) the channel.
- **Sensory neurons** receive information from the peripheral nervous system and relay it toward the central nervous system, consisting of the brain and spinal cord.
  - Ask the students what sorts of different sensory neurons they might have. There are several different varieties of sensory neurons corresponding to each of the senses, including vision, hearing, touch, smell, taste, temperature, pain, etc.
- **Motor neurons**, by contrast, carry information from the central nervous system to the peripheral nervous system.
  - Ask the students what other bodily systems motor neurons must interact with. The most obvious answer is the skeletomuscular system, since muscles are directed by motor neuron activity. However, motor neurons also play an important role in the endocrine system, where they can direct different glands to release hormones. For example, if someone were to come across a bear in the forest, the visual stimulus of the bear would probably direct the brain to have the body release adrenaline, potentially helping the person escape from the bear more effectively!

Ask students if sensory and motor neurons alone are enough to comprise a functional nervous system. What links them to one another? Explain that **interneurons** act as intermediaries between sensory and motor neurons, as well as between other interneurons. In fact, all the neurons whose somata are located in the central nervous system, including those in the brain and spinal cord, are interneurons. Whenever you think, you are thinking with your interneurons!

While neurons are clearly the driving force of the nervous system, ask the students whether they suppose there are other cells that make up the nervous system. Is there any need for additional cells that do not rapidly transfer information as neurons do? If so, what sort of roles might they play?

- Explain that in addition to neurons, the vertebrate nervous system contains **glial cells**, which provide metabolic and mechanical substrates for neurons as well as protection (e.g., the Schwann cells and oligodendrocytes that make up the myelin sheath). Recent findings suggest that glial cells can also communicate via synapses.
  - Glial cells help maintain homeostasis, or biochemical balance, within the nervous system, regulating the concentrations of oxygen, nutrients and other chemicals (e.g., the ionic balance that allows neurons to fire action potentials). They also play roles in insulating neurons from injury and facilitating their regeneration when possible; some glia can also serve an immune function, protecting neurons from pathogens. In many ways, these are the cells doing the behind-the-scenes work!
  - In addition to oligodendrocytes and Schwann cells, other varieties of glial cells include astrocytes, microglia and radial glia.

STOP AND EVALUATE: Ask the students how the variety among actual neurons differs from the variety of Newrons they designed. What are the relative advantages and disadvantages of each design? Solicit specific points of comparison from several different groups.
Neurons and Traumatic Brain Injury

Ask students how many neurons and synapses do they think are found in the human nervous system. Tell them that it is estimated that the human brain has on the order of 100 billion neurons. That number is on the order of the number of stars in the Milky Way! Every neuron is thought to have on the order of thousands of synapses, resulting in hundreds of trillions synapses!

Given the number of neurons and synapses in the human nervous system, ask the students whether they believe that every neuron and synaptic connection serves a unique or indispensable function.

- There is no one neuron that, if lost, will impair the function of the human nervous system in any appreciable way. Put another way, no one neuron encodes the image of your grandmother’s face! Many neurons are redundant, and neural networks are often configured as to tolerate minor, periodic interruptions.

Given the degree of redundancy in the nervous system and the sheer number of neurons, ask the students why traumatic brain injury can still be so dangerous.

- For one, traumatic brain injury can potentially affect millions, even billions of neurons at a time. Have the students think back to the brain dissections they performed in Lesson 2. If a significant number of neurons in any one region of the brain, such as the hippocampus, were killed or damaged through injury, the effects may be noticeable.

Encourage students to think about the danger of TBI from another perspective: what is it that makes neurons different from other somatic cells?

- Students may refer to the morphology of the neurons (e.g., that it has an elongated segment, the axon, that may not be found in other cells) or the fact that they can be electrochemically active. While these are important differences there are others account for the fragility of the nervous system:
  - Neurons do not experience cell division, or mitosis, as other somatic cells do. Therefore, a neuron that dies is forever lost.

- Ask the students whether they suppose new neurons can take the place of old ones.
  - Up until the late 1990s, the creation of new neurons after birth in mammals and in “higher” brain regions of other animals was not thought possible. It is now known that a small number of new neurons can emerge in the cortices of adult mammals, a process known as neurogenesis. Different areas of the brain exhibit different levels of neurogenesis. While new neurons cannot necessarily “replace” older neurons in position and precise function, point out that neurons not previously connected can form new synapses together or change the strength of their synaptic connections. Tell the students that the vast majority of neurons they possess were formed in the womb. Since all neurons eventually die, this means that the net number of neurons one possesses decrease over time.
Ask students some additional questions:

- If a neuron is not killed but merely injured due to TBI, can it regenerate and repair itself?
  - This depends on what part of the neuron is damaged and where the neuron is located. In the human peripheral nervous system, axons can re-grow themselves at up to a half a centimeter per day! This regeneration is assisted in large part by glial cells, such as Schwann cells.

- How about damage to somata? Why may this damage be more serious?
  - The somata of neurons contain the nucleus and other organizing; it can be thought of as “upper management.” Therefore, if the soma is damaged, it is much less likely that the neuron can repair itself.

Explain that damage to the central nervous system can be far more dangerous. Ask the students why this may be the case.

- This is in part due to the density of cells, both neurons and glia, in the central nervous system. For example, damaged glial cells can form what are known as “glial scars” that prevent neuronal axons from re-growing themselves.

Close the discussion by asking the students to reflect on how human behavior might change if the nervous system were better able to regenerate or form new neurons.

STOP AND EVALUATE: Ask the students how the potential to protect and repair actual neurons differs from the protection and repair mechanisms inherent to the Newrons they designed. What are the relative advantages and disadvantages of each design? Solicit specific points of comparison from several different groups.

**Conclusion of Lesson**

Point out that much of what they have just discussed regarding actual neurons is summarized in their “Meet an Actual Neuron” student packet. For homework, students should use the “Meet an Actual Neuron” packet to complete the “Questions on Neurons” worksheet (U4_L4_Homework_QuestionsOnNeurons). Also, as in the previous two lessons, direct the students to complete the Lesson 4 journal entry for homework.

Now that the students have explored the macroscopic and microscopic structures of the nervous system in some detail, explain to student that they will be using this knowledge to investigate what happens to neurons (at the cellular level) after TBI.

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**Teacher Pedagogical Knowledge**

The Lesson Journals are completed for each lesson in the TBI unit, and they are used together as a review and assessment tool in the final lesson. Students will review material from the unit and will contribute to a class ‘zine’ that integrates ideas and
content from the unit. A zine (pronounced ZEEN) is a form self-publication with original text and images. Similar to a magazine, the topics are usually of a particular interest and the method of reproduction is via photocopiers.

**Assessments**
The following are formative formal assessments that can be used to evaluate students’ understanding of neurons and their role within TBI:

- Building Your Newron: Students design a novel neuron-type cell from first principles
- Evaluate Your Newron: Students evaluate their Newron designs after learning about an actual neuron
- Meet an Actual Neuron: Students synthesize what they learn in the post-activity discussion to complete several questions on neuronanatomy and neurophysiology
- Lesson Journal: Students complete a journal entry on their reflections about Lesson 4