YOUR BRAIN
NEUROSCIENCE AND SOCIETY

NEUROSCIENCE AND SOCIETY
Curriculum for High School Teachers

Unit 3: Neurons and Neurotransmission

Center for Neuroscience & Society, University of Pennsylvania

The Franklin Institute

Acknowledgments

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NOTE TO TEACHERS

From sensing to moving to thinking to feeling, neuroscience explains how we perceive and interact with the world around us. This field provides a rich opportunity for high school students to explore fundamental science, framed within the context of everyday decisions and new challenges they will face as they enter adulthood.

Information about the intersection between neuroscience and society abounds online and in the media, yet many sources are unreliable. Meanwhile, there are few textbooks on neuroscience and its societal applications that are designed intentionally for high school students. This curriculum, therefore, is a curated collection of resources—reviewed by experts and tested by teachers—to help you bring this fascinating content into your classroom.

The curriculum is intentionally modular to provide flexibility. Each unit can stand alone, ready to be incorporated into an existing biology, psychology, or other course. Alternatively, multiple units can be linked together to create a semester-long elective course.

You can adapt the content to meet the readiness and capabilities of your class as needed. You can select certain topics and activities to match your students' interest and skip others depending on time constraints.

The goal of the curriculum is to inspire excitement about and increase knowledge of neuroscience. The suggested activities include a variety of instructional approaches, and we encourage you to ask open-ended questions and guide conversations so students are interacting instead of being passive listeners. Students often find personal relevance in these topics, so feel free to extend activities and discussions.

If you feel you have reached the limit of your knowledge about a particular subject, don't worry! Even scientists may not know the answer. Neuroscience is still a developing field and you can create opportunities for you and your students to think critically and learn together. Use the provided links and documents as a gateway to finding additional sources and evaluating their quality.

Your feedback is also welcomed, of course. Please contact the program administrator at neuroscience@fi.edu with comments and suggestions. Thank you for all your hard work!

Alignment with Next Generation Science Standards

The "Neuroscience and Society" curriculum supports Next Generation Science Standards in the following areas.

High School – Life Science

HS-LS1 From Molecules to Organisms: Structures and Processes

Disciplinary Core Ideas

- LS1.A: Structure and Function
- LS1.B: Growth and Development of Organisms

Science & Engineering Practices

- Developing and Using Models

Crosscutting Concepts

- Structure and Function
- Stability and Change

HS-LS3 Heredity: Inheritance and Variation of Traits

Disciplinary Core Ideas

- LS3.A: Inheritance of Traits
- LS3.B: Variation of Traits

Science & Engineering Practices

- Asking Questions and Defining Problems
- Analyzing and Interpreting Data
- Engaging in Argument from Evidence

Crosscutting Concepts

- Cause and Effect
- Systems and System Models
- Science is a Human Endeavor

YOUR BRAIN

NEUROSCIENCE AND SOCIETY

NEURONS AND NEUROTRANSMISSION

This unit covers some of the basic biology of the brain. What are neurons exactly, and how do these cells allow information to be transmitted all the way from a finger (where you just got poked) to many different parts of the brain (that allow you to feel the pain and generate an "ouch" response)? This unit also lays the biological foundation for understanding the different ways in which drugs can act on the brain, which will be addressed in more detail in the "Drugs" unit.

LEARNING OBJECTIVES:

Students will learn that...

- Label the basic parts of a neuron and explain their function.
- Describe the basic characteristics of an action potential, including what causes it to fire in the first place and how myelin helps it to travel even faster and farther.
- Explain how neurotransmitters help pass the signal from one neuron to another neuron.
- Give examples of how neurotransmission can be disrupted or modulated by either disease or drugs.

TABLE OF CONTENTS:

TERMS AND DEFINITIONS

Neuron – Special type of cell in the body that has a unique structure (containing an axon and dendrites) and which transmits signals throughout the nervous system.

Glia – Another type of cell in the nervous system which does not transmit signals the same way that neurons do but plays many other important roles in the brain.

Axon – The part of a neuron that sends a signal on to the next neuron. Neurons only have one axon each, but this axon can branch into many axon terminals that connect to different neurons.

Action Potential – An electrical signal that travels down the length of a neuron's axon.

Dendrite – The part of a neuron that receives incoming signals. Neurons can have multiple dendrites.

Myelin – A fatty coating that wraps around axons. This allows the signal to travel faster and farther.

Synaptic Cleft – The region in between the axon terminal of the sending neuron and the dendrite of the receiving neuron. Neurotransmitters are released into this cleft to pass information between the neurons.

Neurotransmitters – The chemical messengers used to transmit information from one neuron to another. There are over 100 identified types of neurotransmitters (e.g. serotonin, dopamine, GABA). They are released from compartments called vesicles in the sending neuron and bind to receptors in the receiving neuron.

NEURONS

Neurons are the basic units of the nervous system that transmit signals through the body. They are a special type of cell that has "arms" (dendrites and axons) for receiving and transmitting electrochemical signals. They couldn't function, though, without glia. Glia are the other extremely important type of cell in the nervous system and are thought to outnumber neurons by a factor of 10 to 1. Neurons are extremely interconnected with each other, and this allows for the complex computations which are the basis of our thoughts and emotions.

Key Points:

- Neurons and glia are cells that make up the nervous system.
- There are 86 billion neurons in the brain.
- There are at least 10 times as many glia.
- On average, each neuron connects with 7,000 other neurons.
- Neurons have the unique ability to be electrically excited, so they can transmit signals very quickly throughout the body.
- Neurons have dendrites, which receive signals, and axons, which send signals.

Resources and Discussion Questions:

This University of Texas Health website offers an introduction to neurons and actions potentials.

This website has some basic facts about neurons and also demonstrates one way in which neurons can be categorized. Here is another picture of basic neuron types.

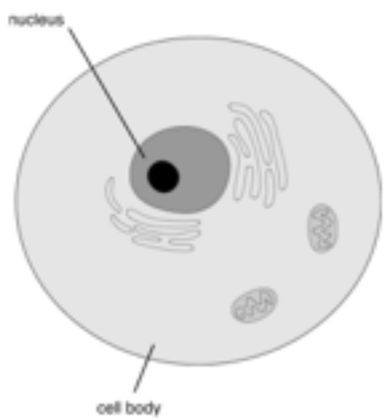
BrainFacts.org has a short description of neurons and the diversity in their structure.

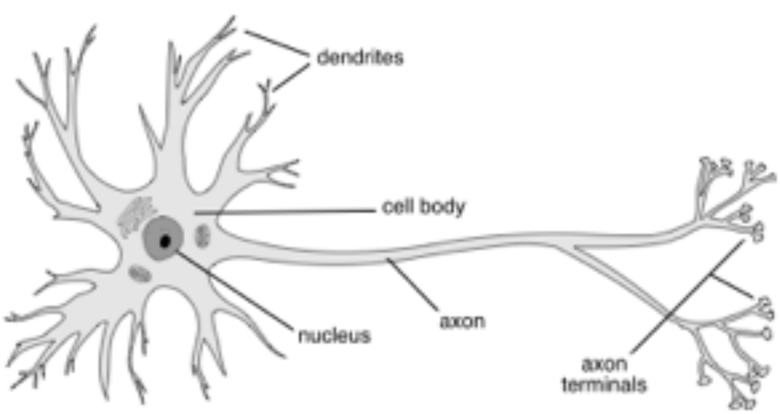
Boundless has some nice images and descriptions of the parts of a neuron on this page.

Classroom Activities:

Activity #1 – Structure of a Neuron

Display the two types of cells below (images taken from *The Brain: Our Sense of Self*) and ask students to make observations about the two cells. How are they similar, and how are they different? Students may say that the top cell is smooth and round, while the bottom cell is long and thin. They may comment that although both cells have a body and a nucleus, there appear to be some "extra" parts sticking out of the bottom cell.





Explain that the top cell is the most common type of animal cell, such as a skin cell. The bottom cell is a special cell that passes information throughout the body: a nerve cell, or neuron. Point out the three parts of the neuron: the dendrites, the cell body, and the axon. Explain that the dendrites receive information, and axons send it, and that the cell body does all the normal functions that would occur in any common animal cell. Briefly explain myelination.

Activity #2- Build a Network

This interactive site allows students to explore how neurons connect and send signals. Challenge students to build networks with different types of connectivity, e.g. a feedback loop or signal amplification through multiple branches.

Activity #3 – Neuron Function

Each student takes the role of a neuron. The student chooses one limb to act as an axon – the other limbs are the dendrites. In groups of 5, students connect to each other (dendrite to axon) and act out different scenarios of information transmission, such as:

1. Neuron A receives information from Neuron B
2. Neuron B receives information from Neuron A
3. Neuron C receives information from Neurons A and B
4. Neuron A receives information from Neuron B and Neuron B receives information from Neuron C

Now, create a huge neural network with all of the students in the class, and attempt to propagate a signal starting with the dendrite of just one student. Highlight the fact that neurons in the brain are highly interconnected with other neurons.

Assignment Ideas:

Assignment #1 – Model Neurons

Students build model neurons out of common objects found at home. Students must then present their neurons to the class and describe what they used to make the different parts of the neuron. For example, using fruit: a banana is the myelinated axon, grape stems are dendrites, and grapes are neurotransmitters. Building model neurons also works well with different colors of Play-doh or similar soft building materials.

ACTION POTENTIALS

Action potentials are the way that a signal in the nervous system travels from the cell body to the very end of the axon. It is an extremely fast way to transmit signals, and is electrical in nature. To make it even faster, many axons are coated in myelin, the fatty membrane of a glial cell. This fatty substance essentially insulates the axon so that signals can travel farther and faster. “White matter” describes the areas of the brain where many of these myelinated axons reside. Because fat is white, this is how white matter gets its color!

Key Points:

- The two important “forces” that lead to an action potential are electrical (differences in charge between two points) and chemical (differences in concentration between two points).
- At rest, the inside of the neuron is more negatively charged than the outside.
- If the signal arriving at the neuron is large enough, a process will begin that quickly depolarizes (makes more positive) and then repolarizes (returns to rest) the cell—this is the action potential.
- Action potentials are “all-or-none.” Their magnitude and duration do not differ based on the strength of the incoming signal, though the strength of the signals does influence the number of action potentials produced.

- At the end of the action potential, the membrane is "hyperpolarized" (more negative inside the cell than usual), meaning that it is harder for another action potential to occur immediately. This causes there to be at least a short pause between action potentials.
- Action potentials travel down the axon, often with the help of myelin that makes the signal faster and able to travel farther (saltatory conduction).

Resources and Discussion Questions:

This video from McGraw Hill shows how the movement of ions in and out of the cell creates an action potential.

A simple description of the action potential, with a few quiz questions at the end.

HowStuffWorks has a description of action potentials here.

An illustrated description of the molecular mechanism from a blog.

Another helpful video, which also explains the basics of how the potential travels down the axon.

A video which uses the metaphor of lighting a fuse to demonstrate how an action potential travels down the axon.

This video uses football as a context for describing the effect of traumatic head injuries on the structure and function of neurons.

Classroom Activities:

Activity #1 – Human Saltatory Conduction

Have ten students link hands, representing a non-myelinated axon. Five other students link hands but stretch to the same length, representing a myelinated axon.

When you say "go", the first student in each line, squeezes the hand of the next student, and so-on down the line. Try this a few times and see who wins each time. Since it should take the longer line about twice as long transmit the hand-squeeze signal to the end, this is a good example of one aspect of saltatory conduction. (See pg. 12 of this activity guide for more details).

Activity #2 – Action Potential Game

In this large group activity to get a "neuron" to reach its action potential threshold, teams of students race to toss ping pong ball "signals" into a "cell body" bucket. Instructions for facilitating the activity are found here.

Assignment Ideas:

Assignment #1 - Solve the Mystery

Explain to students what local anesthetics do (keep us from feeling pain). Have students:

- Research online to find out how this process works (blocks sodium channels).
- Have them write a short paragraph about why this would keep us from feeling pain, making sure that their description uses what they learned about action potentials.

SYNAPTIC TRANSMISSION

When the action potential reaches the axon terminal/synapse, a chemical process called synaptic transmission, or neurotransmission, begins. Neurotransmitters carry the signal from the axon (the pre-synaptic cell) to the dendrite of another neuron (the post-synaptic cell). There are over 100 identified kinds of neurotransmitters, though each neuron only uses a small number of these. Knowing about different neurotransmitters is the key to understanding how drugs influence behavior.

Key points:

- Vesicles filled with neurotransmitters (NTs) bind to the membrane and release the NTs into the "synaptic cleft."
- These NTs bind to postsynaptic receptors, which then allow either positive or negative ions into the postsynaptic dendrite through specific channels.
- If the incoming ions are positive, this creates an "excitatory post-synaptic potential." If they are negative, this creates an "inhibitory post-synaptic potential."
- NTs are brought back into the presynaptic terminal or broken down in the synaptic cleft.

Resources and Discussion Questions:

This video explains how synaptic transmission works.

Here is an audio recording of what firing neurons sound like.

Here is a video that has some interesting animations demonstrating the function of neurotransmitters.

This website gives basic information on neurotransmitters. It includes a link to a study guide.

This website gives an overview of neurons, synapses, action potentials, and neurotransmission.

This article from the NIH gives a good description of how drugs impact neurotransmission.

This is a fun online personality test from NIDA that asks 10 questions and then matches you with a "similar" neurotransmitter.

In what ways is the brain similar to and different from a standard computer?
The information processing aspect of neurotransmission has often led to the analogy of the brain as a computer. However, computer scientists have had a really hard time "replicating" the cognitive abilities of the human brain with computers. Some of the difficulties relate to the fact that brains have more computational power than digital computers (at least, for now). But there are other things that make brains fundamentally different from computers.

- Here is one list from the University of Washington about the similarities of a brain to a computer.
- Here is a good blog post on 10 important differences between brains and computers.

Classroom Activities:

Activity #1 – Neurotransmission Game

This is an active game that gets students involved in acting out the whole signal transmission process. Instructions for facilitating the activity are found here.

Activity #2 – Science in the Classroom: Annotated Article on Modeling Synapses

Science in the Classroom (SitC) is a collection of annotated research papers and accompanying teaching materials designed to help students understand the structure and workings of professional scientific research. This annotated paper, "Overcrowding in Neuronal Synapses" studied how making a 3D computer model of a synapse can tell us more about how neurons use synapses to communicate with each other.

- Assign small sections of the article to student groups to read and discuss during class (or in a computer lab, as the interactive article is web-based).
- Then have each group present or use a jigsaw method to teach the entire class what is in their part of the article.
- See the Teacher Resource guide that accompanies the article.

Assignment Ideas:

Assignment #1 – Jigsaw Classroom Research Project

Using a jigsaw cooperative learning approach, students are divided up into teams and each team is assigned a different aspect of researching how a particular drug affects neurotransmission and behavior. The drug could either be assigned by the teacher or picked by the group. A good resource is the book *Buzzed: The Straight Facts About the Most Used and Abused Drugs from Alcohol to Ecstasy.*

ANNOTATED RESOURCES

General Resources (for further reading and reference)

Neuroscience Online

University of Texas Medical School at Houston

This online resource has all of the information from a basic Intro to Neuroscience college course. Sections are written fairly clearly with many diagrams.

The Mind's Machine: Foundations of Brain and Behavior

Neil V. Watson and S. Marc Breedlove

This resource does not contain the actual text but has chapter outlines, study questions, figures and study questions, etc.

Articles

Why the White Brain Matters

Dana Foundation/Christopher M. Filley

We commonly equate the brain with "gray matter." To understand how brain changes affect behavior, or what causes brain disorders from Alzheimer's disease to multiple sclerosis, researchers are probing how "white matter" is essential to the brain's connectivity.