The *Carbon TIME* Instructional Model
Activity Sequences

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Introduction: Common Features of All *Carbon TIME* Units

It takes more than one activity to achieve a difficult learning objective.

The *Carbon TIME* instructional model is based on research-based sequences of learning experiences that are effective for helping students build deep and connected knowledge and practice. In contrast, using a curriculum that is not informed by an instructional model can sometimes result in teaching a series of activities that are fun and exciting, but that do not help students build connected knowledge and practice about big ideas in science.

The *Carbon TIME* curriculum consists of six units of instruction aligned with *Next Generation Science Standards (NGSS)* addressing processes that transform matter and energy in organisms, ecosystems, and global systems. The *NGSS* emphasize that separating "facts and skills" (sometimes called content and process, or content and inquiry) does not help students develop connected knowledge or an appreciation for how scientific knowledge is developed and used. Instead, the *NGSS* call for "three-dimensional science learning" that integrates *science and engineering practices*, *crosscutting concepts,* and *disciplinary core ideas* (content).

Figure 1: Three-dimensional science learning

Three-dimensional science teaching requires both *responsiveness* and *rigor* in curriculum materials and teaching practice. *Carbon TIME* units support responsiveness with a learning progression framework. This framework serves as the foundation for formative assessments that help students express and discuss their ideas about carbon-transforming processes.[1] *Carbon TIME* units support rigor with a systematic approach to teaching and learning that is described in this introduction.

Each of the units relies on a three-dimensional instructional model that combines content, practices, and crosscutting concepts. Figure 2 (adapted from Covitt, Dauer, & Anderson, in press; and Gunckel, 2010), represents relationships between content and practice. The layers (observations, patterns, and models) represent different kinds of content *knowledge* that are essential elements of scientific understanding. The arrows represent *practices* that scientists and science learners engage in as they develop new knowledge and use their knowledge to make sense of the natural world. The *Carbon TIME* units use this model as the basis for a pedagogical approach that builds meaningful teaching and learning experiences in a science classroom. There *crosscutting concepts* function as rules or principles that constrain and guide scientific knowledge and practice. Each of these is described below.

Layers of the Triangle: Different Kinds of Science Content Knowledge

Scientific knowledge is not just "facts." Above, Figure 1 identifies three distinct kinds of knowledge that scientists use to organize their work, and that we also use to organize the *Carbon TIME* units. Below, Figure 2 identifies the way we organize some of this knowledge in the *Carbon TIME* units. We call this "the triangle," and it is a prominent feature each unit.

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[1] For more on the *Carbon TIME* learning progression framework, see Parker, de los Santos, & Anderson (2013; in press 2015). What learning progressions on carbon-transforming processes tell us about how students learn to use the laws of conservation of matter and energy. *Educacion Quimica, 24*(4), 399-406.

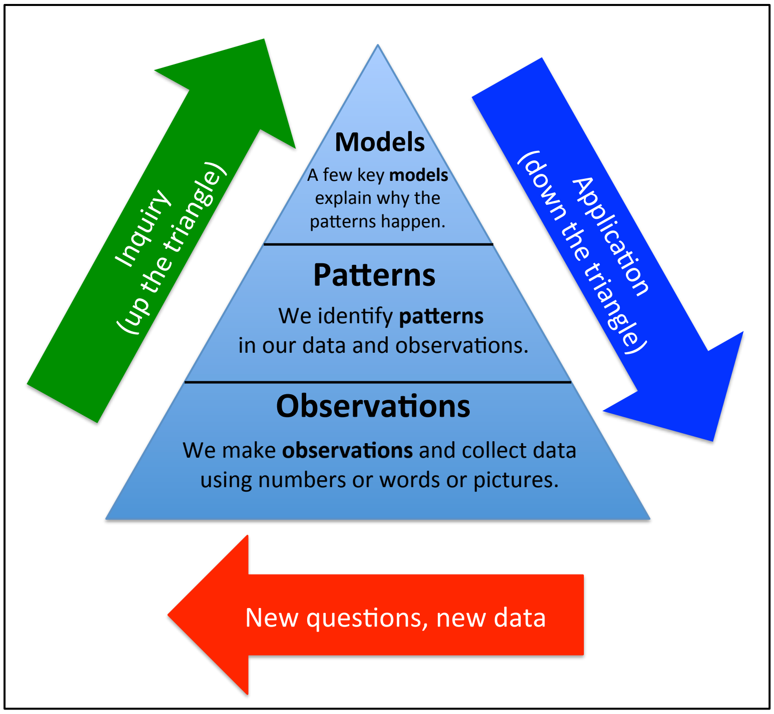


Figure 2 - "The Triangle." This triangle is a foundational component of the units, and contributes to how each *Carbon TIME* unit is organized.

Observations: The world is full of possible experiences in the physical world. When we experience these phenomena, we make observations and collect data. These data become our evidence for "what happened." We do this by taking notes about qualitative observations (e.g., the BTB turned yellow), or recording numbers from measurements (e.g., 2.3 grams). Ideally in a science classroom, there should be numerous opportunities for students to have observations and experiences, just like in the natural world. This is why the Observations layer is the largest in the triangle.

Patterns: After we have made observations and collected data, we organize our evidence to help us identify patterns. These are generalizations about what is happening. Organizing our data into tables, charts, and graphs helps us spot the patterns in what may seem like messy, noisy data. Because patterns are identified in larger amounts of data, there are less patterns than observations. This is why the patterns row is in the middle of the triangle and is smaller than the Observations layer.

Models: Finally, we need to understand why the patterns we observe are happening. There are a few key models that we can use to explain why patterns happen. These models can sometimes be used to explain other similar patterns in other contexts. Because there are so few models, the model layer of the triangle is the smallest.

Arrows of the Triangle: Science and Engineering Practices

The left-hand side of the triangle (going up the triangle) represents a group of science practices that we refer to as **Inquiry**—observing, making predictions, identifying patterns, and developing models that explain why the patterns happen. The right-hand side of the triangle (going down the triangle) represents a group of practices we refer to as **Application**—using scientific models and constructing explanations to connect multiple pieces of information. Application often leads to new questions or new data resulting in starting over with a new inquiry. *Carbon TIME* units are designed to take students on an inquiry journey up the triangle, an application journey down the triangle, and position them for future investigations in another *Carbon TIME* unit.

We use **Inquiry** and **Application** as broad terms that encompass several science and engineering practices. Inquiry includes these *NGSS* practices:

1. Asking questions or defining problems
2a. Developing models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Application includes these *NGSS* practices:

2b. Using models
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
8. Obtaining, evaluating, and communicating information

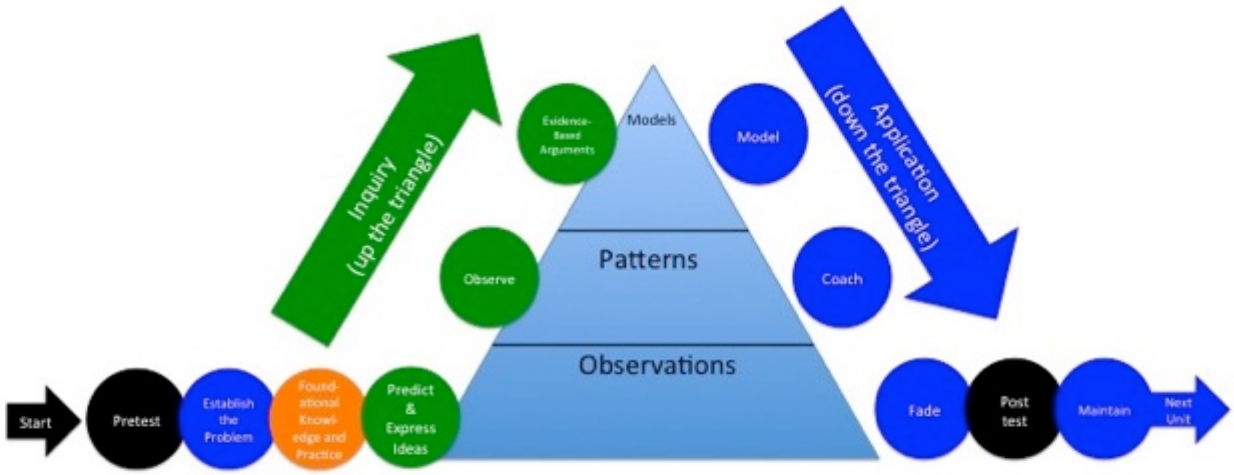
Crosscutting Concepts: Connecting Scales, and Tracing Matter and Energy

Carbon TIME units use crosscutting concepts to define rules or principles that apply to all content and practices. Every unit emphasizes two essential crosscutting concepts:

- **Scale, Proportion, and Quantity.** Our models of the material world are organized into a hierarchy of systems at different scales. Inquiry and application practices almost always involve making connections among models at different scales. Five scales are especially important in *Carbon TIME.*
    - Atomic-molecular scale (around 10^{-9} m)
    - Cellular scale (around 10^{-5} m)
    - Macroscopic scale (around 1 m)
    - Ecosystem scale (around 10^{4} m)
    - Global scale (around 10^{7} m)
- **Energy and matter: Flows, cycles and conservation.** Matter and energy are conserved in all physical and chemical changes, including the carbon cycling processes we study in *Carbon TIME.* This means that a very important way to understand these processes (e.g., photosynthesis, cellular respiration, digestion) is *tracing matter and energy* through them.

The general pattern of unit organization

While the triangle in Figure 1 is at the heart of helping students understand and apply difficult science concepts, the instructional model includes additional elements that assess student understanding, stimulate interest, provide foundational knowledge, follow intentional activity sequences, and assess learning over time. The diagram below maps out these elements.



Description of Elements

1. **Pretest**: An opportunity for teachers to assess student understanding before engaging in the Unit. Teachers use the information from the pretest to inform instruction based on patterns in student understanding.
2. **Establish the Problem and Initial Ideas:** A motivating "teaser" such as a time-lapse video or interesting observable phenomenon poses a guiding question that students will explore in the Inquiry and Application sequences of the Unit. Students share their initial ideas about the phenomenon.
3. **Foundational Knowledge and Practice**: Activities that teach students basic knowledge and practice needed in the rest of the unit.
4. **Inquiry Activity Sequence (up the triangle):** An intentional sequence that engages the students' scientific practices associated with inquiry and constructing arguments from evidence. The inquiry sequence consists of three specific stages: Predict & Express Ideas, Observe, and Evidence-Based Arguments. These stages are often referred to as PEOE in the units.

Stage	***Practices for Students***	***Examples in Carbon TIME***
Predict & Express Ideas: Students PREDICT what will happen during an investigation and then EXPRESS their reasoning behind their prediction.	• Express their ideas about what is happening to matter and energy during a phenomenon (no ideas are right or wrong at this point)	• Using the Three Questions and the Initial Ideas and Predictions process tools to explain what is happening to matter and energy
Observe: Students OBSERVE what actually happens during an investigation, record their data, and then look for patterns in their data (evidence).	• Make measurements • Record data • Look for patterns in data	• Measuring the change in mass of an organism • Observing changes in BTB color • Observing energy indicators (motion, heat, light)
Evidence-Based Arguments: Students construct ARGUMENTS for why the patterns they observed happened using EVIDENCE they observed during the investigation. Then they return to their initial ideas to see how their ideas changed and identify questions that they still cannot	• Connect the pattern to an explanation • Identify unanswered questions	• Answering *parts* of the Three Questions for a specific carbon transforming process Note: The investigations do not give a complete answer to the Three Questions. These answers are completed in the Application sequences.

answer.		

5. **Application Activity Sequence (down the triangle)**: Another intentional sequence that follows up with unanswered questions and asks students to apply what they have learned in a variety of new contexts. Consists of three specific stages: Model, Coach, and Fade. These stages are often referred to as MCF in the Units.

Stage	***Practices for Students***	***Examples in Carbon TIME***
Model: Teachers lead students in a highly scaffolded set of activities to develop model-based explanations of the pattern they observed in the inquiry sequence.	• See and understand how an expert explains the phenomenon	• Molecular modeling activities • Power Point animations of chemical change.
Coach: Teachers lead students in a scaffolded activity where students follow the same pattern of practice.	• Explain the phenomenon with support and feedback from the teacher	• Answering the Three Questions for a specific carbon transforming process. • Completing the process tool.
Fade: The responsibility is transferred to students completely to apply the knowledge from the inquiry sequence in new contexts.	• Use models and principles to explain other related phenomena with minimal support.	• Explain a carbon-transforming process in another context (combustion in methane at the end of the *Systems & Scale* Unit). • Explain a carbon transforming process without using the Three Questions (Unit Posttests).

6. **Posttest**: In this final activity of each Unit, students take a posttest (identical to the pretest) to identify how student thinking changed over time. Students are expected to maintain what they have learned by connecting what they have learned about carbon transforming processes in one Unit to related carbon transforming processes in the next Unit. After the posttest, they move on to the final stage of application sequence: Maintain.

Stage	***Goals for Students***	***Examples in Carbon TIME***
Maintain: Students take the knowledge they learned in this unit and apply the knowledge in the next unit, making connections to other activities and contexts.	• Apply knowledge and principles in other contexts	Explaining the same carbon transforming processes with a different type of organism (cellular respiration in the *Plants* Unit after learning it in the *Animals* Unit) or at a different scale (*Ecosystems* Unit*)*.

All units include each element in list above; however, each unit presents a different variation on this model. For example, some units have an additional inquiry-application triangle, and some units have multiple application sequences for different carbon-transforming processes. Maps for each unit that show these variations can be found below.

The Macroscopic-scale Units

The first four units, *Systems and Scale, Animals, Plants,* and *Decomposers,* focus on macroscopic-scale phenomena: fuels burning, animal growth and movement, plant growth and function, and decay. Students do investigations of each of these processes and learn to explain them in terms of chemical processes taking place at the atomic-molecular scale: combustion, photosynthesis, biosynthesis, digestion, and cellular respiration. Students learn to answer the Three Questions (Table 3) for each process. Note that the Three Questions incorporate key principles based on the *NGSS* crosscutting concepts. Each of the columns of Table 3 plays an important role:

- The Three Questions in the first column define a rigorous explanation for macroscopic-scale processes: A good explanation needs to answer all three questions.
- The second column, “Rules to Follow,” explains how to apply the principles of conservation of matter and energy in any and all contexts.
- The third column, “Evidence We Can Observe,” explains how to connect observable processes at the macroscopic scale with explanations at the atomic-molecular scale.

The *Carbon TIME* units use the Three Questions to reinforce a “sense of necessity” in students about the crosscutting concepts in the units. Matter and energy are *always* conserved, so we should *always* check to make sure that our explanations and arguments from evidence don’t 1) have matter or energy appearing or disappearing, or 2) matter being converted to energy.

Table 3: The Three Questions for Macroscopic-scale Processes

Question	Rules to Follow	Evidence We Can Observe
The Movement Question: Where are molecules moving? How do molecules move to the location of the chemical change? How do molecules move away from the location of the chemical change?	All materials (solids, liquids, and gases) are made of atoms that are bonded together in molecules. **Scle:** The matter movement question can be answered at the atomic-molecular, cellular, or macroscopic scale.	Moving solids, liquids, and gases are made of moving molecules. A change in mass shows that molecules are moving.
The Carbon Question: How are atoms in molecules being rearranged into different molecules? What molecules are carbon atoms in before and after the chemical change? What other molecules are involved?	ʃ**Atoms last forever** in combustion and living systems. **Atoms can be rearranged** to make new molecules, but not created or destroyed. Carbon atoms are bound to other atoms in molecules. **Scale:** The matter change question is always at the atomic-molecular scale.	BTB can indicated CO_2 in the air. Organic materials are made up of molecules containing carbon atoms. • fuels • foods • living and dead plants and animals • decomposers
The Energy Question: What is happening to energy? What forms of energy are involved? What energy transformations	**Energy lasts forever** in combustion and living systems. **Energy can be transformed,** but not	We can observe indicators of different forms of energy before and after chemical changes: • light energy • chemical energy stored in

take place during the chemical change?	created or destroyed. C-C and C-H bonds have more stored chemical energy than C-O and H-O bonds. **Scale:** The energy change question can be answered at the atomic-molecular, cellular, or macroscopic scales.	organic materials • motion energy • heat energy

The Systems & Scale Unit

<table>
<tr><th colspan="2">Observations, Patterns, and Models in the Systems & Scale unit (the layers of the triangle)</th></tr>
<tr><td>

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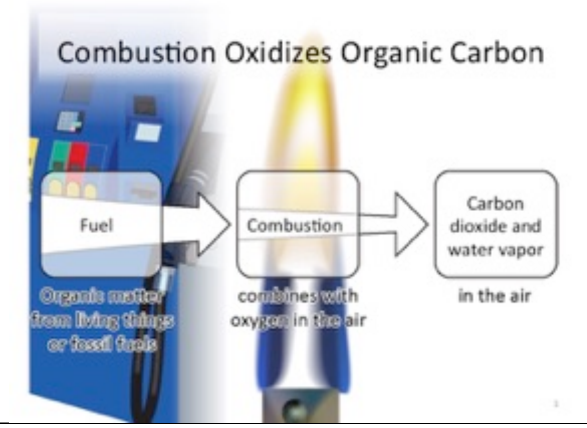

</td></tr>
<tr><td>Observations and Patterns: Students investigate burning ethanol. Key patterns in their observations:

Ethanol loses mass when it burns (detected with a digital balance)
The air gains CO_2 when ethanol burns (detected with bromothymol blue, or BTB)
</td><td>Models (and Explanations): Students explain combustion by connecting the macroscopic and atomic-molecular scales, and by answering the Three Questions:

Movement: ethanol vapor and O_2 move into the flame; CO_2 and H_2O vapor move out of the flame
Carbon transformations: $C_2H_5OH + 3O_2 \rightarrow 3\ CO_2 + 3\ H_2O$
Energy: Chemical energy is transformed into heat and light energy
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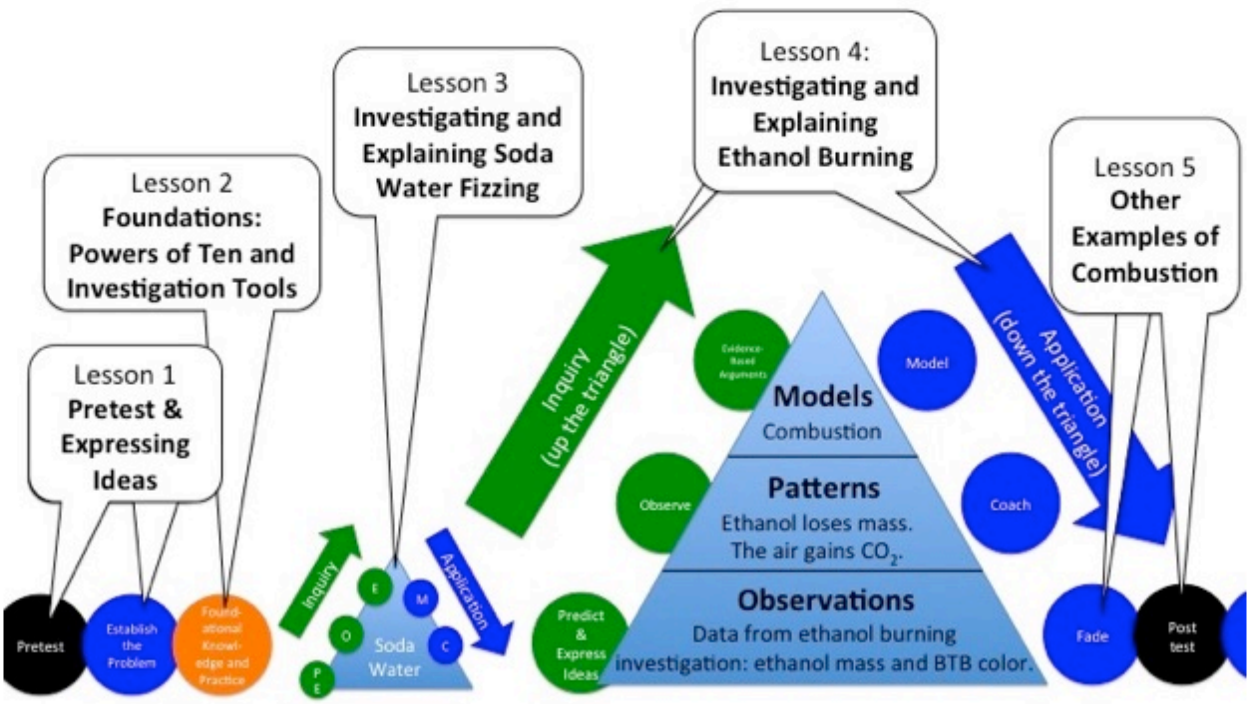


Systems and Scale Unit at a Glance

Lesson 1 – Pretest and Expressing Ideas (40 min)

- Activity 1.1: Systems and Scale Unit Pretest (20 min)
- Activity 1.2: Expressing Ideas about Ethanol Burning (20 min)

Lesson 2 – Foundations: Powers of Ten and Investigation Tools (2 hr 45 min)

- Activity 2.1: Powers of Ten Video and Discussion (45 min)
- (Optional) Activity 2.2: From Big to Small (30 min)
- Activity 2.3: Zooming into Air (30 min)
- Activity 2.4: Atoms and Molecules Quiz and Discussion (30 min)
- Activity 2.5: Using a Digital Balance and BTB (30 min)

(Optional) Lesson 3 – Investigating and Explaining Soda Water Fizzing (2 hr 10 min)

- Activity 3.1: Predictions about Soda Water Fizzing (20 min)
- Activity 3.2: Observing Soda Water Fizzing (30 min)
- Activity 3.3: Evidence-Based Arguments about Soda Water Fizzing (20 min)
- Activity 3.4: Molecular Models for Soda Water Fizzing (40 min)
- Activity 3.5: Explaining Soda Water Fizzing (20 min)

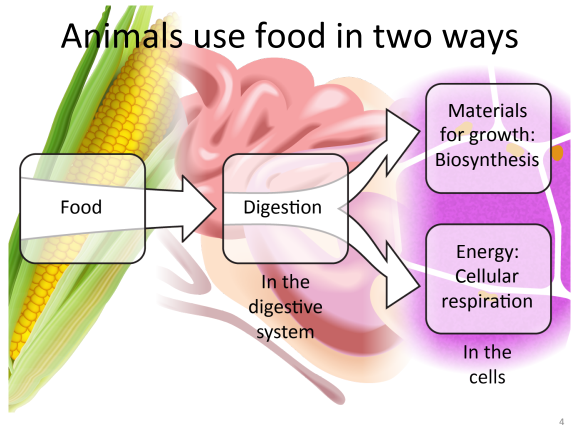
Lesson 4 – Investigating and Explaining Ethanol Burning (2 hr 10 min)

- Activity 4.1: Predictions about Ethanol Burning (20 min)
- Activity 4.2: Observing Ethanol Burning (30 min)
- Activity 4.3 Evidence-Based Arguments about Ethanol Burning (20 min)
- Activity 4.4: Molecular Models for Ethanol Burning (40 min)
- Activity 4.5: Explaining Ethanol Burning (20 min)

Lesson 5 – Other Examples of Combustion (2 hr 20 min)

- (Optional) Activity 5.1: Molecular Models for Methane Burning (40 min)
- (Optional) Activity 5.2: Explaining Methane Burning (20 min)
- Activity 5.3: Preparing for Future Units – Organic vs. Inorganic (40 min)
- Activity 5.4: Explaining Other Examples of Combustion (20 min)
- Activity 5.5: Systems and Scale Unit Posttest (20 min)

The Animals Unit

<table>
<tr><th colspan="2">Observations, Patterns, and Models in the Animals unit (the layers of the triangle)</th></tr>
<tr><td></td><td>
</td></tr>
<tr><td>Observations and Patterns: Students investigate mealworms eating a potato. Key patterns in their observations:
• Mealworms gain mass.
• The potato loses mass.
• The potato loses more mass than the mealworms gain.
• Mealworms release CO_2 into the air.</td><td>Models (and Explanations): Students explain digestion, biosynthesis, and cellular respiration by connecting macroscopic and atomic-molecular scales, and by answering the Three Questions:
• Movement: Animals do not digest all the food they eat, eliminating undigested food as feces. Digested food moves through blood to the cells.
• Carbon and energy:
○ Animal cells get the materials they need to grow and divide through digestion and biosynthesis.
○ Animal cells get the energy they need to move and function through digestion and cellular respiration.</td></tr>
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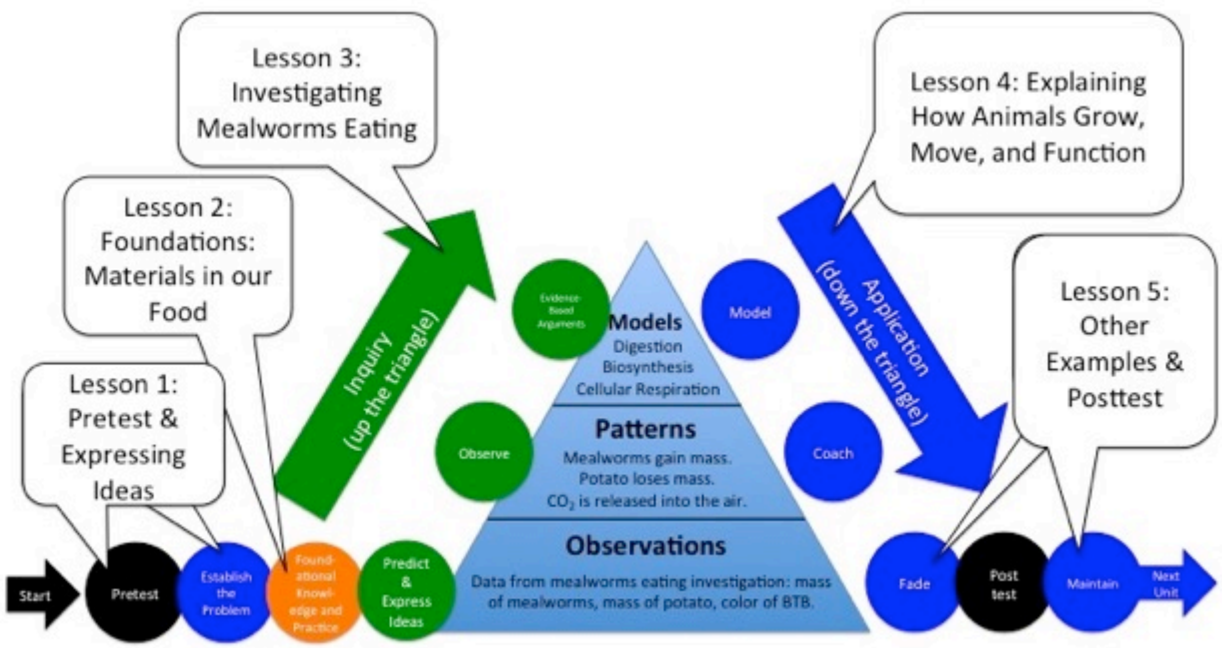


Animals Unit at a Glance

Lesson 1 – Pretest and Expressing Ideas (40 min)

- Activity 1.1: Animals Unit Pretest (20 min)
- Activity 1.2: Expressing Ideas about How Animals Grow (20 min)

Lesson 2 – Foundations: Materials in Our Food (1 hr 20 min)

- Activity 2.1: Zooming into Food (50 min)
- Activity 2.2: Food Molecules Quiz and Discussion (30 min)

Lesson 3 – Investigating Mealworms Eating (1 hr 40 min)

- Activity 3.1: Predictions about Mealworms Eating (20 min)
- Activity 3.2: Observing Mealworms Eating (60 minutes over 2 days)
- Activity 3.3: Evidence-Based Arguments about Mealworms Eating (20 min)

Lesson 4 –Explaining How Animals Move and Function (2 hr 20 min)

- Activity 4.1: Molecular Models for Cows Moving and Functioning: Cellular Respiration (40 min)
- Activity 4.2: Explaining How Cows Move and Function: Cellular Respiration (20 min)

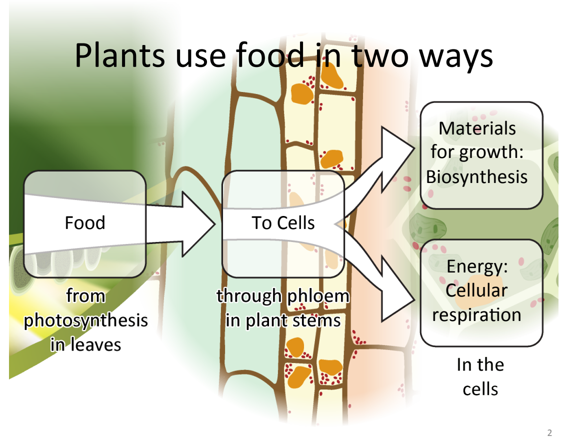
Lesson 5 – Explaining How Animals Grow

- Activity 5.1: Molecular Models for Cows Growing: Digestion and Biosynthesis (40 min)
- (1- or 2-Turtle) Activity 5.2: Explaining How Cows Grow: Digestion and Biosynthesis (40-60 min)

Lesson 6 – Other Examples of Digestion, Biosynthesis, and Cellular Respiration (1 hr 20 min)

- Activity 6.1: Explaining Other Examples of Animals Growing, Moving, and Functioning (60 min)
- NEW Activity 6.2: All Animals Explanation
    - have an introduction about how in spite of their many differences in size, shape, structure, and function, all animals have some basic things in common: they take in food, water, and O2, release feces, (urine), and CO2, are made of cells that are responsible for all their work, etc.
    - come back to the atom tracing questions
    - has students write a general explanation/storyline about what animals do with food to grow and function.
- Activity 6.3: Animals Unit Posttest (20 min)

The Plants Unit

<table>
<tr><th colspan="2">Observations, Patterns, and Models in the Plants unit (the layers of the triangle)</th></tr>
<tr><td></td><td>
</td></tr>
<tr><td>Observations and patterns: Students investigate plants growing and gas exchange in the light and dark. Key patterns in their observations:

When plants grow, they gain more dry mass than the soil loses.
Plants absorb CO_2 in the light.
Plants emit CO_2 in the dark.
</td><td>Models (and Explanations): Students explain Photosynthesis, Biosynthesis, and Cellular Respiration by connecting macroscopic and atomic-molecular scales, and by answering the Three Questions:

Movement: The materials that plants are made of come mostly from CO_2 entering through leaves, along with water and minerals from the soil.
Carbon and energy:

Plant cells get the materials they need to grow and divide through photosynthesis and biosynthesis.
Plant cells get the energy they need to move and function through photosynthesis and cellular respiration.

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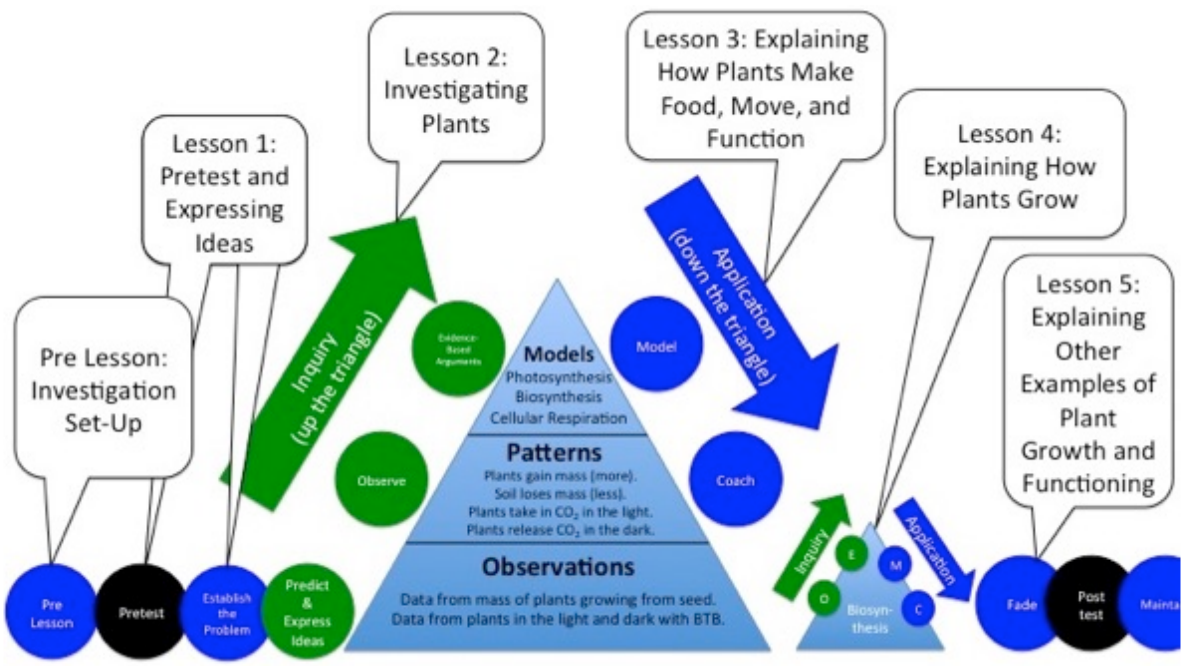


Plants Unit at a Glance

Pre-Lesson – Investigation Set Up

- ☐ **Gel Protocol (2-turtle)**
  - Pre-Activity 0.1: Keeping Track of Water in Solids and Liquids (60 min + overnight or several days)
  - Pre-Activity 0.2GL: Plant Growth Investigation Setup (45-60 min over one or two days)
- ☐ **Paper Towel Protocol (1-turtle)**
  - Pre-Activity 0.2PT: Plant Growth Investigation Setup (45-60 min)

Lesson 1 – Pretest and Expressing Ideas (50 min)

- Activity 1.1: Plants Unit Pretest (20 min)
- Activity 1.2: Expressing Ideas About How Plants Grow (30 min)

NEW Lesson 2 – Foundations: Materials in Our Food (1 hr 20 min)

- Activity 2.1: Zooming into Food (50 min) *(similar to previous Activity 4.3 Materials Plants Are Made Of)*
- Activity 2.2: Food Molecules Quiz and Discussion (30 min)

Lesson 3 – Investigating Plants

- ☐ **Gel Protocol (2-turtle)**
  - Activity 3.1GL: Predictions About Plant Investigations (50 min)
- ☐ **Paper Towel Protocol (1-turtle)**
  - Activity 3.1PT: Predictions About Plant Investigations (50 min)
- Activity 3.2: Observing Plants in the Light and Dark (60 min)
- Activity 3.3: Evidence-Based Arguments About Plants in the Light and Dark (20 min)
- ☐ **Gel Protocol (2-turtle)**
  - Activity 3.4GL: Observing Plants' Mass Changes, Part 1 (30 min)
- ☐ **Paper Towel Protocol (1-turtle)**
  - Activity 3.4PT: Observing Plants' Mass Changes, Part 1 (30 min)

Lesson 4 – Explaining How Plants Move, Function, and Make Food

- Activity 4.1: Molecular Models for Potatoes Moving and Functioning: Cellular Respiration (30-90 min)
  - *Note: The steps that have students construct molecular models in this activity are optional if students did molecular modeling for cellular respiration in another unit and performed well on the pretest for items related to cellular respiration.*
- Activity 4.2: Explaining How Plants Move and Function: Cellular Respiration (30 min)
- Activity 4.3: Molecular Models for Potatoes Making Food: Photosynthesis (60 min)
- Activity 4.4: Explaining How Plants Make Food: Photosynthesis (40 min)

Lesson 5 – Explaining How Plants Grow

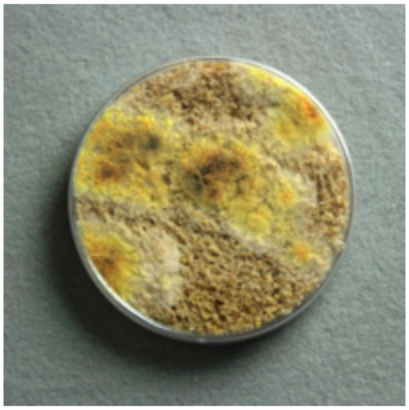
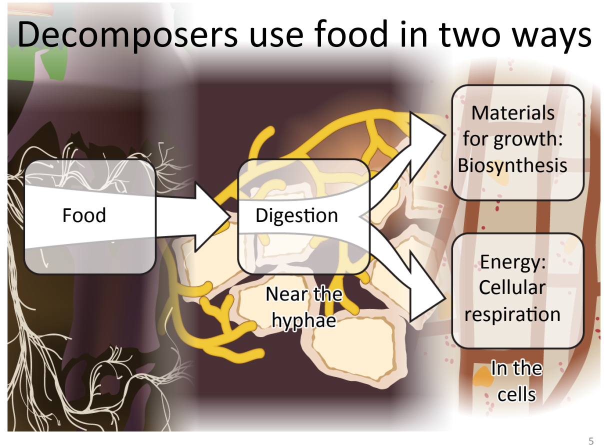
- ☐ **Gel Protocol (2-turtle)**
  - Activity 5.1GL: Observing Plants' Mass Changes, Part 2 (20-45 min)
- ☐ **Paper Towel Protocol (1-turtle)**
  - Activity 5.1PT: Observing Plants' Mass Changes, Part 2 (20-45 min)
- Activity 5.2: Evidence-Based Arguments about How Plants Grow (30 min)
- (2-Turtle) Activity 5.3: Molecular Models for Potatoes Growing: Biosynthesis (40-60 min)

- (1- or 2-Turtle) Activity 5.4: Explaining How Plants Grow: Biosynthesis (30 min)

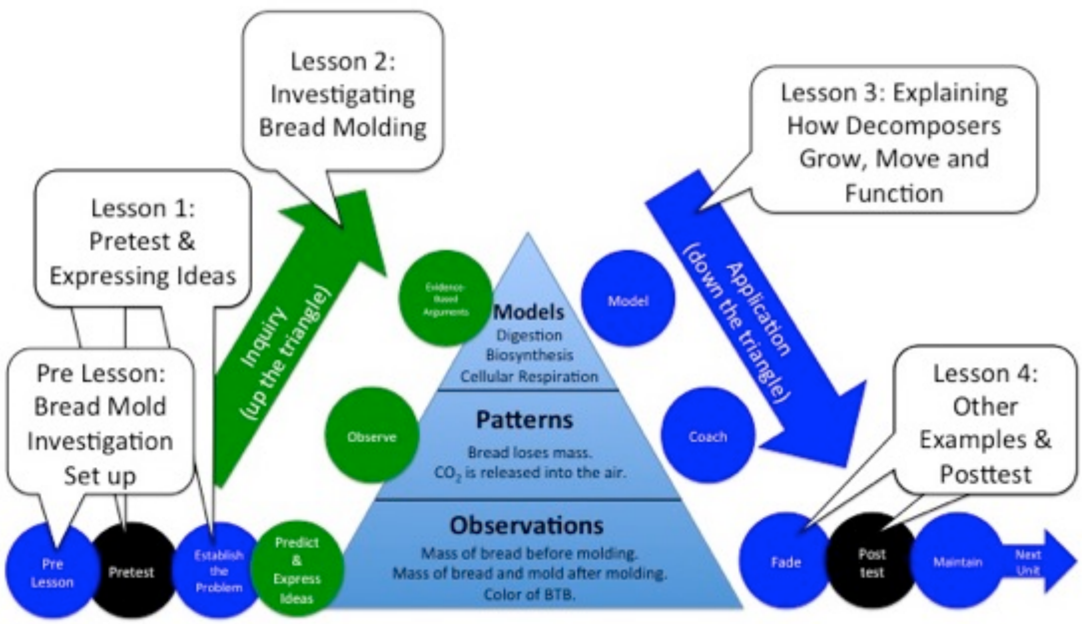
Lesson 7 – Explaining Other Examples of Plants Growing, Moving, and Functioning

- Activity 7.1: Explaining Other Examples of Plants Growing, Moving, and Functioning (60 min)
- NEW Activity 7.2: All Plants Explanation
- Activity 7.3: Plants Unit Posttest (20 min)

The Decomposers Unit

Observations, Patterns, and Models in the *Decomposers* unit (the layers of the triangle)	
	

Observations and patterns: Students investigate bread molding. Key patterns in their observations:
• The combined mass of the bread and the growing fungus goes down as the mold grows.
• Molding bread emits CO_2 into the air.
	Models (and Explanations): Students explain digestion, biosynthesis, and cellular respiration by connecting macroscopic and atomic-molecular scales, and by answering the Three Questions:
	• Movement: Unlike animals, decomposers digest food outside their bodies and absorb digested food.
	• Carbon and energy:
	  ○ Like animals, fungus cells get the materials they need to grow and divide through digestion and biosynthesis.
	  ○ Like animals, fungus cells get the energy they need to move and function through digestion and cellular respiration.



Decomposers Unit at a Glance

Pre Lesson – Bread Mold Investigation Set Up

- Activity Pre 1.1: Bread Mold Investigation Set Up (30 min)

Lesson 1 – Pretest and Expressing Ideas (45 min)

- Activity 1.1: Decomposers Unit Pretest (20 min)
- Activity 1.2: Expressing Ideas about How Things Decay (25 min)

NEW Lesson 2 – Foundations: Materials in Our Food (1 hr 20 min)

- Activity 2.1: Zooming into Food (50 min)
- Activity 2.2: Food Molecules Quiz and Discussion (30 min)

Lesson 3 – Investigating Bread Molding

- Activity 3.1: Zooming into Decomposers (40 min)
- Activity 3.2: Predictions about Bread Molding (20 min)
- Activity 3.3: Observing Bread Molding (40 min)
- Activity 3.4: Evidence-Based Arguments for Bread Molding (50 min)
    - *Note: The construction of models steps of this Activity are optional if students did molecular modeling for digestion and biosynthesis in another unit and performed well on the pretest for items related to digestion and biosynthesis.*

Lesson 4 – Explaining How Decomposers Move and Function

- Activity 4.1: Molecular Models for Decomposers Moving And Functioning: Cellular Respiration (40 min)
    - *Note: The steps that have students construct molecular models in this activity are optional if students did molecular modeling for cellular respiration another unit and performed well on the pretest for items related to cellular respiration.*
- Activity 4.2: Explaining How Decomposers Move and Function: Cellular Respiration (20 min)

Lesson 5 – Explaining How Decomposers Grow

- Activity 5.1: Molecular Models for Decomposers Growing: Digestion and Biosynthesis (40 min)
- (1- or 2-Turtle) Activity 5.2: Explaining How Decomposers Grow: Digestion and Biosynthesis (20 min)

Lesson 6 – Explaining Other Examples of Decomposers Growing, Moving, and Functioning

- Activity 6.1: Bacteria Decomposers in the Soil (60 min)
- Activity 6.2: Explaining Other Examples of Decomposers Growing, Moving, and Functioning (40 min)
- NEW Activity 6.3: All Decomposers Explanation
- Activity 6.4: Decomposers Unit Posttest (20 min)

The Large-scale Units

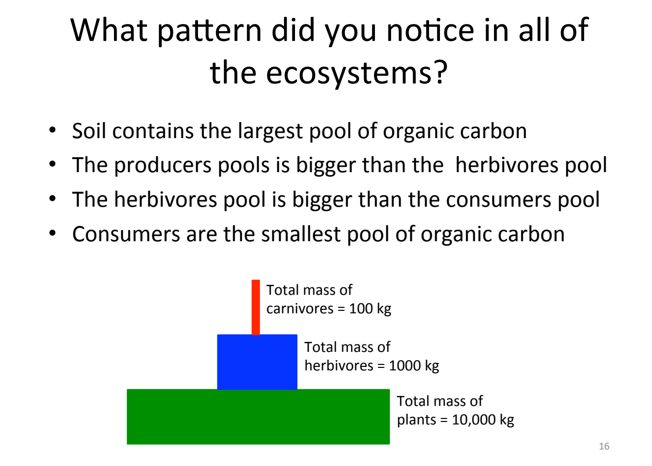
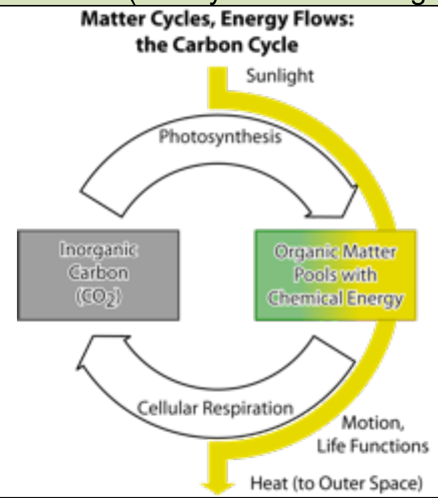
The large-scale units, *Ecosystems* and *Human Energy Systems,* have the same basic structure as the macroscopic scale units—investigations followed by application. They also share the same fundamental goals—tracing matter (especially carbon) and energy through processes at multiple scales. They are different, though, in that students now focus on carbon pools in large-scale systems and fluxes among those pools. This means that the Three Questions take a slightly different form (Table 4 below), but the columns have the same basic purposes:

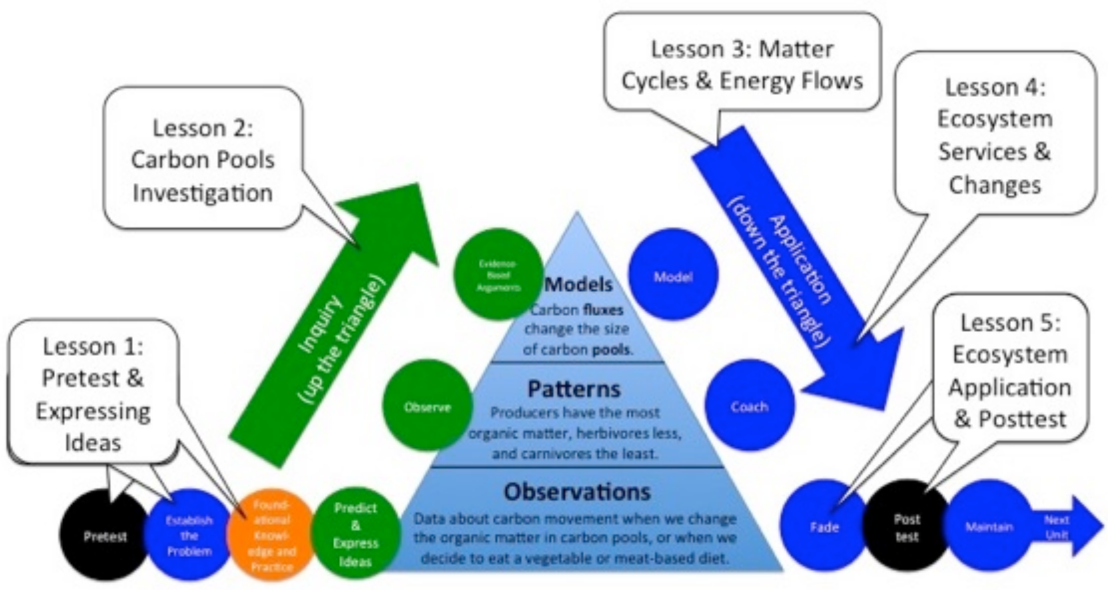
- The Three Questions in the first column define a rigorous explanation for large-scale processes. A good explanation needs to answer all Three Questions.
- The second column, "Rules to Follow," explains how to apply the principles of conservation of matter and energy: *matter cycles, energy flows*.
- The third column, "Evidence to Look For," explains how to connect observable processes at the macroscopic scale with model-based explanations at the atomic-molecular scale and with large-scale carbon pools and fluxes.

Table 4: The Three Questions: Ecosystem and Global Scale

Question	Rules to Follow	Connecting Atoms to Evidence
The Carbon Pools Question: Where are the carbon pools in our environment? How do the pools change size over time?	**Atoms last forever.** For a carbon pool to change size, carbon atoms MUST move in or out of the pool.	**Organic Carbon Pools** • Living producers, herbivores, carnivores (biomass) • Soil organic carbon: dead leaves, plants, animals, feces, and decomposers • Fossil fuels **Inorganic Carbon Pools** • The atmosphere pool (CO_2) • The ocean pool: dissolved (CO_2 and other materials)
The Carbon Fluxes Question: **Movement:** How are carbon atoms moving among pools? **Fluxes:** At what rate are carbon atoms moving among pools?	**Matter cycles** within environmental systems. Carbon-transforming processes move carbon atoms among pools. Carbon fluxes change the size of carbon pools.	**Carbon-transforming Processes** • Plants growing (photosynthesis and biosynthesis) • Organisms eating, growing, moving (digestion and biosynthesis) • Organisms moving, breathing, decay (cellular respiration) • Combustion **Movements of Organic Carbon** • Death, dropping leaves, feces • Mining fossil fuels: coal, oil, natural gas
The Energy Question: How does energy flow through environmental systems?	**Energy flows** through environmental systems. Carbon-transforming processes change energy from **sunligh**t to **chemical energy** to **motion and life processes** to **heat** (eventually radiated into space).	**Indicators of different forms of energy** • light • organic materials with chemical energy • work or motion energy, life processes • heat energy

The Ecosystems Unit

<table>
<tr><th colspan="2">Observations, Patterns, and Models in the Ecosystems unit (the layers of the triangle)</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Observations and patterns: Students use a simulation and data to investigate relationships among producers, herbivores, and carnivores in different terrestrial ecosystems. Key patterns in their observations:
• The organic matter pyramid: Producers have the most organic matter, herbivores less, and carnivores the least.
• Humans depend on farm ecosystems and can choose whether to be herbivores or carnivores.</td><td>Models (and Explanations): Students connect ecosystem, macroscopic, and atomic-molecular scales to explain carbon cycling and energy flow, including:
• Pools: carbon atoms are found in CO_2, living organisms, and soil organic carbon
• Fluxes: carbon cycles among pools; pools change size when fluxes change with the seasons or disturbances
• Energy: Ecosystems transform light energy into chemical energy and then into heat that is radiated into space.</td></tr>
</table>



Ecosystems Unit at a Glance

Lesson 1 –Pretest and Key Features of Ecosystems (50 min)

- Activity 1.1: Ecosystems Unit Pretest (20 min)
- Activity 1.2: Key Features of Ecosystems (30 min)

Lesson 2 – Sunny Meadows Investigation (1 hr 50 min)

- Activity 2.1: Carbon Pools (40 min)
- Activity 2.2: The Sunny Meadows Game (50 min)
- Activity 2.3: Comparing Different Ecosystems (20 min)

Lesson 3 – Matter Cycles and Energy Flows in Ecosystems (1 hr 40 min)

- Activity 3.1: Carbon Dice Game (30 min)
- Activity 3.2: Tracing Carbon Through an Ecosystem (40+ min)
- Activity 3.3: Tracing Energy Through an Ecosystem (30 min)

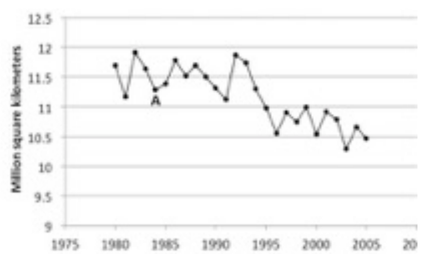
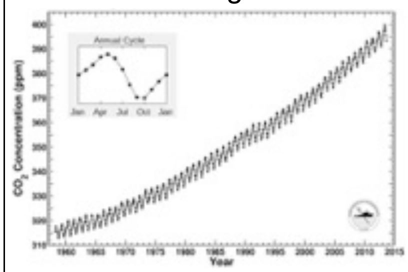
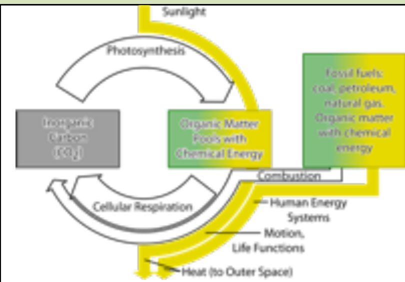
Lesson 4 – Ecosystem Services and Changes in Ecosystems (1 hr 50 min)

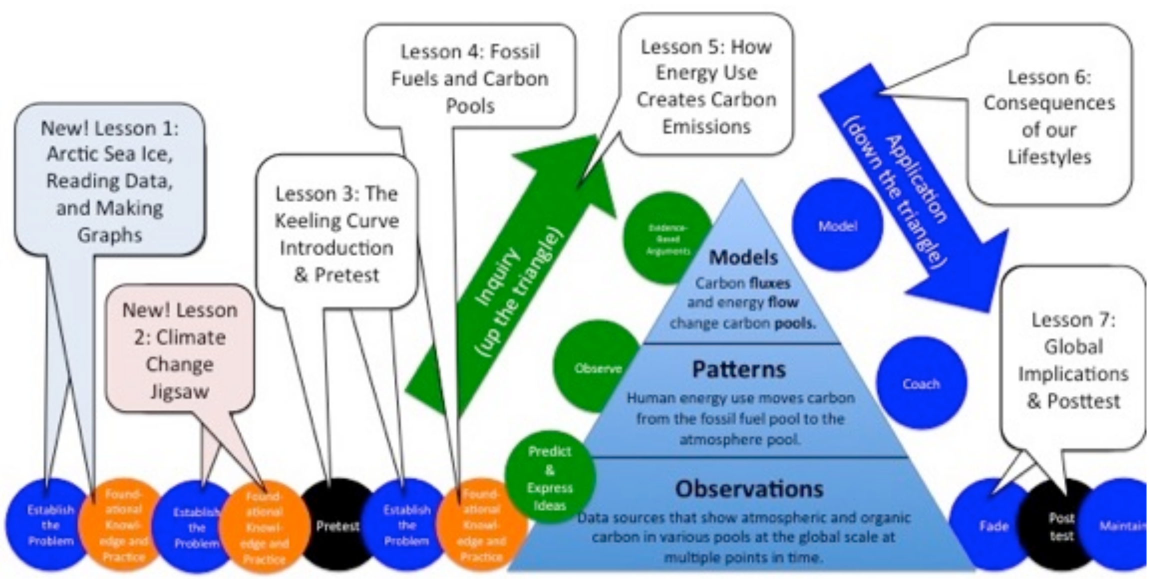
- Activity 4.1: Farms are Ecosystems, Too (30 min)
- Activity 4.2: Changes in Ecosystems Over Time (40 min)
- Activity 4.3: Ecosystem Disturbances (40 minutes)

Lesson 5 – Ecosystems Application and Posttest (1 hr)

- Activity 5.1: Ecosystem Services and Carbon in Ecosystems (20+ min)
- Activity 5.2: Energy and Matter in Food Webs (20 min)
- Activity 5.3: Ecosystems Unit Posttest (20 min)

The Human Energy Systems Unit

Observations, Patterns, and Models for the *Human Energy Systems* Unit		
Arctic Sea Ice 	The Keeling Curve 	
Observations and patterns: Students use visualizations and graphs to investigate patterns of change in global climate-related data, including: • Arctic sea ice has declined erratically since 1975. • Global temperatures have risen about 1° Celsius since 1880. • Global sea levels have risen more than 20 cm since 1870. • Atmospheric CO_2 concentrations have increased from about 310 to 400 ppm since the late 1950s.	**Observations and patterns:** Students also use visualizations and graphs to investigate changes in atmospheric CO_2 concentrations. Key patterns include: • The annual cycle: CO_2 concentrations in the northern hemisphere decline every summer and rise every winter. • The long-term trend: Global CO_2 concentrations have increased from about 310 to 400 ppm since the late 1950s.	**Models (and Explanations):** Students explain carbon cycling and energy flow between carbon pools by connecting global, macroscopic, and atomic-molecular scales, and answering the Three Questions: • **Pools**: carbon atoms are found in CO_2, living organisms, soil organic carbon, oceans, and fossil fuels. • **Fluxes**: Changes in photosynthesis drive the annual cycle; combustion of fossil fuels drives the long-term trend. • **Energy**: CO_2 and other greenhouse gases cause climate change.



Human Energy Systems Unit at a Glance

Lesson 1 – Pretest and Arctic Sea Ice

- Activity 1.1 Human Energy Systems Unit Pretest (20 min)
- Activity 1.2: Graphing Arctic Sea Ice (45 min)
- Activity 1.3: Finding a Trend in Arctic Sea Ice Data (40 min)
- Module 1.4: Identifying Patterns in Arctic Sea Ice Data (40 min)

Lesson 2 – Describing Patterns in Large Scale Data

- Activity 2.1: Three Considerations for Making Sense of Large Scale Data (30 min)
- Activity 2.2: Expert Group Analysis: A Large-Scale Phenomenon (45 min)
- Activity 2.3: Jigsaw Groups Share Expertise (45 min)
- Activity 2.4: Identifying Patterns and Asking Questions for Climate Change Data

Lesson 3 – The Keeling Curve

- Activity 3.1 Millions of Flasks of Air (30 minutes)
- Activity 3.2 The CO_2 Trend: Your Ideas about the Keeling Curve (30 min)
- Activity 3.3 Why We Care About the Keeling Curve (20 min)

Lesson 4 – Fossil Fuels and Carbon Pools

- Activity 4.1 Finding the Carbon (15 min)
- Activity 4.2 The Organic/Inorganic Swap (40 min)
- Activity 4.3 The Seasonal Cycle (20 min)
- Activity 4.4 Zooming Into Fossil Fuels (20 min)
- Activity 4.5 Follow the Carbon (25 min)

Lesson 5 – How Energy Use Creates Carbon Emissions

- Activity 5.1 Carbon Emissions Jigsaw (60 min)
- Activity 5.2 Energy Scenarios (30 min)
- Activity 5.3 The Upward Trend (30 min)

Lesson 6 – Consequences of Our Lifestyles

- Activity 6.1 How We Use Organic Carbon (20 min)
- Activity 6.2 Extreme Makeover: Lifestyle Edition (25 min)
- Activity 6.3 Secrets Revealed (25 min)

Lesson 7 – Global Implications and Posttest

- Activity 7.1 Strategies to Lower Carbon Emissions (30 min)
- Activity 7.2 Making Predictions about Global Temperature Rise (30 min)
- Activity 7.3 Discussing Uncertainty (30 min)
- Activity 7.4 Group strategies for lowering global carbon emissions (30 min)
- Activity 7.5: Human Energy Systems Unit Posttest (20 min)

References

Covitt, B. A., Dauer, J. M., and Anderson, C. W. (in press). The role of practices in scientific literacy. In B. Reiser, C. Schwarz, & C. Passmore (Eds.). *Bringing next generation science & engineering practices into our K-12 Classrooms: Moving beyond "knowing" science to making sense of the world.* Washington, DC: NSTA Press.

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