COLUMBIA | Zuckerman Institute

BIOBUS

BRAIN STEM | Bringing Neuroscience to the Classroom

TOPIC 3

Neurons

Supported by: BNY MELLON

Neurons

There are an estimated 86 billion neurons in the brain, and each neuron can form up to 1000 connections with other neurons. Students will learn how neurons send and receive electrochemical messages between each other and to the rest of the body.

Suggested Duration

- 2 x 45 min classes

Essential questions

- What is the biological basis of brain activity?
- What do neurons look like and how do they work?
- What is the relationship between the structure and function of cells?
- How does information travel to and from the brain?
- How do neurons' structures compare to other cells?

Objectives

Overall STEM goal: The brain and system work through neurons communicating with each other.

All students will...

- Discuss how a cell's structure relates to its function.
- Be able to identify the key structures of a neuron (i.e. axon; dendrites: cell body; axon terminal) and explain their functions.
- Understand how neurons communicate electrochemically between each other.
- Learn how neurons send and receive information to/from the body.
- Explore models that illustrate neural communication.

Advanced students will...

- Understand the "all or nothing" principle of action potentials.
- Identify factors that affect communication between neurons.

Materials

- Projector
- Blank poster paper
- Colored markers
- Plastic balls/marbles/pompoms

Supplementary materials

- Topic 3 slides: Neurons
- Topic 3 activity sheet: Comparing Neurons
- Topic 3 exit ticket: Labeling a Neuron

Instructional Activities

Class 1

1. Do Now | 10min

Use 'Topic 3 activity sheet'

Use 'Topic 3 slides'

Show students slide 3 and explain that the slide depicts an image of a common cell that exists in the body, next to an image of a brain cell (i.e. a neuron). Hand out the activity sheets and instruct students to compare and contrast the two cells, noting similarities and differences between the cells. Remind students how to use a Venn diagram.

Prompt students to think about:

What's so special about neurons? Why do they have this particular shape? What is common to all cells?

Discuss students' responses with the class, generating a class discussion.

Explain:

Similarities between cells:

- All cells have a cell membrane (selectively permeable to certain substances needed for the cells function), a nucleus with the cell's DNA, mitochondria, and other organelles.
- They all carry out processes such as energy production with ATP
- Many cells communicate with their neighbors, like neurons, endocrine system cells (system of glands that release hormones) are responsible for producing long range signals.

Differences between cells:

- Neurons have extensions called axons and dendrites that allow them to communicate with each other.
- Some types of neurons are the largest cells in the human body. Although some are very large, other neurons can be very small.
- Most neurons have a layer of myelin wrapped around them that acts as insulation and speeds conductivity of electrical signals.
- Body cells have all kinds of shapes and sizes. Their shape is tuned to their functions (e.g. white blood cells can change their shape depending on their state of activity). Neurons have a cell body surrounded by webs of receptors (called dendrites) and an axon that transmits signals to other neurons.
- Neurons function involves interacting and communicating with other neurons (they don't really function alone). Some body cells are units on their own, and achieve their functions alone. But many other cells also communicate with their neighbors like neurons do. For example, endocrine system cells, where hormones are produced and released, are responsible for producing long range signals.

EXTENSION

Microscopes: Ask students what tool allows researchers to look at cells. Discuss the microscope and how scientists use microscopes to view samples of cells and organisms that cannot be seen in detail with the human eye because of their reduced size.

2. Think Pair Share | 10min

Use 'Topic 3 slides'

Show students slide 5 and discuss how the shapes of different cells gives us information about their functions. Ask students to:

- Identify the different cells (on slide 5).
- Think about what part of the body might they be located?
- Think about what the functions of these cells might be.

Students should first have some time to think individually about these questions, and then share their thoughts with a partner. After paired disussion, allow students to share their answers with the class and generate a class discussion. Show students slide 6 and discuss:

- Different cells have different structures due to the role that they play. Here are some examples of how these cell structures might be related to their function in the human body:
- Skin cells have this shape to "stick" together, like tiles piling up to form a wall, to create a protective barrier from external environment.
- Sperm cell needs a tail-like structure for swimming, so that they can reach female eggs for fertilization.
- Blood cells have this shape because they need to pack as much hemoglobin as possible to carry oxygen and need to squeeze through capillaries.
- Muscle cells have this shape because they need to be flexible, contracting and relaxing with movement.
- Neurons have this shape because of they role in communicating and sending messages to other neurons. Some neurons have these long axons to send messages from very far distances.

3. Video | 10min

Use 'Topic 3 slides'

Show students slides 7 and use presenter notes for content to discuss with the class.

Show students the video from *Neurotransmissions: What is a neuron? (Min 0:19 - 3:35)* and follow with direct instruction. Instruct students to take notes during the video about the functions of the different parts of the neuron's structure to discuss afterwards with the class.

NOTE: Alternative video options are available in the student resources section.

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4. Neuron Anatomy | 15min

After watching the video, show students slides 8-9 that with labelled diagrams of a neuron. Guide students through a discussion, asking questions about the role of each part and instructing them to refer to what they learned in the video.

BACKGROUND

Cell body: keeps cell alive and functioning. Where the DNA of the cell sits in the nucleus.

Dendrites: (that look like tree branches) the receivers of information into the neuron - can receive hundreds or thousands of inputs from other neurons.

Axon: if a signal is strong enough, passing the threshold, it runs down the axon. Axons vary in lengths.

Axon terminals: The end of the axon, where the signal is then sent to the dendrites of other neurons (to send information/messages).

For differentiation

- Have students identify other key parts of the neuron, such as the axon hillock or myelin sheath.

EXTENSIONS

- 'Create a neuron' model activity:
  - Divide students into groups of 3-5 students (depending on class size). Assign reading to students from the table below.
  - Tell students to read and annotate the texts, highlighting information about the structure and function of the neuron.
  - Provide each group of students with different materials to construct a model neuron. Material ideas include: pipe cleaners, pom poms, textile scraps, different coloured paper, markers, cardboard, clay/Play Doh.
  - Instruct students to construct a model of a neuron using the materials available. All models must include: Cell body, nucleus, dendrites, axon, axon terminals.
  - Students should label each part and accompany their label with a short description of the function of that structure.
- Introduce glial cells, the cells that co-exist with neurons in the brain and provide them with nutrition and support. You can ask students to research the function of these cells and include these in their posters.
- Start engaging students in the concept of neural communication by asking students to research how neurons communicate with each other as homework.

Class 2

5. Visualizing Neural Communication | 5min

Show students animations of neurons communicating. While watching each one you can prompt students to think about what they are seeing in the animations and ask questions about the neurons structure (as a reminder of last class) and how they work. Discuss:

1. vimeo.com/292869793 - A message is received in the dendrites of the axon, runs down the axon as an electrical signal, and is sent across to a neighbouring neuron. Point out that neurons are not actually touching.
2. vimeo.com/16272760 - Networks of thousands of neurons are connected and sending messages every second between each other.
3. vimeo.com/122392443 - The gap between two neurons is a synapse and here the message is converted from an electrical message to a chemical one.

6. Direct Instruction | 10min

Use 'Topic 3 slides'

Show students slide 11 and ask students what direction they think information flows between the two neurons? Prompt them to think about what they already know about the neuron's anatomy.

Continue guiding students through slides 12-13. **Explain** to students some key points of neural communication highlighted in the box below:

KEY POINTS

- There are two types of signals sent when neurons communicate: electrical and chemical.
  - A chemical signal is received in the dendrites of the neuron.
  - The chemicals received in the dendrites might cause a change in the electrical state of the neuron (measured in voltage). A specific level of electrical stimulation is needed to be reached in the neuron's cell body to generate an electrical signal in the neuron, an action potential. If this threshold is reached, the electrical signal is sent down the axon of the neuron.
  - This signal arrives at the axon terminal and initiates a chemical signal across the synapse - the gap between the two neurons.
  - The chemical messengers sent between two neurons are called neurotransmitters. They are released by neurons at the synapse for the purpose of relaying information to other cells.
  - If enough neurotransmitters are received in the third neuron, an action potential is triggered, and so on across multiple neurons.
- Neurons send messages to multiple neurons at once, some are connected to 1000s of other neurons.
- Action potentials follow an "all or nothing" principle. If the signal received is strong enough, an action potential occurs, sending signals across the axon. It is always a full response, you cannot have strong or weak action potentials. It either occurs, when the signal reaches the threshold, or it doesn't occur at all. This minimizes the chances of information getting lost when neurons communicate.
  - What can change is the types of signals received or the speed at which the signal travels down the axon.

PROMPT: Prompt students to think about examples that can illustrate the "All or nothing principle" e.g. firing a gun.

EXTENSIONS

- Demonstrate the "All or nothing" principle: Attach kitchen roll/paper towels onto a bowl. Always using the same sized coins, place one by one the coins on top of the paper towel (you might want to have the paper towel slightly wet). Once the paper towel breaks, this is when a threshold is hit and the full signal is sent (all coins fall into the bucket).
- You can go more in depth into the resting potential of the neuron and the ions involved in the electrochemical communication between neurons. Refer to the resources section.

7. Modelling Neural Communication | 25min

Option 1 (advanced level):

Students are divided into groups and each group is required to generate a model that illustrates neural communication - how neurons send messages between themselves and to a muscle, initiating movement.

Describe the scenario
You are playing a game in your living room and accidentally hit your mom's glass vase standing next to you. You must react quickly to catch it before it drops on the floor and breaks. Tell the class you are going to model how this information is transmitted from your brain to the muscles in your hand so that you can quickly catch the vase.

With little guidance, students can be creative, thinking about different ways to illustrate how neurons send signals between each other and to the muscle, so that the person can catch the vase.

They can use themselves or other students (with permission), arts and crafts materials, drawings or diagrams, or computers, to generate their models.

Option 2 Fishbowl activity (First level):
This fishbowl activity uses human models to illustrate how neurons send messages between themselves, and from the brain to our muscles. Discuss how most of what we do depends and is a consequence of neural communication, from speaking to seeing, to blinking, thinking, walking, and breathing.

Differentiation
You can have students attempt to design the human model of neural communication themselves, providing them with only partial guidance, or you can follow the model actvitiy steps as described below:

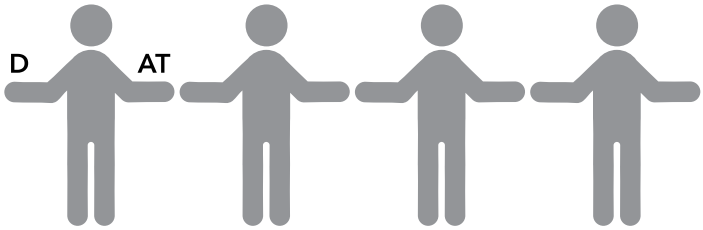
1. Ask for four volunteers and have the students stand in a line facing the rest of the class. The first four students are neurons, and the last student at one of the ends is a muscle nerve.

2. Student volunteers stand with their arms open, with the hands almost touching each other but leaving a gap (i.e. the synapse).

3. Prompt students in the audience to decide how to label the different parts of the neurons by placing post-its on relevant part. For example: the right hands are dendrites (D); left hands are axon terminals (AT) and the body is the Axon (A), as seen in the diagram below:

Keep the audience engaged while the model is at work. Prompt students to describe what the different parts of the neuron model are, their functions and what is happening as the model is at work. Ask questions such as:

- *Where are the dendrites?*



AT = Axon Terminal D = Dendrites

- *In what direction is the signal being sent?*
- *What do the balls represent?*
- *What is the gap between the two hands called?*

Here you can explain to students why the hands of the neurons do not touch each other, i.e. they represent the synapse. This is where chemical messengers (and information) are sent from axon terminals to receptors in the dendrites of close-by neurons.

4. Place 3 balls (neurotransmitters) in the axon terminals of all students representing neurons. Ask students what the balls might represent? Discuss how the balls represent the neurotransmitters, the chemical messengers that are stored in vesicles in the axon terminals of neurons.

5. Start the neural transmission model, choosing the direction of information flow.

- Tap the first neuron and explain that this is the sensory input received in the brain when you see that the vase is falling.
- The first neuron is activated, threshold is reached, and an action potential occurs (and

students representing neurons should make a movement that represents the action potential passing through them).

- The first neuron sends a message to the second neuron by releasing the balls from his axon terminals into the synapse, being picked up by the second neurons dendrites. Discuss that dendrites in the second neuron have specific receptors for those chemical messengers, picking up the neurotransmitters.
- Discuss how the signal picked up by the second neuron must generate a change in electrical charge inside the neuron that reaches a necessary threshold for an action potential to occur in the second neuron. If the second neuron picks up all the balls, and the signal is strong enough (passing the minimum threshold), an action potential (electrical signal) is sent down the axon. Once the action potential reaches the axon terminals of the second neuron, it causes once again the release of neurotransmitters from the second neuron into the synapse.

PROMPT: Prompt students to think about what might happen to the information flow when neurons don't pick up all the neurotransmitters?

- Follow the same signal transmission principles through to the third neuron. Once the signal reaches the fourth student (i.e. the muscle nerve), the student should make a movement showing that the signal was received, causing the muscle to flex (and the hand react to catch the vase).

6. Have students repeat this model of neural communication several times. Discuss how these signals are sent between neurons at extremely high speeds and thousands of signals are being sent per minute in our brains.

NOTES:

- Neurotransmitters do not travel in the neuron. When enough neurotransmitters are attached to receptors and the necessary activation threshold is reached in the neuron, an electrical signal called an action potential is sent down the axon until it reaches the axon terminal, causing the release of neurotransmitters.
- Dendrites do not absorb neurotransmitters. These attach to receptors and then drop off, with some of them later on being recycled back into the neuron's action terminals.

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8. Exit Ticket | 5min

Use 'Topic 3 exit ticket'

Hand out and give students time to complete the exit ticket on labelling a neuron and collect tickets at the end of class.

EXTENSION

Divide students into groups so that all students try the model and explore it further. Below are a few options to take the model a step further:

- Expand the model to use different examples of different types of neurons (e.g. inhibitory vs excitatory neurons; interneurons), neurons from different locations (e.g. occipital lobe vs spinal cord) or different types of messages and neurotransmitters (e.g. experiencing pain).
    - For example, introducing inhibitory neurotransmitters: Add a new neuron and a new coloured ball, explaining to students that the new neuron sends inhibitory signals to the dendrites of the next neuron. The next neuron integrates these signals and if there is a net effect with more inhibitory signal than exhitatory, it stops further signals from being transmitted.
- Have students research what factors influence the rate of neural transmission, looking at substances that accelerate or slow down communication between neurons. Examples include chemical factors (e.g. neurotoxins), myelination of the neurons, size of the axons, number of receptors, etc).

Resources for Students

FIRST LEVEL	2-Minute Neuroscience (video): The Neuron	https://www.youtube.com watch?v=6qS83wD29PY&list=PLNZqyJnsvdMqFNFyHvMFrFnlXLosnwwB_&index=1
	Crash course (video): Nervous system	https://www.youtube.com/watch?v=qPix_X-9t7E&t=14s
	Neuroscience for Kids (reading)	https://faculty.washington.edu/chudler/cells.html
	Eyewire: How neurons connect (reading)	https://science.eyewire.org/science-mapping-neurons
	Neuroscience for Kids: Glial cells (reading)	https://faculty.washington.edu/chudler/glia.html
	Neurotransmissions: What is a neuron? (video)	https://www.youtube.com/watch?v=UDpydfpEads&t=137s
MEDIUM LEVEL	Brain facts: The Neuron (article)	http://www.brainfacts.org/brain-anatomy-and-function/cells-and-circuits/2012/nuts-and-bolts-the-neuron
	BioEd: Neurons (video)	http://www.bioedonline.org/videos/lecture-series/your-brain-is-you/neuron-to-neuron/
	BNA.org: Neurons (pages 4-6)	https://www.bna.org.uk/static/uploads/resources/BNA_English.pdf
	Crash course (videos)	Action potentials: https://www.youtube.com/watch?v=OZG8M_IdA1M&t=621s Synapses: https://www.youtube.com/watch?v=VitFvNvRIIY
	Khan Academy: Action potentials	https://www.khanacademy.org/test-prep/mcat/organ-systems/neuron-membrane-potentials/a/neuron-action-potentials-the-creation-of-a-brain-signal
ADVANCED LEVEL	Chemical neuro-transmission (animation)	http://www.mind.ilstu.edu/curriculum/neurons_intro/flash_chemical.php
	Brain Facts Book (Chapter 1)	https://www.brainfacts.org/the-brain-facts-book

ADVANCED LEVEL	Detailed explanation of synapses (video)	https://vimeo.com/205794541
	2-minute neuroscience: Synaptic transmission (video)	https://www.youtube.com/watch?v=WhowH0kb7n0
	Scientific American: Discovery of the neuron (article)	https://blogs.scientificamerican.com/brainwaves/know-your-neurons-the-discovery-and-naming-of-the-neuron/
	Brain Facts: Glial cells (article)	http://www.brainfacts.org/archives/2010/glia-the-other-brain-cells

Resources for Educators

Background Reading	
Brain Basics: The life and death of a neuron	https://www.ninds.nih.gov/Disorders/Patient-Caregiver-Education/Life-and-Death-Neuron#Birth
Neurons and Action potentials (Page 4-8)	https://www.bna.org.uk/static/uploads/resources/BNA_English.pdf
Overview of neuron structure and function	https://www.ncbi.nlm.nih.gov/books/NBK21535/
Know your neurons (Scientific American article)	https://blogs.scientificamerican.com/brainwaves/know-your-neurons-classifying-the-many-types-of-cells-in-the-neuron-forest/
Neurons: A curious collection of shapes and sizes	http://www.brainfacts.org/archives/2012/neurons-a-curious-collection-of-shapes-and-sizes
Educational Activities	
Brain Facts: Neuron model activity	http://www.brainfacts.org/for-educators/for-the-classroom/2017/light-up-neuron-092717 : Activity for students to create a light-up model of a neuron
Building virtual neuronal circuits (lesson plan)	http://brainu.org/lesson/virtual-neurons
Metaneuron: Exploring an interactive neuron simulation program	http://www.metaneuron.org/
Eyewire: "Map the brain game"	https://eyewire.org/: Students can play a 3D neuron game that helps us understand how neural connections are formed.

Vocabulary

Action Potential	An electrical charge that travels along the axon to the neuron's terminal, where it triggers the release of a neurotransmitter. This occurs when a neuron is activated and temporarily reverses the electrical state of its interior membrane from negative to positive.
Axon	The fiber-like extension of a neuron by which it sends information to target cells.
Cell Body	Also called the soma, the part of a neuron that contains the nucleus (with DNA) and the organelles, but not the projections such as the axon or dendrites.
Dendrite	A tree-like extension of the neuron cell body. The dendrite is the primary site for receiving and integrating information from other neurons.
Neuron	A nerve cell specialized for the transmission of information and characterized by long, fibrous projections called axons and shorter, branch-like projections called dendrites.
Neurotransmitters	Chemical messengers released by neurons at a synapse for the purpose of relaying information to other cells.
Synapse	A physical gap between two neurons that functions as the site of information transfer from one neuron to another.
Threshold	Minimum amount of input signal needed for the neuron to fire an action potential.

Standards

CONTENT SPECIFIC CURRICULUM STANDARDS	Developing and Using Models Engaging in Argument from Evidence Obtaining, Evaluating, and Communicating Information
NEXT GENERATION SCIENCE STANDARDS (NGSS)	Life Sciences: HS-LS1-2: From Molecules to Organisms: Structures and Processes Crosscutting concepts: HS-LS1-1 HS-LS1-3 HS-LS1-4
COMMON CORE STATE STANDARDS	CCSS.ELA-LITERACY: RST.9-10.3 CCSS.ELA-LITERACY: RST.9-10.4 CCSS.ELA-LITERACY: RST.11-12.7 CCSS.ELA-LITERACY: RST. 11-12.9 CCSS.ELA-LITERACY: SL.9-10.1 CCSS.ELA-LITERACY: SL.9.-10.5 CCSS.ELA-LITERACY: SL.11-12.1

Credits and Sources

BioEdOnline: http://www.bioedonline.org/

BrainFacts: https://www.brainfacts.org/

Brain Facts Glossary: https://www.brainfacts.org/glossary

BrainU.org

EyeWire: https://science.eyewire.org/

National Institutes of Health / National Institute of Neurological Disorders and stroke: https://www.education.ninds.nih.gov/

Neurotransmissions Youtube channel

Vimeo

2-Minute Neuroscience Youtube channel

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