Biogeochemical Cycles Research Questions

ELC-4084

Science – Next Generation Science Standards (NGSS)

Life Science (NGSS Life Sciences, Grades 4–8)

- **5-LS1-1:** *Support an argument that plants get the materials they need for growth chiefly from air and water.* This standard highlights that plant biomass comes largely from carbon dioxide in air and water, underpinning the **Carbon and Oxygen cycles** in photosynthesis. (Grade 5)
- **5-LS2-1:** *Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.* Emphasizes **cycles of matter** (e.g. Carbon, Nitrogen, Oxygen, Phosphorus, Sulfur) moving through food webs and decomposition. (Grade 5)
- **MS-LS1-6:** *Construct a scientific explanation for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.* Focuses on plants converting CO_2 and H_2O into sugars and O_2, driving the **Carbon–Oxygen cycle** (matter cycling and energy flow). (Middle School, Grades 6–8)
- **MS-LS1-7:** *Develop a model to describe how food is rearranged through chemical reactions as it is broken down and releases energy.* Covers cellular respiration and waste, which returns CO_2 and other matter to the environment – completing the **Carbon and Oxygen cycles** in organisms. (Middle School)
- **MS-LS2-3:** *Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.* Encompasses nutrient cycles (e.g. **Carbon, Nitrogen, Phosphorus, Oxygen, Sulfur** in ecosystems) and energy flow between the biosphere and environment. (Middle School)
- **MS-LS2-4:** *Construct an argument with evidence that changes to physical or biological components of an ecosystem affect populations.* Addresses ecosystem disruptions – for example, excess fertilizer (altering **Nitrogen/Phosphorus cycles**) or deforestation (altering the **Carbon cycle**) – and their impact on ecosystem stability. (Middle School)

Earth & Space Science (NGSS Earth and Human Activity, Grades 4–8)

- **4-ESS3-1:** *Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment.* Connects to how burning **fossil fuels** (derived from geosphere/biomass) releases carbon dioxide and pollutants, impacting the **Carbon cycle** and other cycles (e.g. sulfur emissions and acid rain). (Grade 4)
- **5-ESS2-1:** *Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.* Covers Earth system interactions such as the **Water cycle** (hydrosphere–atmosphere), and nutrient cycles between soil, air, and living

things (e.g. plants taking up soil minerals – **Phosphorus, Calcium** – and exchanging gases with air – **Carbon, Oxygen**). This standard builds understanding of the **Rock cycle** and biogeochemical cycles as interconnected sphere interactions. (Grade 5)

- **5-ESS3-1:** *Obtain and combine information about ways individual communities use science ideas to protect Earth's resources and environment.* Relates to human stewardship of cycles – for example, conserving water, reducing fossil fuel use (carbon emissions), or recycling nutrients. Aligns with teaching human impact on ecosystems and resource cycles (ties to **Water, Carbon, Nitrogen** cycles, etc.). (Grade 5)
- **MS-ESS2-1:** *Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.* Focuses on geological processes – the **Rock Cycle** (formation and weathering of rocks) driven by Earth's internal and solar energy. This includes cycles of minerals such as **Calcium** (e.g. calcium carbonate in limestone weathering to soil and returning via sedimentation) as part of Earth's material cycles. (Middle School)
- **MS-ESS3-4:** *Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.* Involves understanding how human activities alter Earth's cycles – e.g. fossil fuel burning increasing atmospheric CO_2 (affecting the **Carbon cycle** and climate), agricultural runoff affecting the **Nitrogen and Phosphorus cycles**, or freshwater use impacting the **Water cycle**. (Middle School)

Crosscutting Concepts (NGSS)

- **Energy and Matter: Flows, Cycles, and Conservation –** Students learn that tracking how matter and energy move into, out of, and within systems is key to understanding phenomena. For example, **"Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations"**. In the context of biogeochemical cycles, this concept highlights that **matter cycles** (like carbon or water moving through Earth's spheres) are driven by energy and are conserved within a closed system.
- **Systems and System Models –** Students use the idea of systems and models to understand complex cycles. A **system** can be defined by its components and their interactions, and models help simulate those interactions. For example, we can imagine a boundary around an ecosystem and track flows of matter (e.g. *"the carbon dioxide expelled by an organism"*) across that boundary. In practicing this concept, students learn to represent cycles (e.g. the carbon cycle in a forest) as systems with inputs, outputs, and feedback, recognizing that models focus on certain aspects of the real system.
- **Stability and Change –** This concept deals with understanding conditions under which systems are stable (in equilibrium) and how they change. **"Systems in dynamic equilibrium are stable due to a balance of feedbacks... Stability might be disturbed by sudden events or gradual changes that accumulate over time."** Teaching cycles involves this idea: ecosystems tend to maintain stability as nutrients cycle, but significant changes (like excess carbon from burning fuels or removal of predators) can tip the system into a new state. Students examine how feedback loops (e.g. increased CO_2 -> global warming -> changes in carbon sinks) affect system stability in cycles.

Science & Engineering Practices (NGSS)

- **Developing and Using Models –** Students at this level frequently **develop and use models** to understand and explain cycles. For example, they might build a physical model or draw a diagram of the **water cycle**, or use arrows and charts to model the **carbon cycle** in an ecosystem. *Developing models* is a key practice to represent relationships (like between atmosphere, biosphere, and geosphere) and to predict what might happen if a component changes. (SEP 2)
- **Analyzing and Interpreting Data –** Teaching biogeochemical cycles often involves data – e.g. graphs of CO_2 levels over time, maps of nitrogen pollution, or weather data for the water cycle. Students engage in **analyzing and interpreting data** by creating tables or graphs of such data and drawing conclusions. For instance, a class might examine data on seasonal CO_2 fluctuations (related to plant growth and carbon cycle) and interpret patterns. This aligns with NGSS SEP 4, encouraging use of quantitative skills to understand science.
- **Obtaining, Evaluating, and Communicating Information –** Students read informational texts about cycles (e.g. an article on the nitrogen cycle or a chart of the phosphorus cycle in agriculture) and **communicate** their understanding. In NGSS this might appear as performance expectations like *"Obtain and combine information from reliable sources about ways to protect the environment"* (as in 5-ESS3-1). This practice connects directly to literacy: students must research (obtain information), evaluate its credibility, and explain in writing or presentations how, say, human actions affect the carbon or water cycle. (SEP 8)

English Language Arts – Common Core State Standards (CCSS)

Teaching science content like biogeochemical cycles also supports literacy skills in reading and writing informational text.

- **Reading Informational Text –** Students in upper-elementary and middle grades should read science texts and diagrams about cycles critically:
    - *CCSS.ELA-Literacy.RI.4.7:* **Interpret information presented visually, orally, or quantitatively (e.g., in charts, graphs, diagrams, time lines, animations) and explain how it contributes to understanding the text**. For example, a student might interpret a diagram of the **water cycle or carbon cycle** and explain how the visual complements the written explanation.
    - *CCSS.ELA-Literacy.RI.5.3:* **Explain the relationships or interactions between two or more ideas or concepts in a scientific or technical text**. In the context of cycles, a text might describe how plants, animals, and decomposers interact (concepts from the carbon/nitrogen cycle); students must explain these relationships using text evidence. This standard ensures students can parse cause-and-effect in science texts (e.g., how burning fossil fuels relates to atmospheric CO_2 levels).
    - *Literacy in Science (Grades 6–8), RST.6-8.7:* **Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., a flowchart, diagram, model, graph)**. This is directly applicable when students read about cycles: they should be able to read a

description of the **phosphorus cycle** and interpret the accompanying cycle diagram or graph of data. It reinforces connecting textual and visual information – for instance, aligning a written process (nitrogen fixation steps) with a diagram of the nitrogen cycle.

- **Writing Explanatory Texts –** Explaining scientific processes like cycles is an important writing skill:
  - *CCSS.ELA-Literacy.W.4.2 & W.5.2:* **Write informative/explanatory texts to examine a topic and convey ideas and information clearly**. By 4th and 5th grade, students should be able to write an explanation of how a cycle works (e.g., "Explain the stages of the rock cycle" or "Describe how carbon moves through an ecosystem"), using domain-specific vocabulary and logical structure. These standards even encourage including **illustrations or multimedia** to aid comprehension – for example, a student might include a labeled diagram of the **oxygen cycle** in their written report.
  - *CCSS.ELA-Literacy.WHST.6-8.2:* (Literacy in Science/Technical Subjects, Gr.6–8) **Write informative/explanatory texts, including the narration of scientific procedures or technical processes.** In grades 6–8, this standard expects students to write more detailed explanations of scientific processes – e.g. a report on the **nitrogen cycle** that describes each step (nitrogen fixation, nitrification, etc.) in sequence. This aligns with science class tasks like writing up an ecosystem cycling project or explaining an experiment related to decomposition.
- **Speaking/Listening and Presenting –** Interdisciplinary projects on cycles often involve presentations or discussions:
  - *CCSS.ELA-Literacy.SL.5.5:* **Include multimedia components (e.g., graphics, sound) and visual displays in presentations when appropriate to enhance development of main ideas or themes**. For example, a 5th grader giving a presentation on the **water cycle** might use a poster or slide with a diagram of the cycle, or an animation of the **carbon cycle**, to help the audience understand the concept. This standard ties directly to communicating science content effectively using visuals.

(The ELA standards above reinforce that as students learn about cycles, they also practice reading complex informational texts, integrating diagrams, and clearly writing or presenting scientific information.)

Mathematics – Common Core State Standards (CCSS)

Mathematics standards at the upper-elementary and middle school levels support the teaching of cycles by focusing on data, measurement, and modeling – all of which can be applied to scientific investigations of cycles.

- **Data Representation and Analysis:** Students may collect or examine data related to cycles (e.g. rainfall over months in the water cycle, CO_2 concentration changes, decomposition rates, etc.). Relevant standards include:
  - *CCSS.Math 4.MD.B.4 & 5.MD.B.2:* **Make a line plot to display a data set of measurements in fractions of a unit (1/2, 1/4, 1/8)** and use operations on

fractions to solve problems based on the data. In 4th and 5th grade, students learn to plot and interpret measurement data. For instance, a class might chart daily precipitation over a month (fractions of an inch of rain) to connect with the **water cycle**, or graph growth of plants in different soils to tie into nutrient cycles. These standards build skills in visualizing data from experiments or observations.
  - *CCSS.Math 6.SP.B.4:* **Display numerical data in plots on a number line, including dot plots, histograms, and box plots**. By 6th grade, students handle larger data sets – e.g. graphing annual carbon emissions or temperatures over decades (histogram or line plot) when studying the **carbon cycle** and climate.
  - *CCSS.Math 6.SP.B.5:* **Summarize numerical data sets in relation to their context** (describe patterns, outliers, measures of center/spread). This standard means students should be able to look at data – say, yearly nitrogen levels in a pond – and summarize what the data shows about that ecosystem's cycle. It encourages understanding variability and trends, which is useful in discussing seasonal cycles or long-term changes.
- **Mathematical Modeling and Reasoning:** Beyond just plotting data, students use math to model relationships in cycles and solve problems:
  - *CCSS.Math Practice MP.4:* **Model with mathematics**. This overarching practice standard (for all grades) encourages students to apply math to real-world situations. In the context of biogeochemical cycles, modeling with math could mean creating a simple proportion or formula – for example, calculating a carbon footprint (estimating CO_2 produced by certain activities), or using a ratio to model evaporation and precipitation rates in a closed system. By highlighting MP.4, we note that students should be comfortable using mathematical thinking to represent cycle processes (like using an equation to represent conservation of matter in a closed terrarium).
  - *Ratios and Algebraic Reasoning (Grades 6–7):* While not a specific standard code here, middle school math includes using ratios, percentages, and basic equations to describe changes. For instance, 7th graders learning proportional relationships (7.RP) might examine the percentage of Earth's water in each reservoir (oceans ~97%, freshwater ~3%) – a connection to the **water cycle** and resource distribution. Likewise, 6th graders might use equations (6.EE) to express simple relationships (e.g. water in = water out in a balanced system). These applications connect math content to cycle concepts, reinforcing quantitative literacy in science.

(In summary, math standards ensure students can interpret graphs of cycle data, perform calculations (like averages or rates) relevant to scientific observations, and use mathematical models – all skills that enhance their understanding of scientific cycles.)

Social Studies – Interdisciplinary Connections

Studying biogeochemical cycles connects to social studies through geography, environmental history, and civics/economics (human impacts and resource use). While social studies standards are typically framework-guided, there are clear connections to national frameworks:

- **Human-Environment Interaction (NCSS/C3 Framework):** National social studies standards emphasize understanding how humans and the environment affect each other. For example:
    - *C3 Geography Standard D2.Geo.4.3-5:* **Explain how culture influences the way people modify and adapt to their environments**. This applies when discussing how different societies use natural resources – e.g. farming practices that alter the **nitrogen and phosphorus cycles** (fertilizing soil, crop rotation), or energy use (burning wood/coal, affecting the **carbon cycle**). Students learn that cultural values and needs (food, energy) lead to changes in cycles (such as land clearing or irrigation).
    - *C3 Geography Standard D2.Geo.5.3-5:* **Explain how the cultural and environmental characteristics of places change over time**. This could include studying how a region's environment has been altered by human activity – for instance, how the Industrial Revolution (culture/technology) led to increased coal burning and urban pollution, altering local air quality and contributing to global **carbon cycle** changes. In a classroom, this might be a history or geography lesson examining how deforestation or mining has changed a landscape and its nutrient cycles over decades.
    - *C3 Geography Standard D2.Geo.4.6-8:* **Explain how cultural patterns and economic decisions influence environments and the daily lives of people**. This middle-school standard ties directly to issues like fossil fuel use, climate change, and pollution. For example, students might use it to discuss how a society's economic choice to rely on oil and cars (economic decision) increases CO_2 in the atmosphere, affecting global climate and thus human life (a **carbon cycle** connection). It encourages analysis of how human systems (transportation, industry) and natural systems (climate, ecosystems) are interlinked.
- **Historical and Civic Dimensions:**
    - *NCSS Theme 3 – People, Places, and Environments:* The National Curriculum Standards for Social Studies include a thematic strand focusing on human-environment relationships. This theme notes that **"the study of people, places, and human-environment interactions assists students as they create their geographic perspectives of the world beyond their personal locations."** It covers questions like *"How do landforms change? What implications do these changes have for people?"*. In studying cycles, students see concrete examples of this theme: e.g., how the **rock cycle** creates mineral resources that societies mine, or how the **water cycle**'s patterns (monsoons, droughts) have influenced human settlement and agriculture.
    - *Civics/Economics (Resource Use and Policy):* While not a single national standard, topics like **human impact on ecosystems, conservation, and resource management** are common in state social studies standards. For instance, students might examine policies for managing fisheries (related to the **oxygen and nitrogen cycles** in water) or international agreements on reducing carbon emissions (civics connection to the **carbon cycle**). These interdisciplinary links encourage students to think about how scientific understanding of cycles informs civic decisions and economic trade-offs (e.g., using phosphate fertilizers boosts

crop yield but can cause algal blooms in water systems – a social issue and science issue combined).

Through social studies lenses, learners recognize that biogeochemical cycles are not just abstract science concepts – they are processes that influence and are influenced by human activities, policies, and historical developments. This fosters a holistic understanding of topics like climate change, resource depletion, and sustainability as both scientific and social challenges.

Visual Arts – Interpreting and Representing Cycles

Art education standards highlight skills that can be applied to visualizing and interpreting scientific content, including cycles:

- **Interpreting Visual Information:** Students are taught to analyze and derive meaning from images – a skill that overlaps with studying diagrams of cycles. For example:
  - *National Core Arts Standards (Visual Arts), Responding – VA:Re7.2 (Grade 4–5):* Students learn to **analyze components in visual imagery that convey messages**. In practice, a 5th grader might look at a poster of the **water cycle** or an infographic of the **carbon cycle** and discuss how the symbols, colors, and layout communicate the process (e.g., arrows showing flow, evaporation drawn as rising arrows from ocean to cloud conveys movement). This meets art standards for understanding imagery and also reinforces science learning.
  - *VA:Re7.1 (Grade 6):* Students might **compare their interpretation of an artwork with others'** – applied to science, this could mean comparing how two different textbook diagrams depict the **nitrogen cycle** and discussing which is clearer or more informative. The art standard pushes students to cite evidence from the image for their interpretations, analogous to using evidence in science.
- **Creating Visual Representations:** Art standards encourage creation and presentation of ideas visually, which complements science projects:
  - *VA:Cr1.2 & VA:Cr2.1 (Creating, Grade 4–6):* These call for students to experiment with materials and develop works to express ideas. In an interdisciplinary project, students might create a detailed poster or digital art piece illustrating a cycle (say, a creative painting of the **sulfur cycle** in a volcano and ecosystem). They must consider design elements to accurately and engagingly represent scientific information, merging creativity with content accuracy.
  - *Presentation of Knowledge through Art:* According to the Visual Arts standards, by 5th grade students should be able to **"cite evidence about how an exhibition in a museum or other venue presents ideas and provides information about a specific concept or topic."** This could involve, for instance, a class trip to a science museum exhibit on Earth systems where students identify how the exhibit uses art (models, murals, interactive displays) to teach about the **rock cycle** or climate change. They practice articulating how visuals educate viewers – a skill bridging art critique and scientific understanding.
- **Connecting Art and Environment:** The arts standards also recognize connecting artworks to context. One *Enduring Understanding* in the art standards states that

"through engagement with art, one can develop understanding and appreciation of self, others, the natural world, and constructed environments." In teaching cycles, educators might leverage this by having students examine environmental art – for example, an artist's painting of a polluted river can spark discussion on the **water cycle** and human impact. Or students create a mural that shows the interdependence of life and the **oxygen/carbon cycle** in a rainforest, combining artistic skill with ecological knowledge. This approach meets art standards (by having students create and reflect on art) while deepening their connection to ecological concepts.

In summary, art provides a means for **visual literacy and expression**: students learn to decode complex cycle diagrams (aligning with art interpretation standards) and to **communicate scientific ideas visually** (aligning with art creation/presentation standards). This interdisciplinary link makes the abstract processes of cycles more accessible and personally meaningful.

Technology and Digital Tools – Interdisciplinary Connections

Technology integration in the classroom can greatly enhance the exploration of biogeochemical cycles. The **ISTE Standards for Students** (International Society for Technology in Education) outline skills that overlap with science learning:

- **Using Simulations and Models:** *ISTE Standard 1.c (Creativity and Innovation):* **"Students use models and simulations to explore complex systems and issues."** Biogeochemical cycles are complex systems, and this standard encourages leveraging digital tools to understand them. For example, students might use an interactive computer simulation of the **carbon cycle** or **water cycle** – adjusting variables like CO_2 emissions or rainfall and observing outcomes. This hands-on virtual experimentation helps illustrate feedback loops and system dynamics in ways static diagrams cannot, meeting tech standards and science objectives simultaneously.
- **Data Analysis with Technology:** *ISTE Standard 5.b (Computational Thinker):* **Students collect and analyze data using digital tools and represent it in various ways to facilitate problem-solving**. In a cycles unit, students might gather local data (e.g. school recycling rates, weather data, aquarium water quality readings) and use spreadsheets or graphing software to analyze trends. They could graph carbon dioxide levels from an online database or map nitrogen pollution using GIS tools. By doing so, they practice scientific inquiry and meet tech standards for data literacy – for instance, using a digital graph to identify how seasonal changes affect the **oxygen levels** in pond water.
- **Communication and Collaboration:** *ISTE Standard 6.c (Creative Communicator):* **"Students communicate complex ideas clearly and effectively by creating or using a variety of digital objects such as visualizations, models, or simulations."** This aligns perfectly with students explaining cycles using technology. A class might collaborate to make a short video or an animated presentation about the **nitrogen cycle**, or create an infographic using graphic design software that visualizes the **phosphorus cycle** from farm to waterway to ocean sediment. By producing these digital artifacts, students sharpen their understanding (they must break down the cycle clearly) and also fulfill technology standards by choosing appropriate digital formats to express scientific concepts.

- **Research and Information Fluency:** (Related ISTE Standard 3) Students can be tasked with using the internet or digital libraries to research real-world data on cycles – for example, investigating NASA's climate data on atmospheric CO_2 or researching case studies of acid rain (sulfur cycle issue). They must learn to evaluate credible sources (science journals, .gov databases) and synthesize information. This builds skills in using technology to **"obtain and evaluate information"**, paralleling NGSS practice and ISTE guidelines.