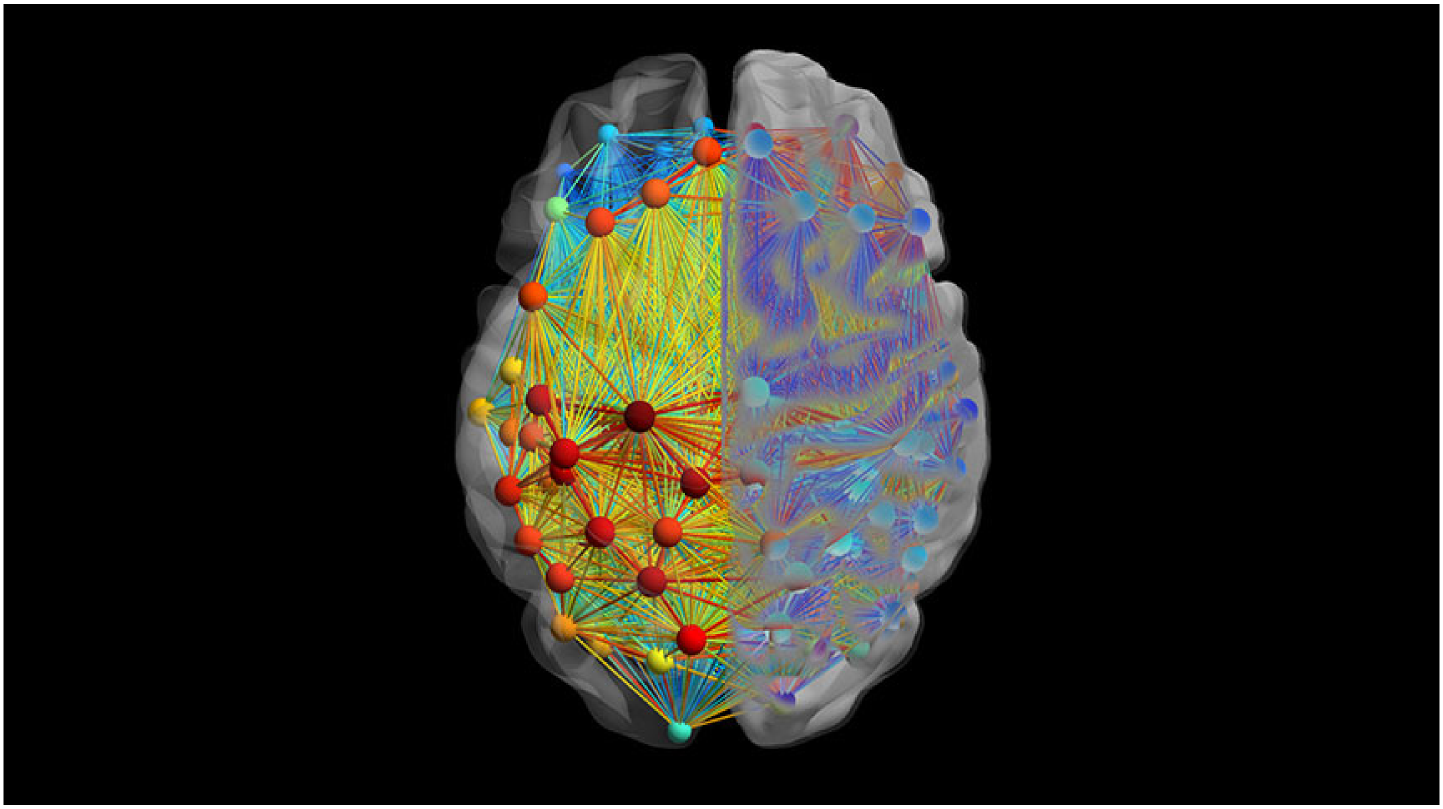
Science News

IN HIGH SCHOOLS | EDUCATOR GUIDE



Stefan Fuertinger and Kristina Simonyan, Icahn School of Medicine at Mount Sinai/NIH/Flickr (CC-BY-NC)

September 16, 2017

Flex Time

SOCIETY FOR SCIENCE & THE PUBLIC

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Flex Time

About the Issue

***Science News* article(s):** "Flex time"

Readability score: 10.2

***Science News for Students* article(s):** "Brain may need flexible networks to learn well"

Readability score: 7.8

The article "Flex time" describes how flexible brains might make for better learning. Students can focus on details reported in the article, follow connections to earlier articles about the neuroscience of learning and explore cross-curricular connections to other major science topics such as the biology of neurons or how magnetic resonance imaging (MRI) works. In a related activity, students can study prepared microscope slides of a variety of neurons and explore how these cells learn by creating models of interconnected neurons.

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What's in this Guide?

Article-based observation: Questions focus on how regional brain connections are altered as the brain learns and why studies are different than previous studies of individual neurons.

Quest through the archives: Use this short section to explore other articles about the neuroscience of learning as reported by *Science News* since 1924.

Cross-curricular discussion:

Physical Sciences questions involve the basic principles of magnetic resonance imaging (MRI), used in some studies of the brain.

Biological Sciences questions concern neurons, synapses and long-term potentiation at the synapses during learning.

Engineering and Experimental Design questions deal with sources of noise during resting state functional MRI, applications of MRI and improving learning.

Activity: How do neurons form connections?

Purpose: To have a better understanding of what neurons look like, how they are interconnected and how learning changes brain connections.

Procedural overview: Create your own data table to study prepared microscope slides of neurons from different types of nervous system tissue and create model neurons to demonstrate how connections among the neurons are altered during learning.

Approximate class time: 30 to 50 minutes.

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Standards

Next Generation Science	Common Core
Motion and Stability: Forces and Interaction: HS-PS2-6	ELA Standards: Reading Informational Text (RI): 1, 2, 4, 5, 7
From Molecules to Organisms: Structures and Processes: HS-LS1-2, HS-LS1-3, HS-LS1-6, HS-LS1-7	ELA Standards: Writing (W): 1, 2, 3, 4, 6, 7, 8, 9
Heredity: Inheritance and Variation of Traits: HS-LS3-1, HS-LS3-2	ELA Standards: Speaking and Listening (SL): 1, 2, 4, 5, 6
Biological Evolution: Unity and Diversity: HS-LS-4-2, HS-LS-4-3, HS-LS-4-4	ELA Standards: Reading for Literacy in Science and Technical Subjects (RST): 1, 2, 3, 4, 5, 7, 8, 9
Engineering Design: HS-ETS1-1, HS-ETS1-2, HS-ETS1-3	ELA Standards: Writing Literacy in History/Social Studies and Science and Technical Subjects (WHST): 1, 2, 4, 7, 8, 9

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Article-Based Observation: Q&A

1. What is a synapse and how do synapses change during learning?

Possible student response: Synapses are bridges or connections between nerve cells (neurons). Synapses among different neurons form, strengthen or weaken as one learns and stores new information.

2. How do the new studies reported in the article differ from previous neuroscience studies of synapses? What metaphor is used to describe the comparison between the studies?

Possible student response: The new studies examine the large-scale connections between regions of the brain, rather than synapses between individual neurons. The author describes studies that focus on individual neurons as missing "the forest for the trees."

3. What do the researchers mean when they say that a brain region is flexible? Do scientists think that all brain regions are flexible?

Possible student response: A flexible brain region can quickly connect to different brain regions, almost like being able to send e-mails to different people in quick succession. But not all brain regions are considered flexible. Some brain regions always send neural signals to the same brain regions, like only being able to send e-mails to the same people.

4. How did cognitive neuroscientist Raphael Gerraty and colleagues use associations between faces to study learning, and what did they find?

Possible student response: Volunteers were previously trained to associate a pair of faces and to associate one of the two faces with a reward. The volunteers were then tested to see how their brain reacted to the face that was not previously associated with the reward to see if a transfer of learning occurred. The brains of volunteers were scanned to measure flexibility or strength of connections among different brain regions. The observed connections were different in good learners compared with poor learners; for example, good learners had weaker connections between the ventromedial prefrontal cortex (which is involved in self-control and decision making) and the hippocampus (which is involved in memory).

5. What did neuroscientist Vinod Menon and colleagues find when they scanned the brains of children with and without disabilities doing math?

Possible student response: Children with developmental dyscalculia who had trouble doing math problems had more connections among brain regions associated with mathematical problem solving than children who did not have the disability. Menon suggests that when compared with other brain regions, overconnected brain regions might not be as responsive to making new connections or breaking down old ones during the learning process.

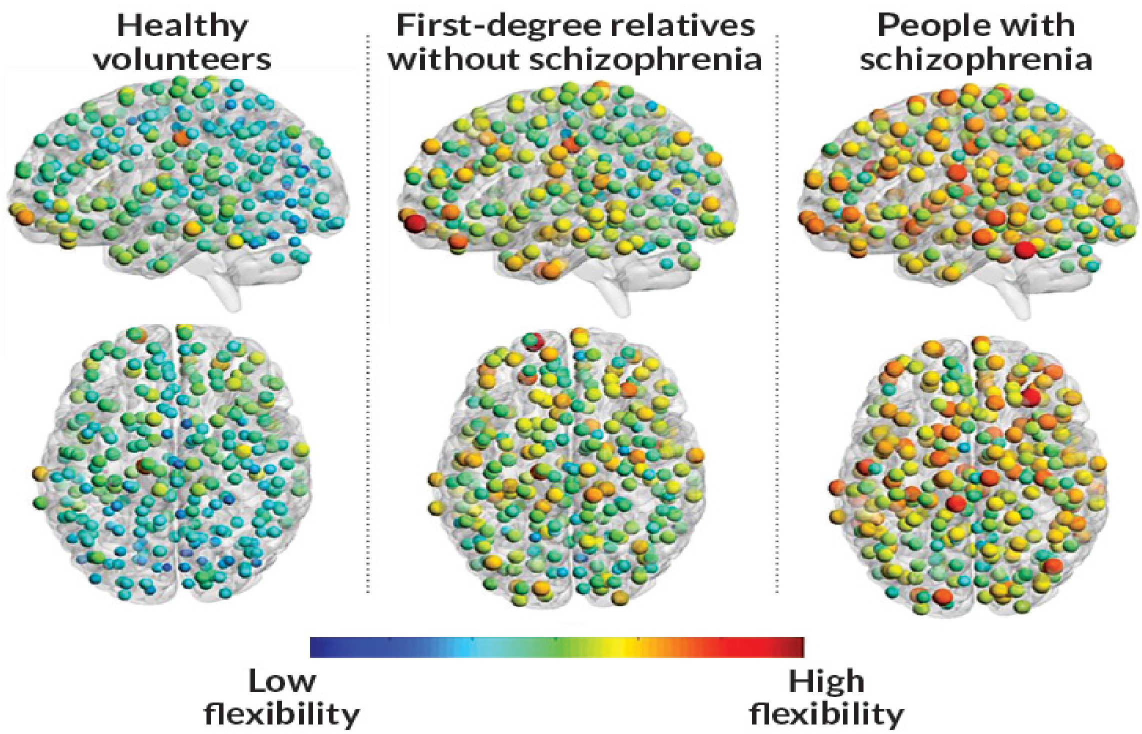
6. What did Danielle Bassett and colleagues find when they scanned the brains of volunteers learning to tap out sequences on a keyboard? What could their finding imply about fast learners?

Possible student response: As the volunteers learned, some connections grew stronger and some grew weaker. For example, connections between the frontal cortex and the cingulate regions of the brain — which may be associated with paying attention, setting goals and making plans — decreased as people learned. Faster learners had fewer of those connections as their learning progressed, which may have made their brains more efficient.

7. How is learning efficiency generally related to brain flexibility?

Possible student response: Faster learning appears to be associated with a certain degree of increased brain flexibility, or the ability of brain regions to change their communications with other brain regions instead of maintaining the same rigid connections.

8. Use the diagram, called "Too much of a good thing," to describe how schizophrenia relates to flexibility in brain regions in this study.



U. Braun **et al/PNAS *2016***

Too much of a good thing Compared with healthy people (top row), people with schizophrenia (bottom) and their close relatives (middle) showed signs of more flexibility across their brains. The greater the flexibility, the larger the spheres and redder the color.

Possible student response: People with schizophrenia appear to have unusually high levels of brain flexibility when they are asked to perform a recall task. As shown in the figure, people with schizophrenia have more brain flexibility than their first-degree relatives who do not have schizophrenia, and in turn, those first-degree relatives have more brain flexibility than other healthy volunteers.

9. What important gap remains between the previous studies of synapses and the studies reported in this article?

Possible student response: Previous studies of individual neurons examined the brain at a very microscopic level. The studies reported in this article describe at a more macroscopic level how brain regions communicate with each other. What is currently missing is the middle ground that shows how the microscopic and macroscopic views of brain function are related.

10. What positive aspect can you take away from this article as you move forward in your own learning this year?

Possible student response: The brain is constantly building neural pathways as it learns and changes in real time. Even if you aren't extremely efficient at a task at first, your brain will likely become more efficient over time. Also, staying in a positive mood may be a way to increase brain flexibility and learn faster, though it hasn't yet been concluded from studies to date.

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Article-Based Observation: Q

Directions: Read the article "Flex time" and then answer these questions.

1. What is a synapse and how do synapses change during learning?

2. How do the new studies reported in the article differ from previous neuroscience studies of synapses? What metaphor is used to describe the comparison between the studies?

3. What do the researchers mean when they say that a brain region is flexible? Do scientists think that all brain regions are flexible?

4. How did cognitive neuroscientist Raphael Gerraty and colleagues use associations between faces to study learning, and what did they find?

5. What did neuroscientist Vinod Menon and colleagues find when they scanned the brains of children with and without disabilities doing math?

6. What did Danielle Bassett and colleagues find when they scanned the brains of volunteers learning to tap out sequences on a keyboard? What could their finding imply about fast learners?

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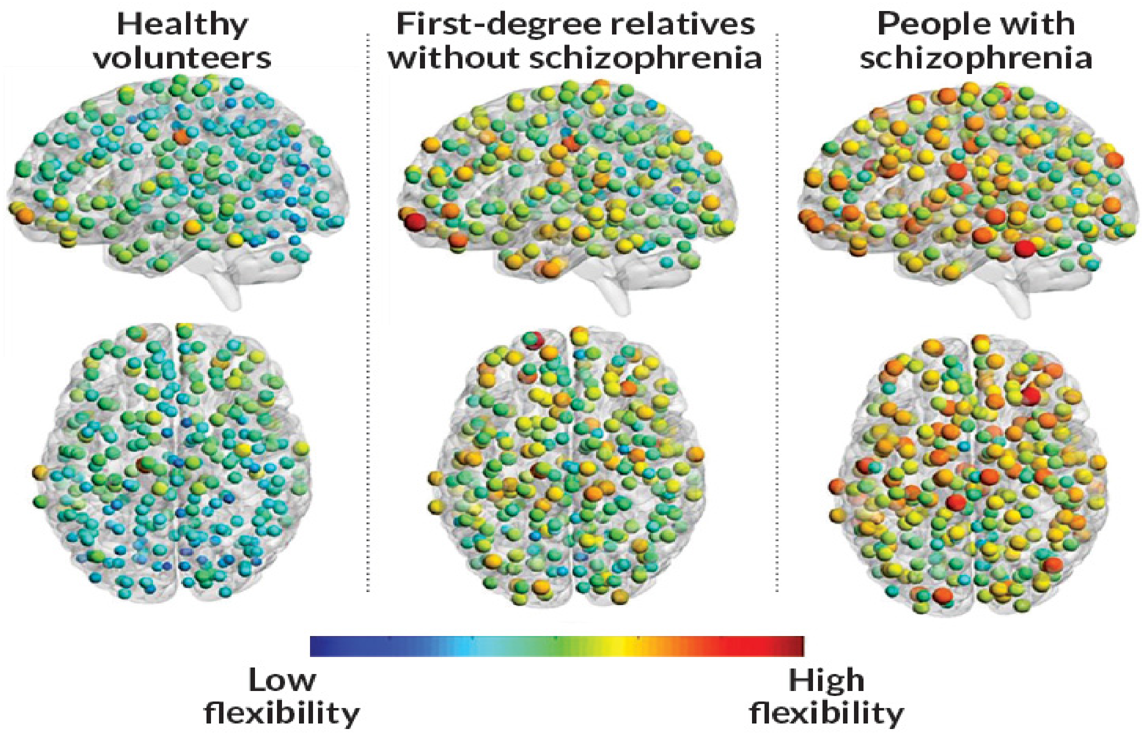
8. Use the diagram, called "Too much of a good thing," to describe how schizophrenia relates to flexibility in brain regions in this study.



U. Braun **et al/PNAS** ***2016***

Too much of a good thing Compared with healthy people (top row), people with schizophrenia (bottom) and their close relatives (middle) showed signs of more flexibility across their brains. The greater the flexibility, the larger the spheres and redder the color.

9. What important gap remains between the previous studies of synapses and the studies reported in this article?

10. What positive aspect can you take away from this article as you move forward in your own learning this year?

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Quest Through the Archives: Q&A

1. Long-term potentiation, or LTP, is an important process in which individual connections between neurons are strengthened during learning. Can you find an article about using LTP to make mice smarter?

Possible student response: The article "Gene tinkering makes memorable mice," published 9/4/1999, discusses how a group of scientists genetically engineered mice to have more receptor subunits involved in LTP. Compared with normal mice, the engineered mice more easily remembered the location of an underwater platform that they could stand on instead of swimming, more quickly learned that a sound was associated with getting shocked and were more likely to explore new objects instead of ones that they had seen before.

2. The network of connections among neurons in the brain is called the "connectome." Can you find an article that explains how the connectome can be studied by functional magnetic resonance imaging (fMRI)?

Possible student response: The article "Cataloging the connections," published 2/22/2014, gives a detailed overview of brain-mapping projects. One of the article's sidebars, called "The functional connectome," explains that increased blood flow is used as a proxy for local brain activity and can be measured by functional magnetic resonance imaging (fMRI). Different regions of the brain that are consistently active at the same time are thought to be connected.

3. Connected brain regions that are most active when the brain is at rest make up the "default mode network." What is the earliest *Science News* article you can find about the default mode network, and what does it say?

Possible student response: The article "You are who you are by default," published 7/18/2009, provides a great overview of the default mode network. It describes how the network can be visualized through both fMRI and positron emission tomography (PET) scans of the brain. The article discusses the roles that the default mode network could play in a wide range of situations, including daydreaming, personal identity, childhood development, schizophrenia and Alzheimer's disease.

Flex Time

Quest Through the Archives: Q

Directions: After reading the article "Flex time," log in to your *Science News* in High Schools account and use the Search page to answer these questions. Make sure you adjust the filters to include articles written before 1999, if the question requires you to do so.

1. Long-term potentiation, or LTP, is an important process in which individual connections between neurons are strengthened during learning. Can you find an article about using LTP to make mice smarter?

2. The network of connections among neurons in the brain is called the "connectome." Can you find an article that explains how the connectome can be studied by functional magnetic resonance imaging (fMRI)?

3. Connected brain regions that are most active when the brain is at rest make up the "default mode network." What is the earliest *Science News* article you can find about the default mode network, and what does it say?

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Cross-Curricular Discussion: Q&A

Directions: After students have had a chance to review the article "Flex time," lead a classroom discussion based on the questions that follow.

PHYSICAL SCIENCES

Discussion questions:

1. What is magnetic resonance imaging and how does it generally work?

[*Magnetic resonance imaging (MRI), uses very powerful magnetic fields to interact with and measure the weak magnetic fields of atomic nuclei. Different types of atomic nuclei contain different numbers of protons and neutrons, and therefore have different magnetic fields, so MRI can distinguish between different elements (nuclei with different numbers of protons) and even different isotopes of the same element (nuclei with different numbers of neutrons but the same number of protons). Thus MRI can measure the amount and location of certain elements or isotopes within an object. The MRI's strong magnetic fields can be used to create images of certain organs and tissues in live humans.*]

Extension prompts:

2. What is functional magnetic resonance imaging and how can it be used?

[*Functional magnetic resonance imaging (fMRI) uses MRI to create real-time maps of oxygen (or oxygenated blood) in a person. Like all human cells, neurons need oxygen, and the more active a neuron is, the more oxygen it draws from the blood. Therefore fMRI can measure the relative activity of different areas of the brain. For example, if a person is asked to do a specific mental task while in an fMRI scanner, regions of the brain involved in performing that task will light up on the image.*]

3. What is resting state functional magnetic imaging?

[*In resting state fMRI, the person whose brain is being imaged is not given a specific task to perform. Thus any brain areas that light up on the image indicate random thoughts or the natural resting state of human consciousness and personality. fMRI is so sensitive that it can detect signals that are in a very small region, very brief and/or very weak. Sophisticated data processing algorithms can find correlations between different regions that experience a signal at the same time after filtering out uncorrelated signals, random noise, head motion and other factors.*]

BIOLOGICAL SCIENCES

Discussion questions: Depending on the level of your class, you may preface this discussion with this brief NBC Learn video describing how neurons process information.

1. Describe the structure of a neuron.

[*Like other human cell types, a neuron has a cell body with a nucleus. However, it also has outstretched tentacle-like structures that help it communicate with other neurons. Dendrites are tentacles that receive signals from other neurons, and neurons have many dendrites. Axons are tentacles that send signals to other neurons, and most neurons only have one axon*.]

2. How does a neuron send signals within itself, and from one neuron to another?

[*An electrical signal within a neuron is called an action potential, and it propagates down the axon away from the cell body*. *The action potential is binary — it either happens or it doesn't happen, like a sneeze. The gap between the end of the axon of one neuron and a close neighboring dendrite of a second neuron is called a synapse. When the first neuron has an action potential, it releases chemical molecules called neurotransmitters from the end of its axon. Protein sensors called receptors on the dendrite of the second neuron detect the neurotransmitters. Some types of neurotransmitters are excitatory (urging the second neuron to fire its own action potential) and some types are inhibitory (urging the second neuron not to fire). Different types of neurons produce different neurotransmitters, and have receptors that specifically detect different kinds of neurotransmitters. The second neuron will react to the excitatory and inhibitory inputs that all of its dendrites receive from neighboring neurons and either fire an action potential or not.*]

Extension prompts:

3. What is long-term potentiation and how does it work?

[*Long-term potentiation is a process for forming long-lasting connections between neurons during learning. Pavlov's dog can be used as an oversimplified example of this process to explain the basic concept. The dog learns that a bell is rung whenever food is given, and eventually will learn to drool with hunger when the bell is rung even without food because of long-term potentiation. To describe long-term potentiation, suppose that the dog's brain has one neuron that causes the dog to slobber, a second neuron that lights up when the dog sees food, and a third neuron that lights up when the dog hears a bell. Initially there is only a strong connection from the food neuron to the slobber neuron. An action potential releasing neurotransmitters from the food neuron's axon will activate dendritic receptors on the slobber neuron and trigger an action potential in the slobber neuron. There is no strong connection between the bell neuron and the other neurons, so ringing the bell and subsequent firing of the bell neuron has no effect on the other neurons. However, if the bell is rung each time that food is presented, eventually the food neuron and the bell neuron will always fire at the same time. Dendrites from the slobber neuron will recognize this association and become more sensitive to signals from the bell neuron. The dog's brain has learned to associate the bell with food and slobbering.*]

4. How could too many connections interfere with learning?

[*"Flex time" gave an example where learners with a disability appeared to have more connections than fast learners. It is possible that having connections that are too many or too rigid interferes with the ability to learn new information and change connections between neurons.*]

5. How could unusually high amounts of brain flexibility be related to typical schizophrenic behaviors?

[*Brain flexibility is involved in learning new information and realizing that different things are related to each other. Unusually high amounts of brain flexibility, one could imagine, might make a person learn things that are not really there or experience hallucinations. It might also make a person mistakenly connect unconnected ideas, causing disjointed thoughts.*]

ENGINEERING AND EXPERIMENTAL DESIGN

Discussion questions:

1. In performing resting state functional magnetic imaging, or fMRI, to measure the connectivity between different brain regions, what factors would need to be screened out by the data processing algorithm to avoid irrelevant or erroneous results?

[*The algorithm would need to adjust for motion due to pulse, respiration and head motion. It would need to ignore neural firings that are not always accompanied by other simultaneous firings. It would also need to screen out neural firings that are correlated with each other simply because they are associated with a task the patient is currently performing, such as sensing or responding to distracting stimuli in the fMRI chamber. Yet the sensors and algorithm would need to capture correlated blips, no matter how brief, how spatially localized or how weak they might be.*]

2. What other applications could fMRI be used for?

[*Some possibilities include diagnosing diseases or measuring the influence of various drugs on the brain, or potentially creating a lie detector.*]

Extension prompts:

3. What are ways that one might improve the ability of the human mind to learn?

[*Possibilities include drugs that improve long-term potentiation or alter brain connectivity and flexibility, external brain stimulation by electrodes and mood-altering activities to make a person happier.*]

4. What are some technologies that are inspired by how brains learn?

[*Neural networks or neural nets are computers designed to emulate the human brain, automatically strengthening and weakening connections among artificial "neurons" as they learn to recognize patterns in data.*]

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Cross-Curricular Discussion: Q

Directions: The following list of discussion questions is provided to help you take notes, brainstorm ideas and test your thinking in order to be more actively engaged in class discussions related to this article. All questions in this section are related to topics covered in "Flex time."

PHYSICAL SCIENCES

Discussion questions:

1. What is magnetic resonance imaging and how does it generally work?

Extension prompts:

2. What is functional magnetic resonance imaging and how can it be used?

3. What is resting state functional magnetic imaging?

BIOLOGICAL SCIENCES

Discussion questions: Depending on the level of your class, you may preface this discussion with this brief NBC Learn video describing how neurons process information.

1. Describe the structure of a neuron.

2. How does a neuron send signals within itself, and from one neuron to another?

Extension prompts:

3. What is long-term potentiation and how does it work?

4. How could too many connections interfere with learning?

5. How could unusually high amounts of brain flexibility be related to typical schizophrenic behaviors?

ENGINEERING AND EXPERIMENTAL DESIGN

Discussion questions:

1. In performing resting state functional magnetic imaging, or fMRI, to measure the connectivity between different brain regions, what factors would need to be screened out by the data processing algorithm to avoid irrelevant or erroneous results?

2. What other applications could fMRI be used for?

Extension prompts:

3. What are ways that one might improve the ability of the human mind to learn?

4. What are some technologies that are inspired by how brains learn?

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Activity Guide for Teachers: How Do Neurons Form Connections?

Purpose: To have a better understanding of what neurons look like, how they are interconnected and how learning changes those connections.

Procedural overview: Create your own data table to study prepared microscope slides of neurons from different types of nervous system tissue and create model neurons to demonstrate how connections among the neurons are altered during learning.

Approximate class time: 30 to 50 minutes.

Materials:

- Activity Guide for Students: How Do Neurons Form Connections?
- Microscopes (preferably with 40x, 100x and 400x power)
- Prepared microscope slides of nervous system tissue (Discovering Nerve Tissue Types Self-Study Unit by Carolina Biological Supply Company or Triarch Nervous Tissue Slides)
- Pipe cleaners in a wide variety of colors (look for extra-large pipe cleaners too)
- Wire cutters or scissors to cut pipe cleaners
- Sticky notes
- Cell phone cameras or other cameras

Notes to the teacher:
This activity has two halves, observing real neurons under the microscope and making pipe cleaner models of neurons, which can be done in either order. Unless you have a large number of microscopes and prepared slides, you can have half the students use the microscopes while the other half work with the pipe cleaners, and then switch.

Neuron modeling activity notes: If students would like to see diagrams of neurons when creating their pipe cleaner neurons, you could provide them with any of these:

- Campbell Biology Ch. 48 (Neurons, Synapses, and Signaling) and Ch. 49 (Nervous Systems)
- The University of Washington's Neuroscience for Kids website provides diagrams and other activities for modeling the nervous system.

Students can use their cell phones or other cameras to take photos of their groups of pipe cleaner neurons before, during and after learning. Depending on your preference, they can present their photos in class or submit them via e-mail or as a printout. If you are teaching about chemical structure, this might be a good opportunity to further explore the structure of some common neurotransmitters and receptors with students and talk about intermolecular attraction. Students may include the general structures of neurotransmitters and receptors in their pipe cleaner models as well.

Neuron observation activity notes: If time permits, have students create their own data table for this activity. They will need to read through the entire procedure for this part to determine what types of slides they are observing and what observations they are trying to collect about each one. If they are working in pairs, allow them time to individually read through the procedure and decide all key information before collaborating with a partner. If creating a data table and writing detailed, efficient observations are skills you are teaching your students, you may want to collect and grade this activity.

Student instructions and questions with answers:

Neuron modeling activity: Use the following set of instructions to create pipe cleaner models of neurons and take photos of the neurons interacting while they "learn" something. Write down your answers to the questions along the way, and be prepared to present your models and photos to the teacher or the rest of the class.

Procedure:

1. Use pipe cleaners to make several model neurons. You could make each neuron a different solid color, or you could choose a more elaborate color scheme if you would like. Look up several diagrams to prepare your neurons. Feel free to make neurotransmitters out of additional pipe cleaners or other materials provided by your teacher. Just remember, a neurotransmitter will chemically fit — meaning it will physically fit *and* be attracted to — a receptor on another neuron, so you'll need to make receptors too. Make at least three complete neurons, or more if you have enough pipe cleaners and time.

[*For the cell body of a neuron, students might make a ball from one pipe cleaner. For dendrites, they may attach several short pieces of pipe cleaner to the ball. For an axon, students could attach one long pipe cleaner to the ball.*]

2. What are the roles of the cell body, the dendrites and the axon in a real neuron?

[*The cell body performs essential functions to keep the cell alive, the dendrites are the "input" to sense signals from other neurons and the axon is the "output" to send signals to other neurons.*]

3. ***Please note that this next step is an extreme oversimplification of neural connections made while learning to complete a task. The focus of this exercise is to determine how individual neurons communicate, and relate this concept to the larger networks of neural connections made during learning.***

Decide what role each neuron will play in a task to be learned, and label each neuron with a sticky note. For example, in a simple model of Pavlov's dog, the "food" neuron fires when the dog sees food, the "bell" neuron fires when the dog hears a bell, and the "slobber" neuron fires to make the dog drool in anticipation of eating. Dogs come pre-wired with the axon of the food neuron connected to the dendrites of the slobber neuron. If the dog always hears a bell when food is presented, the dog's brain learns to connect the axon of the bell neuron to the dendrites of the slobber neuron. Through a process called long-term potentiation, the slobber neuron realizes that it always fires at the same time the bell neuron fires, so it should strengthen its connection to the bell neuron. What roles do your model neurons play? What makes each one fire?

[*Student answers will vary.*]

4. What will your model neurons learn, and how?

[*Student answers will vary.*]

5. Connect the neurons, as they would be before learning. If one neuron is communicating with a second, the end of the first neuron's axon should be nearly connected to one of the dendrites of the second neuron. If you're using neurotransmitter models, show the chemicals leaving one neuron and being accepted by another. If a neuron is not communicating with the others, it can be near the other neurons but not touching them, or neurotransmitters may not be accepted by that cell. Take a photo or video of your network of neurons, making sure the labels on each neuron are visible.

6. In this state before learning has occurred, what does your network of neurons do? What has it not yet learned to do?

[*Student answers will vary.*]

7. Now make the appropriate adjustments to your neurons and take a photo or video of the neurons during the learning process.

[*A new synapse between two neurons is being made, a dendrite of the receiving neuron can be near the axon of the transmitting neuron. If you are using neurotransmitters and receptors, a few new receptors should be formed on the newly receiving neuron. Make sure the labels on each neuron are visible in the photo.*]

8. Make a final adjustment to your neurons, and take a photo or video of the neurons after the learning process.

[*A firm new link should be established between the dendrite of the receiving neuron and the axon of the transmitting neuron. If you are using neurotransmitters and receptors, many new receptors should have formed on the dendrites of the newly receiving neuron. Make sure the labels on each neuron are visible in the photo.*]

9. In this state after learning has occurred, what does your network of neurons do? What has it learned to do that it did not do before?

[*Student answers will vary.*]

10. What have you learned about the structure of a neuron from this activity?

[*Neurons have dendrites for input and an axon for output. Neurotransmitters are the means of chemical communication between neurons.*]

11. What have you discovered about learning from this activity?

[*If two previously unconnected neurons always fire at the same time, they learn that they should be connected together and are chemically altered so a new communication can be made.*]

12. If you had more time and more pipe cleaners, how could you make your model neuron network more elaborate or more scientifically accurate?

[*Student answers will vary.*]

Neuron observation activity: Use the following set of instructions to observe prepared slides of various types of neurons under a microscope. Start at the lowest power, focus on the colored layer of the slide and make observations. Move to the next higher power, refocus and make more observations. Make sure you observe different areas of each slide. Write down your observations.

Before you begin, read through the additional instructions below and create a clearly labeled data table for all of your observations.

Procedure:

1. Observe a slide of cerebral cortex. What overall shapes or structures do you see for the cerebral tissue? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites and axons? Can you see connections between neurons? What does the cerebral cortex do? Draw a simple sketch to show where cerebral tissue is located in a human brain.

[*Depending on the specific slide you obtain, students may be able to see ridges and folds of cerebral tissue at lower power and neurons and their connections at higher power. Depending on how the tissue is sliced, students may see only cut-off parts of some neurons. The cerebral cortex is the outer layer of the brain and plays a role in conscious thought.*]

2. Observe a slide of cerebellum. What overall shapes or structures do you see for the cerebellar tissue? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites, and axons? Can you see connections between neurons? How does the cerebellar tissue appear similar to or different from the cerebral cortex? What does the cerebellum do? Draw a simple sketch to show where cerebellar tissue is located in a human brain.

[*Depending on the specific slide you obtain, students may be able to see ridges and folds of cerebellar tissue at lower power and neurons and their connections at higher power. Depending on how the tissue is sliced, students may see only cut-off parts of some neurons. Cerebellar neurons may appear more densely packed and more organized than cerebral cortical neurons. The cerebellum is located at the lower rear of the brain and is involved in relaying instructions to muscles.*]

3. Observe a slide of spinal tissue. What overall shapes or structures do you see for the spinal tissue? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites and axons? Can you see connections between neurons? What does spinal nervous tissue do? Draw a simple sketch to show where spinal tissue is located in a human body.

[*Depending on the specific slide you obtain, students may be able to see a cross section or a longitudinal section of bundles of neurons (mostly axons). The spinal neurons relay signals from the brain to muscles, and from receptors in the body to the brain*.]

4. Observe a slide of motor neurons. What overall shapes or structures do you see? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites and axons? Can you see connections between neurons? What do motor neurons do? Draw a simple sketch to show where motor neurons located in a human body.

[*Most commercially available motor neuron slides show individual motor neurons that have been removed from their original tissue. They have large, well-defined cell bodies. The bodies of motor neurons are located* *in the spinal cord, and their axons extend to target muscles that they control in the body*.]

5. Observe a slide of a peripheral nerve. What overall shapes or structures do you see? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites and axons? Can you see connections between neurons? What do nerves do? Draw a simple sketch to show where nerves could be located in a human body.

[*Depending on the specific slide you obtain, students may be able to see a cross section or a longitudinal section of one or more nerves (mostly axons). Such nerves relay signals from the brain to muscles, and from receptors in the body to the brain*. *Please note that the spinal neurons and peripheral neurons essentially play the same role in the body. The peripheral neurons are located in tissues outside of the spinal tissue.*]

6. How are the nervous tissue samples similar to or different from your pipe cleaner model?

[*Student answers may vary*.]

7. Based on your microscope observations, how could you make the pipe cleaner model more scientifically accurate?

[*Student answers will vary*.]

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Activity Guide for Students: How Do Neurons Form Connections?

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Procedural overview: Create your own data table to study prepared microscope slides of neurons from different types of nervous system tissue and create model neurons to demonstrate how connections between these neurons are altered during learning.

Neuron modeling activity: Use the following set of instructions to create pipe cleaner models of neurons and take photos of the neurons interacting while they "learn" something. Write down your answers to the questions along the way, and be prepared to present your models and photos to the teacher or the rest of the class.

Procedure:

1. Use pipe cleaners to make several model neurons. You could make each neuron a different solid color, or you could choose a more elaborate color scheme if you would like. Look up several diagrams to prepare your neurons. Feel free to make neurotransmitters out of additional pipe cleaners or other materials provided by your teacher. Just remember, a neurotransmitter will chemically fit — meaning it will physically fit *and* be attracted to — a receptor on another neuron, so you'll need to make receptors too. Make at least three complete neurons, or more if you have enough pipe cleaners and time.

2. What are the roles of the cell body, the dendrites and the axon in a real neuron?

3. *Please note that this next step is an extreme oversimplification of neural connections made while learning to complete a task. The focus of this exercise is to determine how individual neurons communicate, and relate this concept to the larger networks of neural connections made during learning.*

Decide what role each neuron will play in a task to be learned, and label each neuron with a sticky note. For example, in a simple model of Pavlov's dog, the "food" neuron fires when the dog sees food, the "bell" neuron fires when the dog hears a bell, and the "slobber" neuron fires to make the dog drool in anticipation of eating. Dogs come pre-wired with the axon of the food neuron connected to the dendrites of the slobber neuron. If the dog always hears a bell when food is presented, the dog's brain learns to connect the axon of the bell neuron to the dendrites of the slobber neuron. Through a process called long-term potentiation, the slobber neuron realizes that it always fires at the same time the bell neuron fires, so it should strengthen its connection to the bell neuron.

4. What roles do your model neurons play? What makes each one fire?

5. What will your model neurons learn, and how?

6. Connect the neurons as they would be before learning. If one neuron is communicating with a second, the end of the first neuron's axon should be nearly connected to one of the dendrites of the second neuron. If you're using neurotransmitter models, show the chemicals leaving one neuron and being accepted by another. If a neuron is not communicating with the others, it can be near the other neurons but not touching them, or neurotransmitters may not be accepted by that cell. Take a photo or video of your network of neurons, making sure the labels on each neuron are visible.

7. In this state before learning has occurred, what does your network of neurons do? What has it not yet learned to do?

8. Now make the appropriate adjustments to your neurons and take a photo or video of the neurons during the learning process.

9. Make a final adjustment to your neurons, and take a photo or video of the neurons after the learning process.

10. In this state after learning has occurred, what does your network of neurons do? What has it learned to do that it did not do before?

11. What have you learned about the structure of a neuron from this activity?

12. What have you discovered about learning from this activity?

13. If you had more time and more pipe cleaners, how could you make your model neuron network more elaborate or more scientifically accurate?

Neuron observation activity: Use the following set of instructions to observe prepared slides of various types of neurons under a microscope. Start at the lowest power, focus on the colored layer of the slide and make observations. Move to the next higher power, refocus and make more observations. Make sure you observe different areas of each slide. Write down your observations.

Before you begin, read through the additional instructions below and create a clearly labeled data table for all of your observations.

Procedure:

1. Observe a slide of cerebral cortex. What overall shapes or structures do you see for the cerebral tissue? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites and axons? Can you see connections between neurons? What does the cerebral cortex do? Draw a simple sketch to show where cerebral tissue is located in a human brain.

2. Observe a slide of cerebellum. What overall shapes or structures do you see for the cerebellar tissue? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites and axons? Can you see connections between neurons? How does the cerebellar tissue appear similar to or different from the cerebral cortex? What does the cerebellum do? Draw a simple sketch to show where cerebellar tissue is located in a human brain.

3. Observe a slide of spinal tissue. What overall shapes or structures do you see for the spinal tissue? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites and axons? Can you see connections between neurons? What does spinal nervous tissue do? Draw a simple sketch to show where spinal tissue is located in a human body.

4. Observe a slide of motor neurons. What overall shapes or structures do you see? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites and axons? Can you see connections between neurons? What do motor neurons do? Draw a simple sketch to show where motor neurons could be located in a human body.

5. Observe a slide of a peripheral nerve. What overall shapes or structures do you see? Which way(s) do neurons point in the sample? What shapes are the individual neurons? Can you identify cell bodies, dendrites and axons? Can you see connections between neurons? What do nerves do? Draw a simple sketch to show where nerves could be located in a human body.

6. How are the nervous tissue samples similar to or different from your pipe cleaner model?

7. Based on your microscope observations, how could you make the pipe cleaner model more scientifically accurate?

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