Lesson Plan: Biogeochemical Systems – The Flow of Life

7-12th Grade Biology

NGSS Alignment: MS-ESS2-4, MS-LS2-3, HS-ESS2-6

Summary: This unit walks students through how seven of the most common elements involved in life on Earth—carbon, nitrogen, hydrogen, oxygen, phosphorus, sulfur, and iron—take on various forms as they cycle through the atmosphere, land, and water. Students will gain insights into the connections between geology, chemistry, and microbiology as they follow organic molecules through their biogeochemical cycles. The week-long unit ends on 2 full days of formative assessment and play-based application as students utilize systems thinking to navigate Microcosm. This simulation allows students to manipulate variables in biogeochemical systems, applying and synthesizing what they know about chemical reactions, the role of microbes in chemical cycling, and how organic molecules fuel life in various biomes.

This lesson plan provides comprehensive learning goals and instructional guidance for the middle school and high school classrooms. High school-level extensions are marked by a "◊."

Day 1: The Water and Carbon Cycle

I. Alignment and Objectives

Learning Objectives: Model and explain how water and carbon cycle through the hydrosphere, atmosphere, geosphere, and biosphere.

Essential Question: How do water and carbon cycle through the Earth's spheres?

Academic Vocabulary:

- Hydrosphere
- Atmosphere
- Geosphere
- Biosphere
- Precipitation
- Sublimation/Desublimation
- Evapotranspiration
- Condensation
- Leaching/Runoff
- Sediments
- Respiration
- Decomposition

- Weathering
- Detritus
- Fragmentation
- Catabolism
- Humification
- Mineralization

II. Materials Needed

- Large paper (11x17 is ideal)
- Blue and black markers
- Blue, yellow, orange, pink, and green highlighters
- Pencils

III. Instructional Sequence

Hook: *"Did you know that the Earth is a giant water filter? This is a good thing, because at the moment, 97% of water on Earth is unsafe for human consumption and 2% is unavailable in the ice caps. Life on Earth is sustained by 1% of the total water on Earth, and that 1% just keeps being filtered when it goes through the ground or evaporates."*

Explain that students will create their own diagram of the water cycle (in blue marker) and the carbon cycle (in black marker) as the lesson progresses. They should make sure to include all the vocabulary terms in their model. They will have a chance to wrap up their diagrams at the end of the lesson.

Concepts to Cover:

- The water cycle is driven by the sun's energy.
- Groundwater is a significant fresh water reservoir.
- Minerals such as carbon, nitrogen, phosphorus, and sulfur are cycled from land to water through both rain and surface runoff.
- The following processes occur during the water cycle: evaporation/sublimation, condensation/precipitation, subsurface water flow, surface runoff/snowmelt.
- Carbon is found in all living things because it's the primary atom in organic molecules.
- ◊Carbon is found in energy-containing compounds (photosynthesis and respiration connection).
- The following processes occur during the carbon cycle: photosynthesis, respiration, fossilization, weathering, decomposition, burning fuels.
- The decomposition of organic matter is broken into five processes (fragmentation, leeching, catabolism, humification, mineralization), ending in inorganic carbon being released into the environment.

- ◊*Microbe spotlight: <u>Pyrococcus abyssi</u> is an anaerobe that recycles carbon in deep-sea vents.*

Review and Formative Assessment:

Review the difference between the hydrosphere, atmosphere, geosphere, and biosphere. Have students create a key on the back of their diagram where hydrosphere is highlighted blue, atmosphere is highlighted yellow, geosphere is highlighted orange, and biosphere is highlighted green. Then have students highlight the various sinks in the diagram with the matching color. Give students time to finish their diagrams during this time.

Exit Question: Can you walk your table partner through the cycles on your diagram?

Day 2: The Nitrogen Cycle

I. Alignment and Objectives

Learning Objectives: Model and explain how nitrogen cycles through the hydrosphere, atmosphere, geosphere, and biosphere.

Essential Question: How does nitrogen cycle through the Earth's spheres?

Academic Vocabulary:

- Hydrosphere
- Atmosphere
- Geosphere
- Biosphere
- Denitrification
- Nitrification
- Ammonification
- Nitrogen fixation
- Eutrophication
- ◊NO_3^-, NO_2^-, N_2, NH_4^+

II. Materials Needed

- Large paper (11x17 is ideal)
- Light blue markers
- Blue, yellow, orange, pink, and green highlighters
- Pencils

III. Instructional Sequence

Hook: *"Did you know that trees and salmon need each other? Salmon are what's called anadromous, which means that they hatch from eggs in freshwater, migrate to saltwater to live the majority of their lives, and then return to freshwater to spawn before they die. It turns out that salmon are conveyor belts for nutrients. Studies have been done on the trees near where salmon spawn. During years when salmon migration rates are high, the growth rings show that there is more nitrogen available to those trees."*

Explain that students will create their own diagram of the nitrogen cycle (in light blue marker) as the lesson progresses. They should make sure to include all the vocabulary terms in their model. They will have a chance to wrap up their diagrams at the end of the lesson.

Concepts to Cover:

- The following processes occur during the nitrogen cycle: denitrification, ammonification, nitrogen fixation, and nitrification.
- Humans contribute to the nitrogen cycle through the combustion of fossil fuels and the use of artificial fertilizers.
- Eutrophication is a process that causes a detrimental overgrowth of algae due to an overabundance of nutrients.
- ◊ *Microbe spotlight: <u>Thiobacillus denitrificans</u> is a chemolithoautotrophic bacterium which connects the nitrogen and sulfur cycles. Because it removes nitrogen and sulfur compounds, it can be used in wastewater treatments.*

Review and Formative Assessment:

Review the difference between the hydrosphere, atmosphere, geosphere, and biosphere. Have students create a key on the back of their diagram where hydrosphere is highlighted blue, atmosphere is highlighted yellow, geosphere is highlighted orange, and biosphere is highlighted green. Then have students highlight the various sinks in the diagram with the matching color. Give students time to finish their diagrams during this time.

Exit Question: Can you walk your table partner through the cycles on your diagram?

Day 3: The Phosphorus, Sulfur, and Iron Cycles

I. Alignment and Objectives

Learning Objectives: Model and explain how phosphorus, sulfur, and iron cycle through the hydrosphere, atmosphere, geosphere, and biosphere.

Essential Question: How do phosphorus, sulfur, and iron cycle through the Earth's spheres?

Academic Vocabulary:

- Hydrosphere

- Atmosphere
- Geosphere
- Biosphere
- Eutrophication
- Dead zones

II. Materials Needed

- Large paper (11x17 is ideal)
- Yellow, purple, and brown markers
- Blue, yellow, orange, pink, and green highlighters
- Pencils

III. Instructional Sequence

Hook: *"One of the elements that we're going to track through Earth's sphere's today is sulfur. This is one of the elements involved in acid rain. You may have experienced acid rain; it doesn't taste or feel different to us than any other kind of rain, but it can cause major damage to entire ecosystems over time. As we track sulfur through the atmosphere, think about how it can combine with water to form acid rain or acid snow, but also think about how it can float through the air in particles because, yes, some parts of the world experience acid dust."*

Explain that students will create their own diagram of the phosphorus (in purple marker), sulfur (in yellow marker), and iron (in brown marker) cycles as the lesson progresses. They should make sure to include all the vocabulary terms in their model. They will have a chance to wrap up their diagrams at the end of the lesson.

Concepts to Cover:

- Phosphorus is an important component of nucleic acids and phospholipids.
- Phosphorus is found in nature as the phosphate ion.
- The following processes occur during the phosphorus cycle: leaching/runoff, and sedimentation.
- The phosphorus cycle doesn't really contain an atmospheric component.
- Phosphorus is another element involved in eutrophication and can contribute to dead zones.
- Sulfur is an important component of proteins.
- The following processes occur during the sulfur cycle: volcanic eruptions, precipitation, fallout, and sedimentation.
- When combined with rainwater, sulfur dioxide turns into weak sulfurous acid, which damages aquatic ecosystems and chemically degrades buildings.
- The following processes occur during the iron cycle: microbial mediation, ocean fertilization, and anthropogenic contributions.

- ◊ *Microbe spotlight: Salmonella enterica is the bacterium that gives us food poisoning. It can also live in the soil and is a master at incorporating inorganic sulfur into organic compounds.*

Review and Formative Assessment:

Review the difference between the hydrosphere, atmosphere, geosphere, and biosphere. Have students create a key on the back of their diagram where hydrosphere is highlighted blue, atmosphere is highlighted yellow, geosphere is highlighted orange, and biosphere is highlighted green. Then have students highlight the various sinks in the diagram with the matching color. Give students time to finish their diagrams during this time.

Exit Question: Can you walk your table partner through the cycles on your diagram?

Day 4: Game Play

Entrance Question: "Which cycles that we have learned about this week would be the easiest to disrupt and why?"

Think: cycles with atmospheric phases move more quickly and over a larger area while cycles like phosphorus' are mostly limited to rocks.

Teacher Role:

Go through game play instructions. As students play with their table mates, circle the room to answer questions. When the opportunity arises, link game play suggestions to concepts covered in class in the last few days.

Exit Questions:

- "What moves did you make that grew resource availability the most?"
- "What roles do microbes play in biogeochemical cycling?"
- "What part of the game indicated microbial growth?"
- "What could you do to help microbial growth occur?
- "What were some of the most useful microbial mutations that you came across today?"

Day 5: Game Play

Entrance Question: "What happens within an ecosystem if you exceed its carrying capacity?"

Teacher Role:

Review game play instructions. As students play with their table mates, circle the room to answer questions. When the opportunity arises, link game play suggestions to concepts covered in class in the last few days.

Exit Questions:

- “Walk me through the process of how microbes sustain entire ecosystems.”
- “You could only play a microbe into a biome that had enough space for the microbe to grow. What scientific concept does that represent?”
- “What did you do to earn energy points? What does that look like in the real world?”
- “What does it mean if I say that ‘microbes recycle nitrogen?’”
- “Tell me something that clicked for you when you played the game.”