Lesson Summary: The human brain is highly adaptable. This activity demonstrates how the brain adapts to a new situation. Students investigate learning to toss beanbags at a target while wearing prism goggles. Students collect and interpret data and then have an opportunity to design additional experiments (not to be confused with evolutionary adaptation).

Grade Level 9-12

Lesson Length
1 class period

Standards Alignment: Minnesota Science Standards

- Science is a way of knowing about the natural world and is characterized by empirical criteria, logical argument and skeptical review. Benchmark codes: **9.1.1.1.1 & 9.1.1.1.6**
- Scientific inquiry uses multiple interrelated processes to investigate and explain the natural world. Benchmark codes: **9.1.1.2.1, 9.1.1.2.2, & 9.1.1.2.3**
- Natural and designed systems are made up of components that act within a system and interact with other systems. Benchmark codes: **9.1.3.1.3**
- Science, technology, engineering and mathematics rely on each other to enhance knowledge and understanding. Benchmark codes: **9.1.3.4.2, 9.1.3.4.3, & 9.1.3.4.4**
- Organisms use the interaction of cellular processes as well as tissues and organ systems to maintain homeostasis. Benchmark codes: **9.4.1.1.1 & 9.4.1.1.2**
- Cells and cell structures have specific functions that allow an organism to grow, survive, and reproduce. Benchmark codes: **9.4.1.2.2, 9.4.1.2.4, & 9.4.1.2.5**

Objectives—Students will be able to

- Describe structural regions of the human brain and understand outlines of the visual and motor areas of the brain
- Describe neural pathways and how they change as a basis for learning
- Collect and interpret data
- Design and carry out an experiment to solve a problem (optional)

Assessment Options

- Explain how practicing a musical instrument, foreign language, or routine improves the efficiency of neural pathways
- Provide an example of how the brain prefers established neural pathways to new neural pathways
- Turn in lab sheets or write a lab report
- Present the results of an investigation

Teacher's Notes

See the Teacher's Notes documents for graphing examples and goggle assembly instructions.

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Materials (for each group of students)

- 1 pair altered reality goggles
- 5-10 beanbags (same weight, shape, and texture)
- 1 target (a sheet of 8.5" x 11" paper works well)
- A wall with no distinguishing features that might help the students aim at the target
- Student guide
- Individual or group data table(s)

Procedures

Engage

1. Get two student volunteers to come to the front of the classroom.
2. Ask students to observe carefully.
3. Instruct students to shake hands twice - once without goggles and once while wearing goggles.
4. Ask students to silently think about what the goggles did to the volunteer's vision.

Explore - another example

1. Move students into small groups and provide them with one pair of goggles per group.
2. Ask students to observe how the goggles affect what they see and how they perform a simple activity of their choice.
3. Allow enough time so that each student has the opportunity to perform the activity wearing the goggles.

Develop Questions

1. Direct students to share their ideas about what the goggles did to the volunteers' vision and why they came up with that idea. Do their explanations account for what was observed?
2. Ask students to predict how the prism goggles would affect their ability to toss a beanbag and how they might test their prediction further.
3. Give students the opportunity to state the question they will investigate.

Experiment

1. With the help of a student volunteer, demonstrate the lab instructions and data recording method.
2. Ask students to predict the effect of wearing goggles: more beanbags landing on target, to the left of the target, to the right of the target, or no influence.
3. Send students in groups of two or three to get their lab supplies and go to a designated workspace.

4. Direct students to put a piece of notebook paper (target) on the floor and against a blank wall.
5. For Part 1, the thrower should be positioned 6 feet from the target, and with normal vision, underhand toss 3 sets of 5-10 beanbags at the target. For each toss:
   - the recorder will write down where the beanbag lands: on the target, to the left of the target, or to the right of the target.
   - the retriever should hand each beanbag to the thrower and pick up the beanbags after each set of throws.
6. For Part 2, the thrower will put on the goggles and toss the beanbags at the target until he/she hits the target five times in a row. The retriever and recorder function as in Part 1.
7. For Part 3, once the thrower hits the target five times in a row, the retriever will gently remove the goggles from the thrower and continue to hand the thrower beanbags to throw towards the target. The retriever and recorder again function as in Part 1. Stop once the thrower again hits the target five times in a row.
8. Have partners switch roles and complete another round or two of beanbag tossing.

Explain

1. After all the data is collected, have small groups discuss their individual results. Then, have the class come back together to discuss results as a group.
   - Discuss different ways to graph the data.
   - Tabulate the data and determine the average number of tosses it took to hit the target in each part.
   - Summarize the data in as many ways as possible. Use simple factual statements like, "When the goggles first went on, everyone always missed to the left."
   - Discuss what the data shows. Use comparative factual statements like, "It took more throws to learn to hit the target with goggles on than when they were just taken off." "Errors were on one side with the goggles on and on the other side after the goggles came off."
2. Review the parts of the brain that were active during the throwing (Occipital Lobe, Motor Cortex, Sensory Cortex, and Cerebellum).

Expand – additional options or questions to answer

Altered Reality Experiment – Ask students to formulate their own questions about the goggles and to design and implement another experiment to test their questions.

How long will the adaptation persist?

1. The first student in a group completes Parts 1 and 2 then moves off to the side while a second student completes Parts 1 and 2. Student 1 sits with the adapted hand behind her/his back and watches the second student.

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2. Student 2 completes Parts 1 and 2 then moves off to the side, sitting with the adapted hand behind her/his back and watches Student 1 who completes Part 3. (The altered aim should still persist.)
3. Student 1 completes Part 3 and the students switch places. Student 2 completes Part 3 and should see the same results - persistent altered aim.

What is being adapted?

After completing Parts 1 and 2, the students should take off the goggles and toss with the other hand to see if it will show a correctly adapted aim. Students can also try throwing gently overhand instead of underhand.

Neither case should show a correctly adapted aim because the adaptation is specific to neural pathways for visual control of the actual muscles used when the goggles were worn -- not just the visual pathways alone. (W.T. Thach et al., 1992)

Terms

Important vocabulary that can strengthen the lesson. Select terms according to the needs and abilities of your students.

- **Motor learning** -- the process of improving the smoothness and accuracy of movements through practice. During motor learning (and other learning), synapses in neural pathways in the brain are strengthened so that the actions (or thoughts) progress smoothly with less conscious direction.
- **Neural pathway** –- set of connected neurons that are regularly activated in sequence to produce a specific function, neural circuit or network.
- **Synapse** –- the gap between two neurons forming the site of information transfer via neurotransmitters, from one neuron to another, including the presynaptic nerve terminal and the post-synaptic dendritic site; at synapses, neurotransmitters released from pre-synaptic axon terminals bind to receptors on post-synaptic dendrites.
- **Synaptic plasticity** -- the ability of the neurons within neural pathways to make lasting changes in the efficiency of their synaptic connections and thus strengthen or diminish that pathway.
- **Motor map** -- a complete map of the motor cortex where the areas assigned to various body parts on the cortex are proportional to the complexity of the movements that they control, not to the size of the body part.

Background Material

1. Why are we doing this experiment and what does it show us?
2. How do prism goggles work?
3. What is prism adaptation?
4. What is going on in our brains as we learn how to throw more accurately with practice?
5. How does what we learn in this experiment apply to real life?

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In the explanations below, the highlighted terms are important vocabulary for this lesson and are detailed in the **Terms** section above. You may also visit the glossary on the BrainU website at http://brainu.org/glossary-neuroscience-terms for definitions of terms used in this and other lessons.

Question 1. Why are we doing this experiment and what does it show us?

Neural plasticity forms the basis for the **motor learning** demonstrated in this experiment. The prism goggles create a situation that demonstrates motor learning in the classroom. To adapt to the goggles, the synapses in the visual sensory pathway and motor output pathways must change. Such synaptic changes are an example of neural plasticity.

Key ideas in this lesson are: the structure and function of the cerebral cortex and the cerebellum, the neural basis of learning, and the real processes of improvement of motor skills through practice. Given that we demonstrated motor skills improving with practice, what would students expect practice to do to intellectual skills?

Question 2. How do prism goggles work?

The horizontally-displacing prism goggles use Fresnal lenses to cause a distortion within the visual system by shifting the light coming into the eyes. Because the light is shifted, the eyes rotate to focus on the seen object. As a consequence, visual-motor coordination is disrupted because the object's actual location is shifted from where it appears to be (see Question 4 for more explanation).

Figure 1a. Goggles on a student

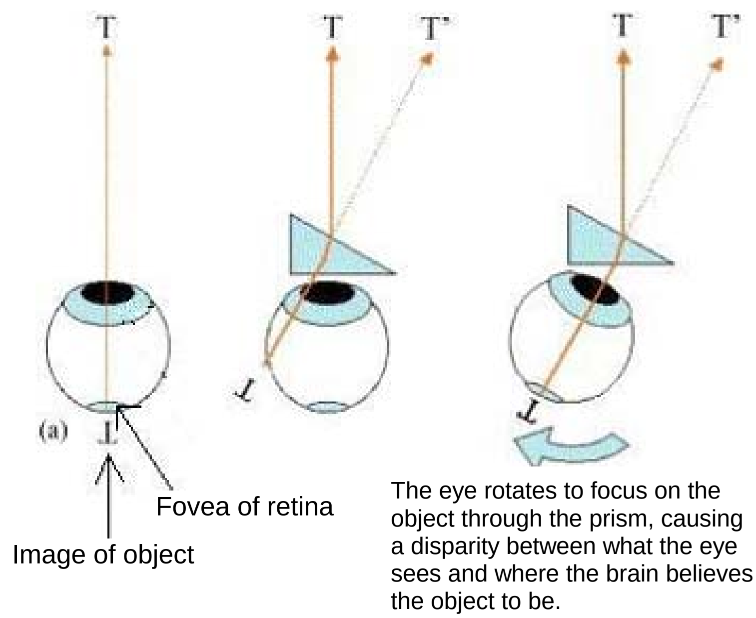

Figure 1b. Actions of goggles on light entering the eye

Question 3. What is prism adaptation?

Prism adaptation can be demonstrated by having students throw an object at a target. Initially, large errors will occur with the throws hitting far from the target center. With a brief period of practice, the brain compensates for the visual displacement caused by the prism goggles and students are able to accurately hit the target. Compensation occurs as the brain recalculates distances and displacements in the world based upon the new information coming in from the eye movements. Actively moving or interacting in the world, i.e. throwing the ball, brings more sensory information into the brain to speed this adaptation process. Immediately after removing the goggles, overshoot in the opposite direction occurs.

Question 4. What is going on in our brains as we learn how to throw more accurately with practice?

Prism adaptation is a form of **motor learning** in which the visual and motor systems are realigned to correct for the distortion caused by the goggles. Incoming visual information is altered (compare figures 1a and 1b).

Initially, the information coming from the regions controlling hand movements (**motor map**) is not altered (figures 2a and 2b). These motor commands assume external space remains the same as it was during the initial throws without the goggles.

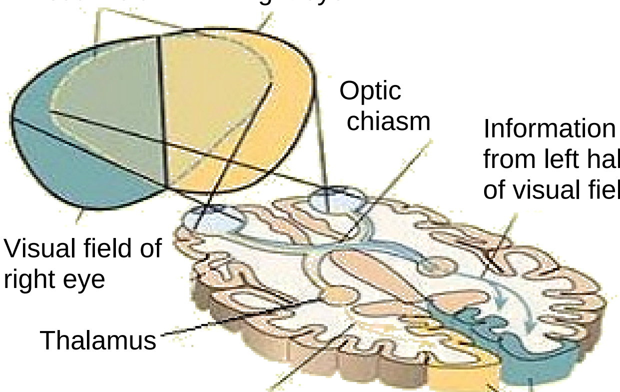

Figure 2a. Neural pathway of normal vision

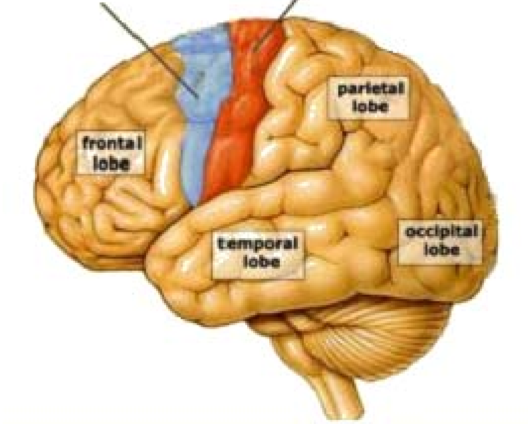

Figure 2b. Neural motor pathways

When the remembered representation of external space does not match the incoming visual information, the body's movements are uncoordinated. Fortunately the human brain is designed to compensate and correct for changes in visual-motor coordination; therefore, as the human body grows and changes shape, the "hand-eye" connection changes with it.

The primary brain area responsible for recalibrating the motor maps with the visual space is the cerebellum (figure 3). Cerebellum means "little brain."

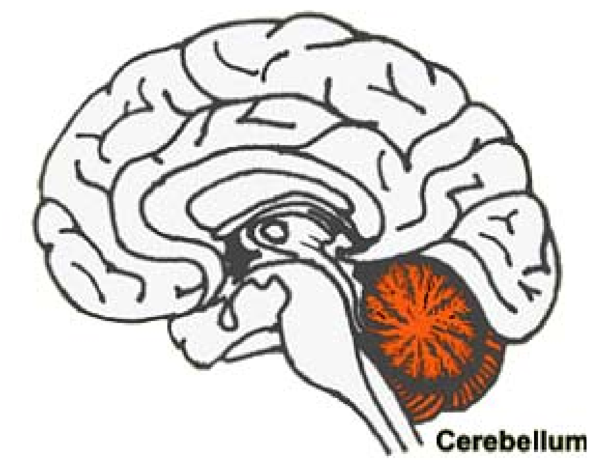

Figure 3. Human cerebellum (highlighted in red)

The cerebellum is very important for **motor learning** because it combines information about the intended movement from the motor cortices with sensory information from the muscles about body position in space.

The cerebellum calculates the required direction, force, and duration of this movement and sends this information back to the motor cortex.

If a change is needed in the motor sequence, for example, adjusting to a 15 degree distortion of the visual field, the neurons in the cerebellum adapt to the change through a complex process of **synaptic plasticity**.

If the pathway needed to correct for the visual distortion has not been used before, it is weak.

After throwing with the goggles on, a new pathway and firing sequence are activated in a much stronger manner and synapses in the old firing sequence grow weaker. This happens because synapses in the new pathway get stronger and those in the old pathway get weaker. After some practice, this new pathway is stronger than the old "normal" pathway and accuracy for throwing with the goggles improves. After the goggles are removed, the new pathway for throwing (goggles on) is still stronger than the "normal" pathway and the throws are again uncoordinated until the cerebellum relearns the "normal" pathway and unlearns the "goggles on" pathway.

Question 5. How does what we learn in this experiment apply to real life?

The process of motor learning demonstrated in this experiment is similar to learning to ride a bike or learning to play the piano where new motor pathways, **synapses**, and firing sequences in the cerebellum are strengthened through practice.

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