

PLANT GROWTH AND GAS EXCHANGE

HIGH SCHOOL TEACHER'S GUIDE



Culturally relevant ecology, learning progressions and environmental literacy
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Environmental Literacy Project
<http://edr1.educ.msu.edu/EnvironmentalLit/index.htm>

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Overview and Background for Teachers

The activities in this unit engage students in collecting data about plant growth and gas exchange, then in developing a scientific explanation for their observations. A major focus of the unit is to engage students in the question of where the dry plant matter came from (i.e., not from the soil or water, but from the air), and what plant matter is (it is based on carbon). These activities will lay a foundation for tracing carbon through organisms and ecosystems, improving student understanding of the global carbon cycle.

The key observations are as follows:

1. Plants need light, water, soil nutrients, and air to grow.
2. Plants gain more weight than the soil loses when they grow.
3. Carbon dioxide has an observable weight.
4. In the light, plants absorb carbon dioxide and (by inference) gain weight.
5. In the dark, plants emit carbon dioxide and (by inference) lose weight.
6. Although the weight of plants is mostly water, the actual plant structure or dry weight is not water.

Some observations probably will not be surprising to your students. However, many students probably will not predict observations 3, 4 and 5. Beyond that, very few students will see these observations as *connected*. The key connection that students need to make is the connection between weight change and gas exchange: Plants gain weight *because* they are absorbing carbon from the air, and when plants (or animals or decomposers) lose weight, it is primarily because they are losing carbon to the atmosphere.

In order to understand these observations that they make at the organismal scale, students will need to connect their observations with processes occurring inside cells at the atomic-molecular scale—photosynthesis and cellular respiration. In order to appreciate their significance, students will need to extend the patterns they see here to carbon-cycling in ecosystems and on a global scale.

Ultimately, students will need to connect key biogeochemical processes in socio-ecological systems at multiple scales, including cellular and organismal metabolism, ecosystem energetics and carbon cycling, carbon sequestration, and combustion of fossil fuels. These processes: (a) create organic carbon (photosynthesis), (b) transform organic carbon (biosynthesis, digestion, food webs, carbon sequestration), and (c) oxidize organic carbon (cellular respiration, combustion). The primary cause of global climate change is the current worldwide imbalance among these processes.

Unit goals

This unit is designed to help students make the connections described above by engaging them in two kinds of practices:

1. Inquiry or investigating practices, in which students learn to:
 - a. Make careful measurements of plants' dry weight or biomass and gas exchange (absorbing and releasing carbon dioxide) in light and dark conditions, and
 - b. construct arguments from evidence about how plants grow and exchange gases with their environment, and how growth and gas exchange are related.
2. Accounts or explaining and predicting practices. This unit addresses five different aspects of explaining and predicting plants' growth and gas exchange. Two are core goals of this unit. They are:
 - a. Identifying reactants and products of the key carbon-transforming processes in plants: photosynthesis, biosynthesis, and cellular respiration.

- b. Tracing mass by connecting changes in plant biomass with gas exchange.

Three other explaining and predicting practices are less central. They are:

- c. Explaining photosynthesis, biosynthesis, and cellular respiration using atomic-molecular theory
- d. Explaining energy transformations in photosynthesis, biosynthesis, and cellular respiration
- e. Locating photosynthesis, biosynthesis, and cellular respiration in the general carbon cycle

One important conclusion from our research, and our experiences in classrooms, is as follows: When students enter school, they use narratives (or stories) to explain how the world works. This is the students' natural discourse. The information they learn in science class teaches them more detailed narratives and new vocabulary, and they try to fit the new information into their existing narratives. Thus, students tell the same stories with more details, instead of learning new, more principled accounts about their world. The figures below illustrate a pattern we see in many students.

For example, Figure 1 contrasts most high school students' understanding of the carbon cycle (Level 2 reasoning) with the understanding prescribed in the *National Science Education Standards* and reflecting environmental science literacy (Level 4 reasoning). Rather than a single cycle, in which carbon moves from atmospheric carbon dioxide to organic carbon and back again, Level 2 students see two cycles: (1) a *nutrient cycle* in which plants get nutrition from the soil and serve as the foundation for food chains and food webs that ultimately return nutrients to the soil, and (2) the *oxygen-carbon dioxide cycle*, in which animals breathe in oxygen and breathe out carbon dioxide while plants do the opposite. Energy, in this view, cycles along with the nutrients. Thus, Level 2 reasoning conserves neither carbon nor energy, although this is difficult for many students to realize as they focus on mastering the details of terminology. Reasoning which is built more on sound principles and models would recognize the need for clarification from this description.

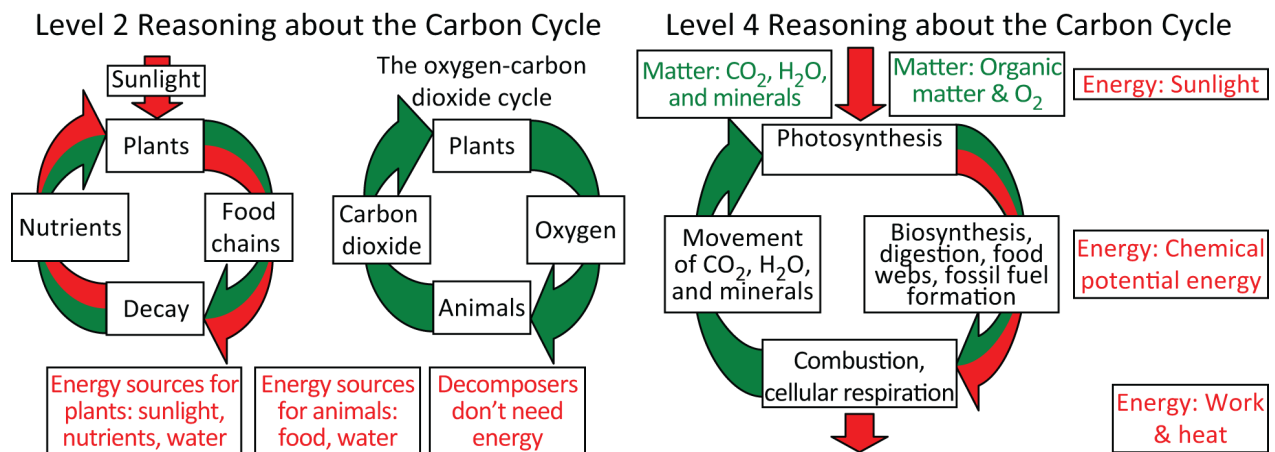


Figure 1: Comparing typical student understanding and scientific understanding of the carbon cycle

It might seem that the Level 2 students' understanding of carbon cycling has a few misconceptions that can be "fixed" easily. Our experience, though, has shown that this is not the case. The student and scientific understanding contrasted above aren't just different in the labels for the boxes and arrows; they depict fundamentally different ways of making sense of the world. Figure 2, below, shows another way of representing students' understanding that may be more accurate.

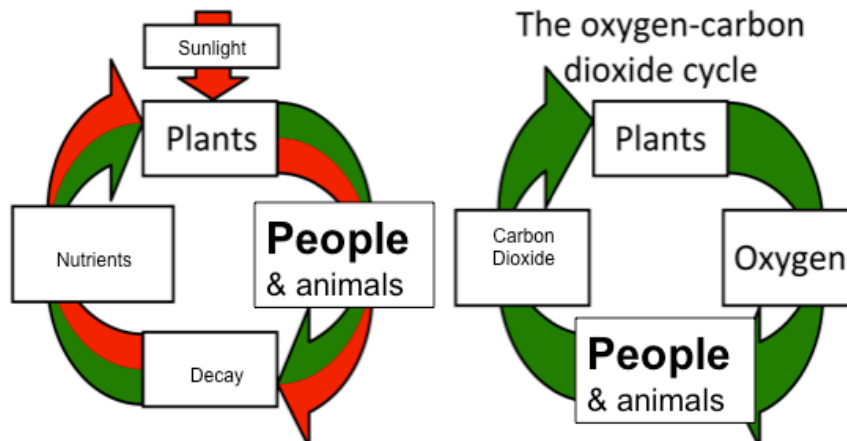


Figure 2: A better representation of most students' understanding

Figure 2 shows that it might be better to think of students as speaking a different “language” (what educational researchers call a *discourse*) from students. Here are some key points about carbon cycling as students understand it.

- As shown in Figure 1, scientists see carbon cycling as being about the movement of *matter* and *energy* through *systems*. Although most students use these words (more about this below), their thinking focuses much more on *actors* and their actions.
- People are the main actors, then animals, then plants
- Everything else is there to meet the needs of actors

So the size of the text in Figure 2 shows what students are likely to have thought about more and less. They are familiar with all the words, but they haven't thought very much about the nature of the ones in fine print—sunlight, carbon dioxide, decay, nutrients—or their role in energy flow and matter cycling.

And that's connected with another problem: the *meanings* that students have for the words they use. We have found that many middle and high school students use words such as matter, energy, oxygen, and carbon dioxide with confidence, but with different meanings from scientists who use the same words. Table 1, below, shows some of what we have found out about the contrasting meanings.

Table 1: Comparing Level 1 and Level 4 Meanings for Key Vocabulary Words

Level 4 general categories	Matter			Energy: Heat, chemical, etc.	Conditions: Temperature, care, etc.	
	Organic matter (including organic gases)	↔	Inorganic matter (including inorganic gases)			
Linking states	Solids and liquids		Gases	Not matter		
Linking material kinds	Plants, animals	Dead plants and animals	Water, soil	Air	Light, heat	Temperature, care
Level 1 general categories	Living things	→	Dead and inanimate things	Insubstantial kinds: gases, conditions, energy		

Here are some key things to notice about Table 1:

- The familiar words that everyone uses are in the two gray rows in the middle. We call them *linking words* because they are familiar to students of all ages. Because these words are familiar, we can use them in our teaching, but a key goal of our teaching must be to help students learn new scientific meanings for these words. There are two kinds of these familiar words:

- *Linking states* include the familiar states of matter—solids, liquids, and gases—which scientists (but not always students) distinguish from other things that are not matter at all, such as forms of energy (heat, light, motion, chemical energy) and conditions (temperature, music, care).
- *Linking material kinds* include the different kinds of “stuff” that we and all the world around us is made of—what scientists would call different substances.
- The top row shows how scientists (and, we hope students in your classes by the end of this unit) classify the “stuff” in the linking states and material kinds:
 - The different cells show some key categories that students need to master in order to understand plant growth and function: matter (divided into organic matter which is high in chemical energy and inorganic matter which is not), energy, and conditions.
 - The blue arrows show what kinds of changes take place in carbon cycling. Inorganic matter CAN change into organic matter and vice versa, but matter CANNOT change into energy or the other way around.¹ And there is a clear distinction between forms of energy such as heat and light and conditions such as temperature.
- The bottom row shows how students reasoning at Level 1 (typical of many elementary school students) make sense of the linking states and material kinds.
 - The different cells show distinctions that are clear in Level 1 students’ reasoning: living organisms are clearly very different from the dead “stuff” that the rest of the world is made of; they have “energy.” Then there is a large and fuzzy category of insubstantial “stuff” that they don’t think of as having weight or being matter, including air, forms of energy, and conditions.
 - The blue arrows show the transformations that they commonly think about: Living things can become dead, but Level 1 students don’t usually think of dead matter becoming living things. They think of eating and growing as actions rather than as ways of transforming matter—they do not believe that “you are what you eat.” Food, air, sunlight, the right temperature, etc., are all needed for living things to survive and grow, but they are not the “stuff” that living things are made of.

We have found that most middle and high school students have sort of a muddled mixture of Level 1 and Level 4 meanings for the key vocabulary words. They know that gases are forms of matter but commonly don’t consider gases in accounting for mass changes. They think that matter can become energy and vice versa. So our goal in this unit is to help them learn to use these words with their clear scientific meanings when they are “talking science.”

The fundamental differences in the knowledge that students bring to the classroom and the knowledge we expect them to achieve present numerous challenges to educators. One solution to meeting these challenges is to refocus our curriculum and teaching in ways that enable students to use scientific principles and scientific models to explain and predict processes. This is what we try to do in this unit.

Our key goals are expressed as changes in students’ practices in Table 2, below.

¹ Many high school students have heard of the theory of relativity and $E = mc^2$. This is a great example of a little knowledge being a dangerous thing. These students often use matter-energy conversions as a “fudge factor” to explain processes when they are unable to account for separate changes in matter and energy. We feel that it is important for students to learn how to account for matter and energy separately in chemical and physical changes—including those involved in plant growth and functioning—before they study the relativistic equivalence of mass and energy.

Table 2: Unit Goals as Changes in Student Inquiry Practices and Accounts

Practice	Typical Entering Student Practices	Goal Practices
<i>Inquiry or Investigating Practices (finding patterns in data and constructing arguments from evidence)</i>		
Measuring mass (see discussion of Tracing Mass below)	Unfamiliar with balances, including ideas about tare weight and what differences are significant Unfamiliar with idea of biomass as dry weight	Able to measure dry mass accurately and explain rationale for techniques
Measuring gas concentrations	View O ₂ and CO ₂ as something more like indicators of air quality than as gases mixed with other gases in the air Do not clearly distinguish concentration from amount Not familiar with probes	Able to use probes to measure CO ₂ concentrations and interpret measurements appropriately
Constructing arguments from evidence	More familiar with confirmation labs or investigations as “horse races” to decide which product or method works best	Able to engage in type 1a investigations, constructing an argument from evidence in support of a theoretical model.
<i>Accounting Practices (explanations and predictions): Core goals</i>		
Identifying material reactants and products	Describe plants as actors capable of two types of actions: <ul style="list-style-type: none"> • growth as an action if the needs of plants are met: sunlight, soil (nutrients), water, air • plants breathe in carbon dioxide (bad air) and breathe out oxygen (good air) Not aware of differences between plant functioning in the light and dark	Plant growth as a two-step process: <ul style="list-style-type: none"> • Photosynthesis in leaves converts CO₂ and H₂O to glucose and O₂ • Biosynthesis converts glucose and soil minerals into other organic materials Plant functioning as using energy from cellular respiration that converts glucose and O ₂ to CO ₂ and H ₂ O
Tracing mass (see discussion of Tracing Mass below)	Tend to view growth as an action rather than as a process of transferring mass from outside the plant to inside the plant Growth depends on “eating” nutrients from the soil Not committed to mass as a fundamental measure of the amount of matter Gases may have weight, but are not “massive” enough to account for changes in plant mass Do not distinguish biomass from water	Qualitatively trace mass from CO ₂ and H ₂ O to biomass and back again Recognize soil minerals and water as essential to plant growth but making up a small portion of biomass
<i>Accounting Practices (explanations and predictions): Secondary goals</i>		
Tracing atoms	Able to state facts about atoms and molecules, perhaps including balancing chemical equations, but do not use atomic-molecular models to explain macroscopic processes	Recognize that physical and chemical changes to not create or destroy atoms Able to trace C, O, and H atoms through photosynthesis, biosynthesis, and respiration Recognize that soil minerals provide other essential atoms for organic compounds (e.g., P, S, N)
Tracing energy	View energy as a “motive force” that makes thing happen, so all of the essential needs (sunlight, air, water, soil nutrients) provide plants with energy for growth Do not distinguish between chemical potential energy and materials that contain chemical potential energy (e.g., sugar, ATP) Matter and energy are not clearly distinguished	Clear distinction between forms of matter (solids, liquids, and gases made of atoms and molecules) and forms of energy Trace energy separately from matter Identify chemical potential energy as contained in organic molecules Recognize differences between high-energy bonds (C-C and C-H) and low energy bonds (C-O and H-O)
Locating the process in the carbon cycle	See separate nutrient and oxygen-carbon dioxide cycles (see figure in Appendix A)	Locate photosynthesis, biosynthesis, and cellular respiration within a unified carbon cycle

Tools for Reasoning

This unit is designed to introduce students to *TOOLS FOR REASONING* that embody three key principles that are essential for reasoning about environmental processes: SCALE, MATTER, and ENERGY.

- **SCALE:** All environmental processes occur in a hierarchy of systems at different scales; we focus in particular on *atomic-molecular*, *microscopic*, *macroscopic*, and *landscape* scales. Many students struggle to connect events that they see at the macroscopic scale to explanations at the atomic-molecular scale and to matter cycling processes at landscape and global scales. In this unit we introduce students to reasoning about scale with the *Powers of 10 Tool*.
- **MATTER:** Although many high school students can recite the Law of Conservation of Matter², few can apply it in practice. At the macroscopic scale, students struggle to account for mass because they do not consider the mass of gases. At the atomic-molecular scale, even students who can balance chemical equations do not realize that atoms are never created or destroyed in physical and chemical changes. In this module we introduce students to reasoning about matter with *molecular models* and with the *Matter and Energy Process Tool*.
- **ENERGY:** High school students who can recite the Law of Conservation of Energy are rarely able to trace energy through carbon-transforming processes and consistently distinguish energy from matter. In this module students use the *Matter and Energy Process Tool* to trace the conservation and degradation of energy in environmental processes.

Unit summary

The unit is designed to support students in achieving the goals for inquiry and accounting practices above. Some of the activities—Activities 1, 5, 6, 7, and 9—focus on inquiry, helping students to master the skills of measuring mass changes and gas exchange in plants and constructing an argument from evidence about how plants use water and carbon dioxide to grow. A sequence of key *questions in italics* below shows the key steps in constructing the argument from evidence.

Other activities—Activities 2, 3, 4, 8, 10, and 11—focus on students' accounts, teaching them to use the Tools for Reasoning to account for plant structure and function using the key scientific principles of matter, energy, and scale. In addition to the Tools for Reasoning, these lessons include videos, PowerPoint slides, activities, and embedded assessments that engage students in scientific explanations of plant structure and function.

All of the activities in the unit are designed to help students make the transitions from typical entering student practices to goal practices described in Table 2 above. The unit includes the following activities.

² In this unit and in all our materials we treat matter and energy as separate entities that are separately conserved. Our research on student reasoning convinces us that this understanding is a necessary developmental predecessor to more sophisticated understandings based on Relativity and Quantum Mechanics.

Activity 1: Starting plants growing, making initial measurements and posing initial questions

Since it will take a while for plants to grow, the first step in the unit is to make initial measurements of the mass of soil (Vermiculite), seeds, and cups, to start radishes and bean plants growing, and to establish questions about plant growth that students will answer later in the unit. In addition to planting their seeds and making initial measurements, students will discuss a key question that they will investigate during this unit: *How do you think that plants use the things they need in order to grow?*

Activities 2, 3, and 4: Introducing Powers of 10 and atomic-molecular models of matter

These activities introduce students to the idea that systems can be understood at multiple scales. An important goal for this unit is to help students gain understanding of 4 benchmark scales (atomic-molecular, microscopic, macroscopic, and large-scale) that can help students compare the size of systems. Also, students use Powers of Ten as a tool for locating and comparing systems at different scale.

- During Activity 2 students define the terms “system” and “scale” and view Ray and Charles Eames’ DVD on Powers of Ten. Students think about what appears and disappears as you zoom in and out of Powers of Ten. They also classify these systems in terms of the benchmark scales.
- Activity 3 uses a Powers of Ten poster and PowerPoint to look closer at a more limited range of scales from 10^8 (Earth) to 10^{-9} (Molecules). The teacher can use this powerpoint to review the different Powers of Ten and to think about how the four benchmark scales map onto the Powers of Ten. At this time students have an opportunity to try to locate systems on the Powers of Ten and discuss how their predicted locations match the actual location of those systems.
- Activity 4 introduces students to atomic-molecular models of the key substances or material kinds that they will be studying in the unit:
 - The molecules in air, including carbon dioxide, oxygen, and water vapor
 - Key organic molecules that make up the biomass of plants
 - The materials that plants can absorb from the soil: water and minerals such as nitrates and phosphates

Students’ initial ideas about things that plants need in order to grow probably were not stated in terms of chemical substances. After Activity 4, students will know something about the chemical substances that make up water, air, and soil, so they will conclude Activity 4 with a quiz that asks them to summarize what they have learned about the molecules of air, plants, and soil, and to consider another key question—a more specific form of the question posed in Activity 1: *Where do the molecules in plants come from?*

Activities 5 and 6: Tracing mass and CO₂ in simpler systems

Tracing changes in plant biomass and gas exchange in plants is a complex process, involving equipment, techniques, and reasoning that will be unfamiliar to most students. Activities 5 and 6 enable students to practice on simpler systems before they apply them to plants.

- Activity 5 engages students in measuring masses of materials in wet and dry conditions—wet and dry sponge, wet and dry soil, and students before and after drinking water. It introduces the *Matter and Energy Process Tool* as an aid to explaining mass changes and tracing mass through changes of state. They will see that when water is added or evaporates, the underlying solid mass of the object does not change. This leads to a key methodological question that will be important for Activity 9: *You learned in Activity 4 that plants are made mostly of water and large organic molecules (what*

scientists call biomass). *How could you find the mass of JUST the organic molecules in a plant?*

- Activity 6 engages students in both measuring changes in CO₂ concentration and changes in mass for three processes: baking powder in water, candle burning, and person breathing. They will see that, like water, CO₂ leaving a system is associated with a change in mass. For baking powder and the candle, though, the changes in mass are changes in solid mass, not just changes in liquid mass. They will use the *Matter and Energy Process Tool* to trace mass through these changes, and they will end with questions: *Do people lose mass when they breathe out CO₂?*

Activities 7 and 8: Measuring and explaining plant gas exchange

The students are now ready to make and interpret measurements of how plants change the air around them. Activities 7 and 8 focus on gas exchange.

- In Activity 7 students measure changes in CO₂ concentration for the bean plants that they have been growing in the light and in the dark, observing that the plants absorb CO₂ in the light and emit CO₂ in the dark. At the end of the activity students will consider three questions about the implications of these results:
 - Based on your other experiments with CO₂, what do you think might be happening to the biomass of plants in the dark?
 - What might be happening to the biomass of plants in the light?
 - How could this be happening? What are your ideas about what the plants are doing in the light and in the dark?
- In Activity 8 students are introduced to photosynthesis and cellular respiration as explanations of the gas exchange patterns, and they will make predictions for their next activity: *How do you think that photosynthesis affects the biomass of plants? How could we test your ideas with the plants that you have been growing?*

Activities 9 and 10: Measuring and explaining changes in biomass when plants grow

The next activities focus on making and interpreting measurements of changes in plant biomass.

- In Activity 9, students harvest their radish plants and measure changes in dry mass of soil and plant biomass, establishing that the plants gained more mass than the soil lost and that the mass they gained was not just water.
- In Activity 10, students learn about a historical experiment that used a similar technique, von Helmont's experiment, and they use ideas about photosynthesis, biosynthesis, and cellular respiration to explain their results.

By the conclusion of Activity 10, students should be able to answer the question posed at the beginning of the unit—*How do you think that plants use the things they need in order to grow?*—with confidence and in chemically specific terms, explaining how plants grow through the processes of photosynthesis and biosynthesis and maintain their body functions through cellular respiration.

Activity 11: Bringing it all together

The final activity of the unit,—What's the "Matter" with Carbon?—brings all the previous activities and arguments from evidence together and locates plants in the ecological carbon cycle.

Table 3: Summary table of unit activities

Activity	Purpose	Time	Comments
1. How do plants grow?	To elicit students' initial conceptions of plant growth by providing opportunities for students to observe seed germination and plant growth, to learn about the requirements for plant growth.	1.5 hours (over the course of 1-2 weeks)	This activity finishes by harvesting the seeds, which is described in activity 9
2. Powers of 10	To introduce students to the idea that systems can be understood at multiple scales using the Powers of 10 process tool.	40-50 minutes	
3. Powers of 10 as a tool	To look closer at a more limited range of scales from 10^8 (Earth) to 10^{-9} (Molecules). To review the different Powers of Ten and to think about how the four benchmark scales map onto the Powers of Ten.	50 minutes	
4. The molecules of air, plants and soil	To introduce students to atomic-molecular models of key molecules, stressing the chemical differences between energy-rich and energy-poor molecules.	65 minutes	
5. Investigating weight gain and weight loss	To illustrate that weight gain is associated with a net/lasting incorporation of dry mass.	70 minutes (split over 2 days)	Best if run over 2 days to allow materials to dry back out
6. Does CO₂ have mass?	A variety of simple demos to illustrate the significant fact that gases, esp. CO ₂ , have mass	60 minutes	Classroom demos
7. Plant gas exchange	To demonstrate gas exchange in plants that are 1) photosynthesizing (in sunlight) and 2) respiring (in darkness)	50 minutes	Classroom demos
8. Photosynthesis and Respiration	To build fuller accounts of these two processes using the process tools	55 minutes	
9. Harvesting plants and measuring changes in soil and biomass	Harvest plants and compare wet weight to dry weight.	35-40 minutes	Completes plant growth measurements begun in activity 1
10. von Helmont and explaining changes in mass	To complete the discussion integrating photosynthesis w/ cell maintenance (biosynthesis) and respiration	45 minutes	
11. What's the "matter" with Carbon?	Ties all of the processes discussed in the unit back to global-scale carbon cycles and broader implications	40-55 minutes	Possible matter & energy process tool extension (15 mins.)

Materials List

Student Activity Pages

Activity 1: How do Plants Grow?

Activity 2: Zooming In and Out

Activity 4: Molecules Quiz

Activity 5: Investigating Weight Gain and Weight Loss

Activity 6: Does CO₂ Have Mass?

Activity 7: Gas Exchange in Plants

Activity 8: Photosynthesis and Respiration

Activity 9: Harvesting Plants

Activity 10: Gaining, Transforming and Losing Plant Mass

Activity 11: What's the "Matter" with Carbon?

Student Readings

Activity 4: The Molecules of Air, Plants, and Soil

Activity 8: Photosynthesis and Cell Respiration

Activity 10: von Helmont's Willow Tree

PowerPoints

Activity 2: Zooming In and Out

Activity 3: Powers of 10 - General

Activity 4: Powers of 10 - Air

Powers of 10 - Plants

Activity 5: Weight Gain and Loss

Activity 8: Plants and Photosynthesis

Plants and Respiration

Activities 10 and 11: General and Mass-tracing Process Tools

Activity 1: How Do Plants Grow?

General Overview

Activity 1: Introduction to Plant Growth and setting up plant growth experiment ~ 40 minutes

During the following 14-18 days: Observations of plant growth ~ 30 minutes

*Continue working with activities 2 to 8 of the unit

Activity 9 (after 14-18 days): Summarizing results and discussion at time of harvesting plants
~ 30+ minutes

Purpose/Learning Outcomes

This lesson is designed to elicit students' initial conceptions of plant growth through discussion and planning for the upcoming experiment. This experiment provides opportunities for students to observe seed germination and plant growth under several conditions. The lesson provides an investigative and experimental starting point for discussions on plant physiology, photosynthesis, the importance of carbon, and the global carbon cycle, which will all be further fleshed out in subsequent activities.

Materials

General

- Soil or soil amendment. For this experience, it is preferable working with inert amendments such as perlite or vermiculite (or a mixture of both).³ If not supplied by your university partners, these amendments are currently available in garden centers or stores.
- Large, shallow trays (such as baking sheets) for students to place cups on to facilitate moistening plants from below
- Dehydrator or drying oven. Teacher may need to use oven at home.
- Copies of *How do Plants Grow?* Student Worksheets (1 per student)

Per student group (~4 students/ group):

- 1 Seed packet. Seed numbers can vary slightly across groups. The number of seeds to be used depends on their size, assuming that for bigger seeds, you can use fewer.
- 3 Growing Containers (tin utility cups)
- one 300g (x0.01) digital balance
- 1-2 Weigh Boats
- 50 mL graduated cylinder for pouring water
- Masking tape
- Marker
- Paper towels

Since vermiculite does not have any mineral nutrients for the plants to aid plant growth you may want to add a small amount of crystallized, soluble fertilizer to each cup, such as Miracle-Gro. This will allow the plants to sustain healthier growth for a longer time if you would like to keep them alive for longer than 2 weeks or so.

³ Regular potting soil contains organic carbon that provides food for decomposing bacteria. These bacteria will produce carbon dioxide that affects the results of Activity 7, and the decomposition of the organic material may affect the mass of the soil, measured in Activity 9.

Advance Preparation

- Prepare seed packets containing 40 radish seeds and four bean seeds (in “Seed Bank” Envelopes) for small groups of 3-4 students.
- Use a pen or tape and markers to label all growing cups with a number. Alternatively, students can carry out the plant growing activity without weighing their own plants. The teacher can prepare a set of pre-weighed and filled cups for a few plants that the teacher will monitor and use for demonstration on mass changes. Students can still record weight changes of teacher’s demo plants in table provided (see Activity 7, Harvesting Plants).

Procedures/Suggestions

Introduction to Plant Growth and setting up plant growth experiment ~ 30 minutes

1. Divide the students into groups of 4 for the experiments (use labeled desks to help facilitate this process). Then, start the activity by asking the students about the things that plants need for growing and the materials that contribute to plants’ weight increase. Explain that plants are, similarly to all living things, made of carbon based materials.
 - a. Continue the discussion by asking about where and how plants get energy (from photosynthesis), as opposed to where seeds get energy (from stored chemical energy in starches). Be sure to discuss how seeds usually have enough initial energy resources to be able to start growing even in unfavorable conditions.
2. Introduce the overall experiment to students, noting that the experiment will take several weeks, and then have them make predictions and answer the questions on page 1 of the handout in their groups.
3. Have the students carefully read through the procedures before passing out the materials.
4. Have students complete the procedures for planting their seeds.
5. Make sure cups are placed in a well-lighted place (by sunlight or full-spectrum fluorescent lighting). When placing bean seeds cups be sure they are in a place where the temperature is adequate for germination (e.g. over 55°F).

Observations of plant growth ~ 30 minutes (over 14-15 days)

NOTE: While the seeds germinate and grow, continue working on the activities 2 to 8 of the unit. In 14-18 days, plants may be ready for harvest. You may allow more time for observing growth, depending on your unit plans.

1. In the next 14-18 days, select 2 times for students to register their observations (in Table 1). Also, remind students to check their seeds every day and to make sure the pots are still damp but not overly saturated. Placing all of the tin cups on a large rimmed baking sheet will allow the water to be drawn into the cups from below through the wicking material, which can minimize disturbance of the (very light-weight) vermiculite.
2. After 14-18 days the class will make their final observations and take their final weights (procedures described in Activity 9).

In addition to students growing plants in their cups, you may also wish to set up several plants in a simple hydroponic arrangement as a classroom demo. One simple way to do this is to staple a quart size plastic baggie partially shut about 3cm from the bottom of the bag. Then spread seed of either beans or radishes onto the line of staples – after sprouting the seeds will send roots down into the water, but will remain easily separable from the water at the conclusion of the experiment. This can underline for students that soil is not the primary source of dry biomass for plants, although we would not recommend using only this growth medium since it can easily be discounted as an unusual case by students. Once set up, these hydroponic baggies can be placed in a dark cupboard, on the sunlight windowsill, or anywhere else the students might like to try as they examine best growing conditions.

Name: _____ Period: _____ Date: _____

Activity 1: How Do Plants Grow?

Large plants can grow from small seeds into large trees. What do you think a plant needs to grow?

They need water, sunlight, soil minerals/nutrients, air (carbon dioxide).

What evidence can you use from your own previous experiences that plants need these things?

Plants die if they don't get enough water or are kept in the dark too long. Don't usually see plants growing without their roots in the soil. Most students have no direct evidence of trees taking up carbon dioxide, but have often heard it throughout earlier grades.

How do you think that plants use the things they need in order to grow?

I think the water helps their cells stay hydrated, like ours. They can use the sun's energy in order to make food that has energy available within it. The chemical bonds with the sugar and other food molecules "store" energy for later use by the plant. Soil minerals help, in smaller quantities, with other essential life processes of the plants.

Today you will set up an experiment to test some of your ideas about what plants need to grow. Your group will grow plants from seeds and measure their growth. You will set up the experiment today and monitor the growth of your seeds over the next two to three weeks.

**** KEEP THIS HANDOUT TO RECORD YOUR DATA! ****

We will be setting up two types of plants to grow.

One: We will grow radishes in soil

Two: We will grow beans in soil

Methods

Radishes

1. Make a 1-cm long cut in the bottom of your dish, then feed a small piece of the wicking cloth through the cut, with about half the length in and half out of the dish.
2. Label your dish with your group name and/or class period.
3. Weigh your empty cup and record its mass below.
4. Fill the cup $\frac{3}{4}$ full with vermiculite (if not already done by your teacher).
5. Use the table below to record the following measurements for the radish seeds:

Radish seeds: Cup number _____			
Mass of empty cup:	Mass of cup filled with vermiculite:	Mass of just the vermiculite:	Number of radish seeds:
Mass of radish seeds:	Mass of cup with vermiculite and seeds:		
Your prediction: What will happen to the mass when the plants grow? <i>It will increase.</i>		Reason for your prediction: <i>We expect students to connect growth with mass gain, but not necessarily with adding on materials from outside the plant.</i>	

Plant your seeds in the soil – do not put all the seeds in the same spot.

6. Water the growing containers carefully.
7. Place your growing containers in the light near a window if possible.

Beans

8. Follow the same steps for bean seeds as for radish seeds. Use the table below to record data about your bean seeds

Bean seeds: Cup number _____			
Mass of empty cup:	Mass of cup filled with vermiculite:	Mass of just the vermiculite:	Number of bean seeds:
Mass of bean seeds:	Mass of cup with vermiculite and seeds:		
Your prediction: What will happen to the mass when the plants grow? <i>same as for radishes</i>		Reason for your prediction:	

9. Water the seeds as you did for the radish and place the cup in the growing area.

You will need to monitor your plants to track their progress and add water as necessary. You should check your plants every day and fill out the data table on the following page about every 2 days. You should note the general health and growth patterns of the plants: Have all survived? Are all producing healthy green leaves? and so forth. Make sure that you write complete and accurate descriptions of your plants.

Date							
Radish: number of shoots							
Radish Observations							
Bean: number of shoots							
Bean Observations							

Additional Observations:

Activity 2: Powers of 10

General Overview

Introduction: What does “system” and “scale” mean to you?	~ 10 minutes
Whole class: Powers of 10 video	~ 20 minutes
Individual/small groups: Zooming in and out: What can you see?	~ 10 minutes
(If Time): Whole group: Zooming In and Out with a 2 nd look at video	~ 10 minutes

Estimated Time: 50 minutes

Purpose

This lesson introduces students to the idea of using multiple scales to describe and connect systems. Students at the high school level are likely aware of different scales, but usually have trouble connecting visible systems and processes at the macroscopic scale to less visible processes at atomic-molecular, microscopic and large scales. This disconnect can be especially problematic when students have to think about gases as either products or reactants. Since they aren't visible to our senses in the same way as most solids or liquids, it can be hard for students to remember to include them in their accounting. This activity begins to teach students about benchmark scales and the idea of Powers of Ten.

- The lesson begins by eliciting students' understanding of scales.
- The students then watch the Powers of 10 DVD (17 minutes), a video that shows the relative size of systems, from galaxies to subatomic particles. The video is approximately 17 minutes, but if time is an issue, the introductory material at the beginning of the video can be skipped (view video ahead of time to determine whether or not to use the full 17 minutes). The online versions cited below have already done this, and are ~10 minutes long. The video should be used as a starting point for 1) revising students' ideas about scale, 2) showing how systems can be viewed from multiple scales, and 3) providing students with a Powers of 10 framework for comparing different systems.
- After the video, the students have the opportunity to revise and modify their understanding of scale and systems. At this point, the main objective for secondary school students is to start establishing or confirming 4 “benchmarks” for thinking about scale: atomic-molecular, microscopic, macroscopic, and large scale. Students will build on these benchmarks in Activity 3.

Materials

- Powers of 10 DVD or online versions of the same (check the school library for this resource)
- Student copies of *Zooming In and Out*
- Transparency or PowerPoint slide of *Zooming In and Out*
- Overhead projector & vis a vis markers

The original Powers of Ten video is available online at <http://www.youtube.com/watch?v=0fKBhvDjuy0> (as well as other places that you can find by Googling Powers of 10).

There are also some interactive sites that allow students to navigate among images at different scales:

- Scale of universe: http://primaxstudio.com/stuff/scale_of_universe.swf
- Cell size and scale: <http://learn.genetics.utah.edu/content/begin/cells/scale/>
- Java tutorial: <http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/>

Advance Preparation

- Watch Powers of 10 DVD (17 minutes) and determine how much of the video to use
- Get equipment to play DVD, or prepare to show it from an online source
- Make copies of *Zooming In and Out* worksheets (1 per student)
- Make transparency of *Zooming In and Out* or prepare to project from PowerPoint slide

Procedures

Introductory discussion: Systems and Scale

~10 minutes

1. Before watching the video, it is important that students have some understanding of 'system' and 'scale'. Spend the first 10 minutes developing a reasonable definition for these terms with your students. Some possible discussion questions might include:
 - a. In science we look at many different "systems". What does this term mean to you? What do systems have in common that make them "systems"?
 - b. What does the word "scale" mean to you? (try to cue students to move beyond measuring scales, such as weight scales).
 - c. Possible definitions to use (you can use these before the video or wait until the discussion after the video, but at some point the class needs to have common working definitions for the terms 'systems' and 'scale' to use throughout the unit)
 - i. System: Set of connected and mutually interacting components (as in an *ecosystem*)
 - ii. Scale: the size or range of measurement used for describing a particular system. You can use scale and measurement to compare the relative sizes of systems.

Powers of 10 video

~20 minutes

2. Explain to students that they will watch a short film looking at how the same location can be part of many different systems at different scales. Students might want to take mental notes of what they see in the video, because images will change quicker than most will be able to write notes down. The DVD can be paused to allow students to further discuss particular images, but this can also wait until Step 4 below.

Zooming In & Out: What Can You See?

~10 minutes

3. Pass out the *Zooming In and Out* student worksheet. Read the instructions with students and tell students that the list of things at the beginning of the worksheet are different systems or components of systems that were included in the video. Tell them that one way of thinking about scale is to group things in terms of 4 broad categories. These include atomic-molecular (things that are too small for even a powerful microscope to see⁴), microscopic/cellular (we cannot see but can use a microscope to see), macroscopic (things we can see with our eyes), and landscape scale (things that are too large to see with our eyes, but that we can use representations and models [i.e.-diagrams, maps, etc] to see)⁵. Encourage the students to dissect the words, for example, discussing what "scopic", "micro", and "macro" means and develop a set of working definitions for each of these benchmark

⁴ Atomic force microscopes can create images of individual atoms or molecules, but the light microscopes that students are familiar with cannot.

⁵ The Powers of 10 video shows both smaller scales (sub-atomic) and very large scales (global, solar system, galaxy, universe). While it is good for students to be aware of these systems at smaller and larger scales, we will not use them in our materials on carbon-transforming processes.

scales. Tell students to look through the list on their handout and think about the video. Then have the students classify each system or component into 1 of the 4 broad benchmark categories.

Reflective Discussion: Systems and Scale

~20 minutes

4. The reflective discussion can take a variety of forms depending on the available class time. NOTE: You will only need page 1 of the student handout unless you plan to watch the Powers of Ten video again. If time is short, focus the discussion on how students categorized the various systems on page 1 of *Zooming In and Out* and any discrepancies or disagreements they may have. Try to come to consensus about how to categorize the list of systems in terms of the benchmarks, and continue to review the benchmarks with students. If there is enough time remaining during the class period, consider watching the Powers of 10 video again, and review the zooming in and out table as a class, by pausing at each Power of 10. What appears and what disappears? Let students use Page 2 of handout if necessary. As you pause the DVD, ask students which of the 4 broad categories each system belongs to: atomic-molecular, microscopic, macroscopic or large scale. Again, focus the discussion on discrepancies and try to reconcile them by asking questions such as “Can we see it with our eyes? Can we see it with a microscope?”

NOTE: In Activity 3 you will continue to build on the 4 key benchmarks for scale (atomic-molecular, microscopic, macroscopic, and landscape scale) using Powers of Ten to locate things on the scale. Mostly, this activity includes modeling of Powers of Ten by the teacher, and manipulation of a few key objects on a chart.

Name: _____ Period: _____ Date: _____

Zooming In and Out

When thinking about different scales, we can generally group systems and parts of systems into one of four groups: 1) atomic-molecular (things we cannot see even with a microscope), 2) microscopic/cellular (we cannot see with our eyes, but can use a microscope to see), 3) macroscopic (things we can see with our eyes), and 4) large scale (things that are too large to see with our eyes as a whole).

The following is a list of systems included in the Powers of Ten video. Try to sort these systems into one of the four categories described above.

Universe	Man or Woman	Cell Nucleus	United States
Hand	Earth	Lake Michigan	DNA molecule
Skin	Carbon Atom	Picnic Blanket	Galaxy
Capillaries	Skin Cell	Quarks	Chicago
City Park	White Blood Cell	Solar System	

1. What systems would you see at the atomic/molecular level?

DNA molecule, Carbon atom, quarks

2. What systems would you see at the microscopic or cellular level?

Skin cells, cell nucleus, white blood cells, capillaries

3. What systems would you see at the macroscopic level?

Body of a Person, skin, hand, picnic blanket

4. What systems would you see at the large-scale level?

City park, Lake Michigan, Chicago, United States, Earth, Solar System, Galaxy, Universe

5. Are there any systems that you are unsure about?

You may watch the Powers of Ten video again. However, this time your teacher will pause the video at each scale, and you will need to think about what appears and disappears when you zoom in or out. You will need to complete the table below, and as you watch the video again, think about the size of different systems and if they match the groups you made on the first page.

What You See When You Zoom In	Starting Point: What You See	What You See When You Zoom Out
Picnic Blanket	City Park	Chicago
City Park	Chicago	Lake Michigan
Lake Michigan	United States	Earth
Earth	Solar System	Galaxy
Solar System	Galaxy	Universe
Skin	Hand	Body of a Man or Woman
Skin cells	Skin	Hand
White Blood Cell	Capillaries	Skin
Carbon Atom	DNA molecule	Cell Nucleus
Quarks	Carbon Atom	DNA

After watching the video again, is there anything you would change from your groups on the first page?

Activity 3: Powers of 10 as a Tool

General Overview:

Introduction to Powers of 10 Powerpoint	~ 20 minutes
Introducing Powers of 10 Chart	~ 15 minutes
Practice Placing Items & Benchmark Scales	~ 15 minutes

Estimated Time: 50 minutes

Purpose

By watching the Powers of 10 video your students have learned somewhat how to talk about the relative sizes of systems, from galaxies to subatomic particles. They have also learned definitions for the words “systems” and “scale” and learned about 4 benchmark scales: atomic-molecular, microscopic, macroscopic, and large scale. In this second lesson, the Powers of 10 chart will be used as a framework for comparing systems at different scales, for example, comparing the size of molecules to cells and cells to leaves, etc. One of the most useful aspects of this approach is that students can ask themselves about the appropriate scale to use when discussing a process that they might study at some later time in your class, so encourage that kind of applied thinking whenever you can.

In this activity, you will first use a set of slides to bridge what students saw in the Powers of 10 video to using Powers of 10 as a comparative tool. The Powers of 10 slideshow zooms in and out from Earth to molecules. Then students practice mapping benchmark scales to the Powers of 10 chart, and they will also begin mapping systems to charts. The goal of this lesson is to give students more practice with understanding scale and to help students see how Powers of 10 and the benchmark scales are both useful ways of comparing systems.

Materials

Powers of 10 – General slideshow

Computer and projector OR overhead set and overhead projector

Class Powers of 10 poster

Magnets to hold up the poster on white board or chalk board

Illustrations to go on Class poster or projected slide

- Prepared and blank magnetic cards
- Prepared and blank illustrations on paper or card stock

Overhead projector & vis a vis marker

Advance Preparation (If not completed by your university partner)

- View *Powers of 10 - General* slideshow and practice projecting this PowerPoint in classroom OR make overhead copies of each slide to use on overhead/opaque projector.
- Gather overheads for *Comparing Powers of 10 (blank, partial)*

Procedures

Introduce Powers of 10 using PowerPoint slides

~20 minutes

A PowerPoint slideshow has been developed as a way of bridging the Powers of 10 DVD viewed during Activity 2 with the Powers of 10 charts that are used in this activity and throughout other classroom activities. The slideshow allows the teacher and students to zoom in and out at various steps similar to the DVD. This format allows the teacher to go step by step through various systems and scales and talk about the size of the system (and start making comparisons to other systems).

There are two ways to use the PowerPoint slides: Either on a computer projected to the class or by printing off overheads of the PowerPoint slides and showing them on an overhead projector.

NOTE: The PowerPoint corresponds with many images of the Powers of Ten video but some images have also been replaced.

First have students review what they learned about systems and scale from Activity 2. Also ask students to share what they learned about the 4 benchmark scales.

Then use the PowerPoint slides to teach about systems and scale. For each slide first ask students what the system is (i.e., a solar system, planet, flower, virus, etc). Ask students what benchmark scale the system belongs to (i.e., atomic-molecular, microscopic, macroscopic, or large-scale). As you get to the most familiar systems (Earth, cities, flowers, cells, virus, DNA), start modeling how to use the Powers of Ten to compare systems. These comparisons may be difficult for students, particularly those who struggle with math. As you model comparisons, pick examples from the familiar objects. For example, you might say, "A virus is 1 micrometer, but bacteria are 10 micrometers. That means bacteria are roughly 10 times larger than viruses".

While an important goal for high school students is to strengthen their ability to use the 4 key benchmark scales, the Powers of Ten can also be a useful tool for quantitative comparisons. Consider building on the most familiar scale comparisons (i.e., systems at a meter are 100 times larger than systems at a centimeter, systems at a centimeter are 10 times larger than something at a millimeter, etc), and gradually extend that to systems that are more orders of magnitude apart.

Introducing Powers of 10 Chart

~15 minutes

Introduce the "horizontal" Powers of 10 charts to students using the blank Powers of 10 overhead transparency or your classroom poster. Explain that this new chart is a second way of representing the Powers of Ten chart and make comparisons to PowerPoint slides (i.e.- each vertical line represents a 10-fold change, equivalent to adjacent slides from the slideshow). At this time consider mapping the PowerPoint systems on the chart to bridge what students learned in the PowerPoint slides to what they will be doing next with the powers of ten charts. Use a wet erase pen to write these items on your blank powers of 10 overhead, or a blank magnetic square or post-it note to place them on the classroom poster.

As you map items from the PowerPoint to the chart, explain the axis on the chart and how to use Powers of 10. Although students may be familiar with powers of 10, they may not realize how to use it to compare the size of objects. One idea to emphasize here is that when you are comparing across such a wide range of scales, you don't need to know exact sizes of objects- that the powers of ten are very helpful in making estimates about sizes and differences in scale.

Whole class: Comparing Powers of 10 to 4 Broad Categories of scale ~15 minutes

At this point students need to discuss the 4 benchmarks indicated on the poster, and whether they think the categories are well-assigned. Using the partial Powers of 10 overhead, have the students decide which powers of ten fall into each scale benchmark. The following are suggestions for how to divide the chart into benchmarks:

- Atomic-molecular (10^{-9})
- Microscopic (10^{-8} through 10^{-6})
- Macroscopic (10^{-5} through 10^2)
- Large Scale (10^3 through 10^5)

Also point out the familiar measurements to students again: millimeter, centimeter, meter, and kilometer.

Pass out the magnetized squares with objects on them to your students, and give them an opportunity to place their object on the chart where they think it best fits. After everyone has placed their object, guide a class discussion as to whether the illustrations are placed appropriately or not.

Approximate Key: 10^{-10}	Carbon atom
10^{-9}	Methane, Carbon Dioxide, Water, Glucose
10^{-8}	DNA
10^{-7}	Organelles
10^{-6}	Sperm
10^{-5}	Animal Cells, Plant Cells
10^{-4}	Egg
10^{-2}	Insect
10^{-1}	Plant
10^0	Dog, Person
10^1	Kelp
10^3	Kelp Forest, Rain Forest
10^5	Ocean, Atmosphere

Please keep in mind that for many objects, their size is likely to fall within a range of sizes depending on species, age, etc. Once you have completed the discussion, you may want to find a space on your classroom wall to tap up the completed poster for all students to refer to it throughout the year. Alternatively, you could print out 8.5 x 11" versions of the chart and objects, and allow students or groups to keep track of one for their reference.

Activity 4: The Molecules of Air, Plants, and Soil

General Overview

Reading *The Molecules of Air, Plants, and Soil* ~40 minutes

Embedded Assessment Quiz ~15 minutes

Discussion of the last question on the Embedded Assessment quiz ~10 minutes

Estimated Time: 65 minutes

Purpose

This lesson expands on the Powers of 10 lessons with a discussion of air, plants, and soil at the atomic-molecular scale. Students will learn that each of these materials is a complex mixture of different kinds of molecules, but there are important differences between air and soil on the one hand and plants on the other:

- Air and the materials in soil that plants can absorb through their roots (water and minerals) are made of small, low-energy, inorganic molecules.
- Plants are made of water and large, high energy, organic molecules.

This leaves students with a question to be answered in the rest of the unit: *Where do those large, organic, high energy molecules in plants come from?*

Materials

- PowerPoint slides: *Powers of 10 - Air*
- PowerPoint slides: *Powers of 10 - Plant*
- Student copies of the reading: *The Molecules of Air, Plants, and Soil*
- Student copies of *Molecules Quiz*

Advance Preparation

Make copies of student readings and quiz if not provided by your university partner

Procedures

1. Read *The Molecules of Air, Plants, and Soil* with your students. Make sure to discuss the key differences between the molecules of plants and the molecules of air and soil (see the statement of purpose above).
 - a. Use the Powers of 10 slides for air as students read the section on air molecules. Have students locate the slides on the classroom Powers of 10 poster.
 - b. Similarly, use the Powers of 10 slides for plants as students read the section on plant molecules, and have the students locate plant cells and molecules on the Powers of 10 poster. (Note that actual cellulose molecules are made of hundreds or thousands of glucose monomers.)
2. Have students take the embedded assessment *Molecules Quiz*.
3. Discuss the last question of the quiz with your students: *Where do those large, organic, high energy molecules in plants come from?* Emphasize that they will be learning about the answers to this question as they continue the unit.

Answer Key for Molecules Quiz

1. Fill in the table below about the kinds of atoms and molecules in air, plants, and soil.

Material	What kinds of atoms are in this material?	What kinds of molecules or ions are in this material?	Do these molecules have stored chemical energy (in C-C or C-H bonds)?
Air	Mostly C, H, O, and N	N₂, O₂, H₂O, and CO₂	No
Plants	Mostly C, H, O, and N (and P, etc.)	H₂O, large organic molecules, including cellulose, starches, proteins, and fats	Yes
Soil (include only water and minerals that plants can absorb through their roots)	Mostly, H, O, N, and P	H₂O, with dissolved minerals like nitrate (NO₃⁻) or phosphate (PO₄³⁻).	No

2. What are your thoughts about the question at the end of the reading: *Where do the molecules in plants come from?*

More than whether their answers are correct or not, check to see whether students recognize the key problem—do they see that in order for plants to grow, they must take in the atoms that they are made of from somewhere?

Activity 5: Investigating Weight Gain and Weight Loss

Overview

Day 1

Introduction ~ 10 minutes

Does water make a sponge or vermiculite “grow?” (Initial measurements) ~25 minutes

Day 2

Does water make sponges and vermiculite “grow?” (Completion) ~15 minutes

Does water make people and plants grow? ~20 minutes

Estimated Time: 70 minutes split over two class periods (Day 1: 35 mins, Day 2: 35 mins)

Purpose

This lesson is designed to further elicit students’ conceptions of growth, and in particular to discuss the difference between permanent structural growth (i.e. lasting incorporation of mass) and transient changes in mass due to water weight. Although water intake can lead to an increase in size, in most materials it does not effect a permanent structural expansion, as can be seen by simply drying it out. This is also true in organisms, but because of the difficulties (logistical and ethical!) involved in drying organisms, and students’ knowledge of the importance of water for growth, it can be difficult for them to apply this idea in biological systems. Yet without being able to disentangle the effect of water, the experiments related to tracking mass gain from CO₂ will be overshadowed and potentially unconvincing to students.

This lesson also has two other major functions: giving the students further experience using the digital scales for careful measurements, and introducing them to a version of the Process Tool, which in this lesson is designed to facilitate tracking of energy.

Materials

Slideshow to facilitate discussion: *Carbon Activity 5*

Copies of *Investigating Weight Gain and Weight Loss* handout

Per student group (This lab can also be done as a demonstration, if you prefer):

- tin or plastic cup
- small square of sponge (could be cut from a kitchen sponge)
- 1 tin or plastic cup half full with vermiculite
- Small plastic or Styrofoam bowls
- Drinkable Water
- 300g digital pocket scales
- Beaker or graduated cylinder

Per class: 400-lb capacity scale for measuring people

Advance Preparation/ Safety Considerations:

- Make copies of *Investigating Weight Gain and Weight Loss* handout
- Insure that classroom projection system is ready to display slideshow
- Clear a small piece of sunny and/or dry counter space for the sponges and vermiculite to dry out

Procedures/Suggestions:

Day 1

Introduction

~10 minutes

1. Briefly explain that this activity will focus on differences between substances that increase objects in size, without changing structure, and those that also enlarge an object's structure. Then divide the students into groups of 3-4 for the experiments.
2. Pass out the handout to students and have them work in their groups to respond to the first three questions. Then lead a whole class discussion based on the groups' responses, making sure that the following key idea comes up:
 - * There are different meanings that the word "growth" can have, and it is important to work with a common scientific definition for the rest of the unit. Namely, that growth involves permanent increases in the structural size of organisms, and not shorter-term fluctuations in mass due to water content.
3. Using the slideshow, introduce students to the conservation of mass and the simple process tool designed to help them account for that fact in this activity (slides 2 & 3). One subtlety about the tool: it has no obvious way to display situations where mass resides in a mixture of solids & liquids, liquids and gases, etc. We suggest having students draw a box around the two components that they believe will form a mixture (such as the sponge and water, for instance), and estimate or report a single mass value for the mixture.

Does water make a sponge or vermiculite "grow?"

~25 minutes

4. Instruct students to complete the sponge and vermiculite activities in their groups, as described on their worksheets. After the groups have had time to look at the instructions and take initial measurements of the dry materials, bring the class back together to walk through slides 4 & 5, where they will make predictions as to the changes they expect to see once the materials are wetted. The slides have sample values, but students should use their own measured values to make predictions.
5. Then let the groups complete the process of wetting the materials and take measurements on the revised masses of each. Close the day by using slides 6-8 to guide a discussion on their results so far.

Day 2

You can either wait for the sponges and vermiculite to dry out at room temperature for 5-7 days, or if you prefer, you can dry out the cups overnight at low temperature (~150-200°) in an oven. This will allow you to complete the activity on the following day.

Sponges and Vermiculite Revisited

~15 minutes

1. As a class, use slides 9 & 10 to make predictions about the dried masses of their sponges and vermiculite that groups expect to find. Again, students' predictions should be based on their measured values rather than the sample values on the slides.
2. Allow groups time to complete the measurements of the dried sponges and vermiculite and to discuss the associated questions on the worksheets. Use slides 11-13 for a concluding discussion.

Does water make plants and people grow?

~10 minutes

1. Students will now try to apply the evidence they have gathered to a more complex situation: living organisms. In this case, a person and their radish or bean plants. Using slides 14 & 15, have students make predictions for the mass changes they would expect to see.
2. Working as a whole-class demonstration, use one volunteer to be a "sample organism." Since this student will be stepping on a scale in front of their peers, please be sensitive to weight and body image issues. After that follow the instructions on the worksheets to test out mass changes in one or more groups' radish/bean plants. Give students time to complete the rest of their worksheets and allow time for any questions that might come up. Use slides 16 & 17 to discuss their predictions. NOTE that students may need help converting grams to kilograms.
3. Using slide 18 as a prompt, have a concluding discussion on all of the demonstrations and observations the students have made, specifically addressing the ideas of permanent structural change and growth. Students should conclude that drinking or adding water produced a change in mass, but not in size.

The final question on Slide 18 is important: *How could we tell whether plants are gaining dry weight (not just water) when they grow?* Their answers to this question will help you see how well prepared they are to understand the logic behind the harvesting and drying procedures in Activity 9.

Name: _____ Period: _____ Date: _____

Activity 5: Investigating Weight Gain and Weight Loss

First Questions about Gaining and Losing Weight

We all know that people can eat food and gain weight, and that plants can grow and gain weight. But what does it REALLY mean to gain weight? Try filling out the table below.

When you add water to a sponge, does it gain weight?	Yes No	Explain your answer <i>May answer 'yes' and focus on additional mass due to water or 'no' because water isn't permanent</i>
When you drink a cup of water, do you gain weight?	Yes No	Explain your answer <i>Same as above, although more students likely to say 'no' because of familiarity with the subject – themselves!</i>
When a plant grows in the sunlight, does it gain weight?	Yes No	Explain your answer <i>'Yes' if focused on mass acquired during photosynthesis, although 'no' if focusing on lack of mass for sunlight</i>
What measurements do you need to make to determine if a plant has gained weight? <i>Measure it's mass before and after a period of growth</i>		

Does water make a sponge gain weight?

Materials:

- 1 plastic cup
- 1 dry sponge
- Tap or distilled water
- 1 small digital balance (300-g capacity)

What to do:

This will be a two-day experiment:

- On the first day, you will predict and measure the mass of the sponge before and after you add water. This means you will:
 - Weigh the dry sponge
 - Weigh a cup, then add some water and weigh the cup filled with water.
 - Figure out the weight of just the water. How can you do that?
 - Predict the weight of moist sponge after it soaks up the water.
 - Weigh the moist sponge to see how well you predicted.
 - Your teacher will dry the sponge out overnight
 - On the second day, you will predict and measure the mass of the dried sponge.
- You can use the table below to record your predictions and measurements.

Day 1: Weighing Wet and Dry Sponge			
Mass of dry sponge:	Mass of empty water cup:	Mass of cup with water added:	Mass of just the water:
Your prediction: What will the mass be when the water is added to the sponge? Equal to sponge + water	Reason for your prediction: All the matter is still in the combined system at this point	Actual measurement: What mass did you measure?	
Day 2: Weighing Sponge that Has Been Dried Overnight			
Your prediction: What will the mass be when the sponge is dried overnight? If totally dried, then back to original sponge mass	Reason for your prediction: Water mass will have been lost as vapor through evaporation.	Actual measurement: What mass did you measure?	

When we added water, did the sponge gain weight? Explain your reasoning?

The sponge-and-water system did, although the sponge itself did not change in a permanent way and gained no permanent mass.

Use the mass tracing process tools to trace the masses for the wet and dry sponge.

Wetting sponge: Fill in the masses that you measured. Is mass conserved?

Drying sponge: Fill in the masses that you measured. What happened to the mass of the water?
Measurements should show that mass is conserved, IF unmeasured water vapor is included.

Does water make vermiculite gain weight?

Materials:

1 tin or plastic cup

Enough vermiculite to fill cup halfway

Tap or distilled water

1 small digital balance (300-g capacity)

100-mL beaker or graduated cylinder

What to do:

This will be a two-day experiment:

- On the first day, you will predict and measure the mass of vermiculite before and after you add water. This means you will:
 - Put some vermiculite in a small cup and weigh it.
 - Weigh another cup, then add some water and weigh the cup filled with water.
 - Figure out the weight of just the water. How can you do that?
 - Predict the weight of the cup of vermiculite after the water is added.
 - Weigh the cup to see how well you predicted.
- Your teacher will dry the vermiculite out overnight
- On the second day, you will predict and measure the mass of the dried vermiculite.

You can use the table below record your predictions and measurements.

<i>Day 1: Weighing Wet and Dry Vermiculite</i>			
Mass of cup filled with vermiculite:	Mass of empty water cup:	Mass of cup with water added:	Mass of just the water:
Your prediction: What will the mass be when the water is added to the cup of vermiculite? <i>as above for sponge</i>	Reason for your prediction:		Actual measurement: What mass did you measure?
<i>Day 2: Weighing Vermiculite that Has Been Dried Overnight</i>			
Your prediction: What will the mass be when the cup of vermiculite is dried overnight?	Reason for your prediction:		Actual measurement: What mass did you measure?

When you added water, did the vermiculite did gain weight? Explain your reasoning?

same as above for sponge


Use the mass tracing process tools to trace the masses for the wet and dry vermiculite.

Gas → g

Liquid → g

Solid → g

Matter Inputs



Process:

g → Gas

g → Liquid

g → Solid

Matter Outputs


Wetting vermiculite: Fill in the masses that you measured. Is mass conserved?

Gas → g

Liquid → g

Solid → g

Matter Inputs



Process:

g → Gas

g → Liquid

g → Solid

Matter Outputs

Drying vermiculite: Fill in the masses that you measured. What happened to the mass of the water?
Measurements should show that mass is conserved, IF unmeasured water vapor is included.

Does water make people grow?

Materials

- Bathroom scale
- Scale for weighing large glass or bottle of water
- Glass or bottle
- Water

What to do:

Now try an experiment with a member of your class who volunteers:

- Weigh your classmate on the bathroom scale.
- Weigh the bottle or glass, then add some water and weigh the bottle filled with water.
- Figure out the weight of just the water. How can you do that?
- Predict the weight of your classmate after s/he drinks the water.
- Weigh your classmate to see how well you predicted.

You can use the table below to record your predictions and measurements.

Mass of your classmate:	Mass of empty water bottle:	Mass of bottle with water added:	Mass of just the water:
Your prediction: What will your classmate's	Reason for your prediction: all the matter is still	Actual measurement: What mass did you	

mass be after s/he drinks the water? equal to weight + water weight	here, just contained in my classmate	measure?
--	--------------------------------------	----------

1. What do you think might happen to the mass of your classmate overnight? Why?

If they don't take any other mass in (food, etc), it should go down as the water is breathed out as vapor.

2. Do you think your classmate REALLY gained weight after drinking the water? Explain your reasoning.

Again, not permanently; the water can easily be lost through respiration.

Do Plants Gain Mass When You Water Them?

Materials

1 small digital balance (300-g capacity)

Plant that you are growing

Small plastic cup

Water

What to do:

- Weigh your plant in its cup on the digital balance.
- Weigh the cup, then add some water and weigh the cup with water.
- Figure out the weight of just the water. How can you do that?
- Predict the weight of your plant after you have watered it.
- Weigh your plant to see how well you predicted.

You can use the table below to record your predictions and measurements

Mass of your plant in its cup:	Mass of empty water cup:	Mass of cup with water added:	Mass of just the water:
Your prediction: What will your plant weigh after it is watered? same as above systems	Reason for your prediction:		Actual measurement: What mass did you measure?

1. What do you think might happen to the mass of your plant in its cup overnight? Why?

It would decline, although probably not all the way down to original mass, since plant loses water in a controlled manner through transpiration.

2. Do you think your plant REALLY gained weight when you watered it? Explain your reasoning. Again, only temporarily. Not necessarily a structural change.


Use the mass tracing process tools to trace the masses for the student and your plant.

Gas → g

Liquid → g

Student → g

Matter Inputs



Process:

g → Gas

g → Liquid

g → Student

Matter Outputs

Student drinking water: Fill in the masses that you measured. Did the student gain weight when s/he drank the water?


The student's overall mass changed, but not the student's (non-water) biomass. NOTE that students will have to convert g to kg to make appropriate predictions.

Gas → g

Liquid → g

Plant in cup → g

Matter Inputs



Process:

g → Gas

g → Liquid

g → Plant in cup

Matter Outputs

Watering Plants: Fill in the masses that you measured. Did the plant gain weight when you watered it?

The plant's overall mass changed, but not the plant's (non-water) biomass..

One final question: You can see that the measured weight of something—soil, plants, or animals—can vary a lot depending on how much water is in the system, even though the water does not affect the underlying dry weight of the thing. How could we tell whether plants are gaining dry biomass? We would have to compare dry masses before and after a period of growth to see if it has actually added on dry mass.

Activity 6: Does CO₂ Have Mass?

General Overview

Introduction: Does gas have mass?	~10 minutes
Overview of probe set-up	~5 minutes
Measuring CO ₂ before and after exhaling into chamber	~10 minutes
Measuring CO ₂ in chamber during combustion	~10 minutes
Measuring CO ₂ in chamber with cup of water & baking powder	~10 minutes
Discussion: Concentration, %, ppm	~15 minutes

Estimated Time: 60 minutes

Purpose

This lesson is designed towards two main ends: 1) demonstrating for students the apparatus for measuring carbon dioxide concentrations that they will be using over the next few lessons, thus helping them to build confidence in the readings they will gather, and 2) confirming for them the fact that gases (and CO₂ specifically) have mass. It is crucial that students have a firm understanding of these two ideas so that they will be able to eventually construct explanations for plant growth that are scientifically sound. In addition, this activity will introduce students to the concept of concentration and simple units of measurement for gas concentrations (% O₂, ppm CO₂).

Materials:

Copies of *Does CO₂ Have Mass?* student handout

Per student group

- Approx. 50 ml of carbonated soda beverage (per group)
- Small cups (one per group; approx. 50 ml capacity)
- 300-g digital pocket scales

Per class

- Vernier CO₂ probe
- #10 size glass aquarium w/ Lexan or plexiglass lid
- Rubber stopper (size #6)
- 200-g classroom scale, set with 'Auto Shut-off' deactivated (see instructions)
- Plastic straws (2-3 per class period)
- 3-4 small (tealight) candles
- plastic (sealable) 20oz soda bottle filled 1/3 full with tap water
- 5g baking powder

Advance Preparation/ Safety Considerations:

1. Make copies of *Does CO₂ Have Mass?* student handout.
2. Make sure you are familiar with how to use the Vernier CO₂ probe and GoLink interface (see manuals or go to to <http://www.vernier.com>). The real-time data output can be projected to a screen from a laptop computer. The best way to do these activities will probably be as demonstrations in front of the class. Set-up and test probe, interface, computer and projection system before class. Make sure CO₂ probe is set to read high levels of CO₂ (switch on side of probe).

Procedures

Introduction: Does gas have mass?

~10 minutes

1. Briefly explain to the students that this activity will explore the question of whether gases such as CO_2 have mass. Students should be in groups for the first activity and then they will observe the others as a class demo.
2. Pass out the handout to the students and have them work in groups to respond to questions 1 and 2.
3. Move around to each student group, pouring ~50mL of the carbonated beverage into their cups.
4. Let students observe the reading immediately after pouring, and have them record the mass. (Note: The weight will drop immediately, so have students be ready).
5. Have students fill in the data table provided, noting the mass of the system three other times over the class period, including once at the very end of the period.

Overview of probe and chamber set-up

~5 minutes

1. Place a CO_2 probe into one hole of the aquarium lid, and a rubber stopper into the other (or use a broad piece of tape). Use a small piece of tape to cover the smallest hole.
2. Allow students a chance to see the chamber and probe set-up.
3. Explain how the probe works in very general terms (see Vernier website or Activity 7 Notes). It's not necessary for the students to understand all the intricacies, but it is important that they trust the probe is in fact measuring carbon dioxide levels out of all the gases in the air.

Measuring CO_2 before and after exhaling

~10 minutes

1. Have students make their predictions regarding $[\text{CO}_2]$ on page 2 of their handout, either individually or in consultation with their groups.
2. Start measuring the background levels of CO_2 in the chamber and project data output to a screen that all students can see.
3. Levels of CO_2 should be stable. After a few minutes of data output, insert a straw into the aquarium via the small hole, and exhale one time into tube. (You may ask for a student volunteer to come forward and exhale into the straw).
4. Quickly remove straw and replace the tape securely over the hole.
5. Watch the data output respond to the influx of CO_2 into the chamber.
6. Allow CO_2 to stabilize again at new levels.
7. Have students complete the appropriate cells in the table on p. 2.

Measuring CO_2 in aquarium with candle(s) burning

~10 minutes

1. Immediately after the previous demo, remove the lid from the aquarium and allow the carbon dioxide levels to equilibrate with the rest of the room (fanning the air around can help).
2. Place the 200g scale in the aquarium, with the auto shut-off feature deactivated.

3. When ready, replace the lid and the probe. Again monitor the background level of CO₂ in chamber. It should be stable.
4. Briefly open the lid in order to place several small tea light candles on the tray of the scale (using 2-3 candles is recommended simply to show a quick signature in CO₂ concentration, but even a single candle will work). Then light the candles.
5. Begin measuring and projecting data output immediately after closing chamber.
6. Watch the data output respond to the influx of CO₂ into the chamber from the candle.
7. Read for approximately 5 minutes.
8. In this demonstration, the production of water vapor during the reaction will be quite apparent, and offers an opportunity to discuss the chemical nature of reactions like combustion. While the data is being collected, you may want to lead a discussion on what the reactants & products of combustion are, as evidenced by the vapor and CO₂ production. Then ask the students how this is or is not similar to cellular respiration. In addition, write down the mass of the candles about every minute or so for the students to see. You should see a steady decrease in their mass, which provides another opportunity to emphasize the mass of gases.

Measuring CO₂ in chamber with baking powder and water

~10 minutes

1. Immediately after the previous demo, remove the lid from the aquarium and allow the carbon dioxide levels to equilibrate with the rest of the room. Take out the used candles.
2. When ready, place the plastic soda bottle on the scale. Then quickly pour the baking powder into the bottle (perhaps using a funnel) and replace the cap. Students should be able to see the powder dissolve and the production of bubbles, but as long as the cap is tight, the mass of the bottle should remain constant. The CO₂ in the aquarium should also remain stable at the background level. (This reaction is releasing CO₂ from the carbonate in the baking powder.)
3. After the baking powder has all dissolved, quickly open the cap, placing it on the scale and then closing the lid of the aquarium to begin measuring and projecting data.
4. Watch the data output respond to the influx of CO₂ into the chamber from the candle.
5. Read for approximately 5 minutes.
6. As the data are being output to the screen, allow students to finish the data tables on their handouts.

Discussion: Using process tools to analyze changes in mass

10 minutes

Ask students to check the mass of their carbonated beverage container one last time, and complete that portion of the handout. Then close the activity by asking students to summarize the class's findings: what patterns did they see in the carbon dioxide concentration as it changed in the aquarium and how did it affect the mass of the remaining materials? Where do they think the CO₂ came from?

Complete the discussion by having the students fill out the matter and energy process tools for the candle and baking powder and discuss the final question about what happens to their mass when they breathe out carbon dioxide. These questions are leading toward the key observations about plants:

- Plants gain mass from water in the soil and lose mass through evaporation (transpiration), but this does not affect their dry weight or biomass
- Plants gain mass when they absorb CO₂ and lose mass when they release CO₂, and this DOES affect their biomass.

Name: _____ Period: _____ Date: _____

Activity 6: Does CO₂ Have Mass?

Do gases (like air, oxygen or carbon dioxide) weigh anything? In this activity, we will investigate whether the bubbles in a bottle of soda have weight (mass). We will weigh a cup filled with soda immediately after pouring. After some time has passed and bubbles have escaped out of the cup, we will weigh the cup again, still with the soda but without the bubbles.

Before weighing the soda, answer the following questions.

Do you think the air around you weighs anything?	Yes No	Explain your answer <i>Answers will vary.</i>
After we pour the soda and let gas escape will the weight of the cup + soda increase, decrease or stay the same?	Explain your answer <i>Answers will vary.</i>	

Does the gas in soda have mass?

Materials:

Approx. 50 ml of carbonated soda beverage

Small cup

200-g scale

What to do:

- Your teacher will pour about 50mL of the soda into your cup.
- Read the mass on the scale immediately after the soda is poured, and record it in the table below.
- Record the mass of the cup and soda at two other times during the class period and once at the very end.

Fill in the table below over the rest of the period:

There should be a trend in the data showing that the cup is losing mass—the mass of the gas lost.

Time	Minutes since start	Weight of soda + cup	Weight of gas lost since start
At Pouring	0		
After pouring			

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The next three experiments will be done as classroom demonstrations.

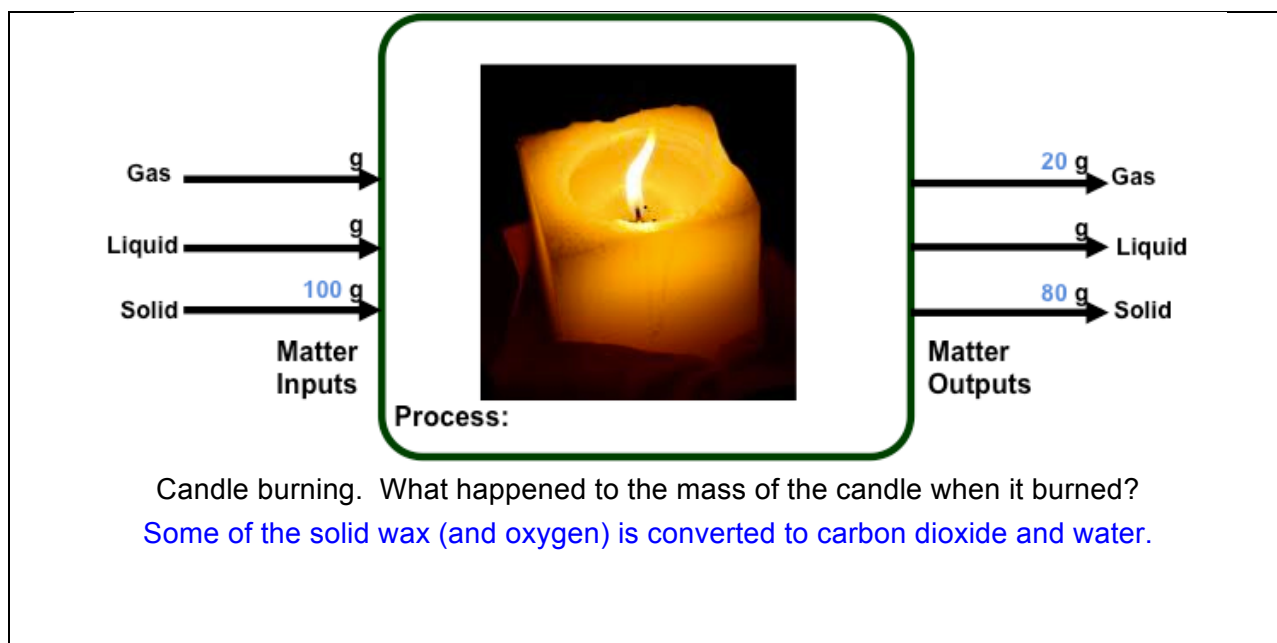
As your teacher prepares each of the three demonstrations:

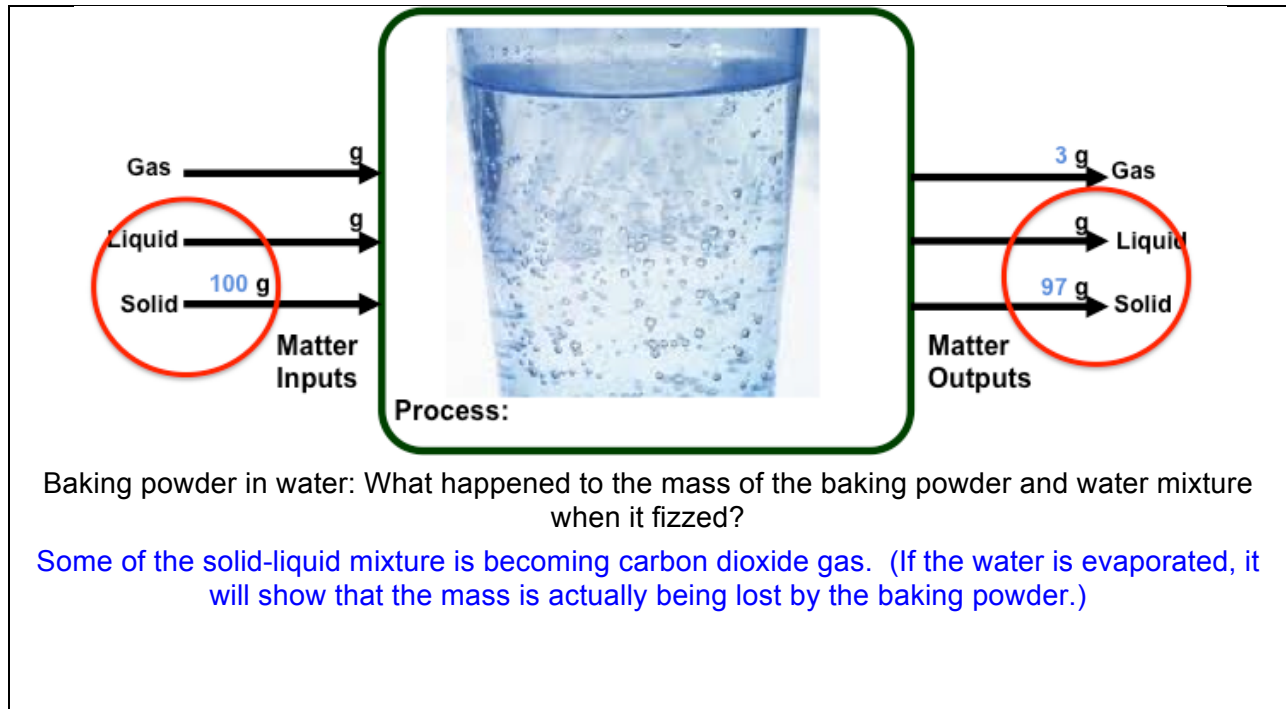
- Observe the concentration of CO₂ in the chamber and the mass before the demo. Record your observations in the table below in the appropriate column.
- Observe what happens to the levels of CO₂ and mass, and record a final concentration and mass.
- Please give a brief explanation for why you think this change occurred.

All three demonstrations should show an increase in concentrations of CO₂ and a decrease in mass for the candle and baking powder in water.

	Concentration of CO ₂ before activity	Concentration of CO ₂ after activity	Mass before the activity	Mass after the activity
Candle Burning				
Baking Powder + Water				
Exhalation				

Use the mass tracing process tools to trace the masses for the candle and baking powder in water.





One last question: What do you think happens to your mass when you breathe out carbon dioxide?

We hope that many students will suggest that people lose mass when they breathe out carbon dioxide. This is an important step toward understanding the transformations between carbon dioxide and biomass in the carbon cycle.

Activity 7: Plant Gas Exchange

General Overview

Introduction and overview of probe set-up	~5 minutes
Measuring CO ₂ for plants in the light	~15 minutes
Measuring CO ₂ for plants in the darkness	~15 minutes
Discussion: Gas exchange in plants	~15 minutes

Estimated Time: 50 minutes

Purpose

This lesson is designed to demonstrate gas exchange in plants that are 1) photosynthesizing and respiring (in light) and 2) respiring (in darkness). The goal is to inspire discussion about how carbon moves between the plant and the environment and how this movement is related to the physiological needs of the plant. Students should consider the relationship between the pattern of CO₂ moving in and out of plants with the pattern of weight loss when CO₂ leaves a system that they observed in Activity 6 (and by inference, weight gain upon uptake). In Activity 8 they will use the processes of photosynthesis and cellular respiration to explain more fully the results that they have observed.

Materials

- Vernier CO₂ probe (a Vernier O₂ probe is an option as well)
Vernier Go-Link interface cable (LabQuests or LabPros will also work if you have them)
- 10 gallon aquarium w/ Lexan or plexiglass lid
- Rubber stopper (size #6) or tape for covering any unused holes in custom lid
- Potted bean plants from activity 1, or any other small potted plant planted in inert soil mixture.
- Alternative: Very fresh leaves taken off of an outside tree or plant (if potted plant is not available).
- Copies of student handout: *Gas Exchange in Plants*
- Heavy gauge aluminum foil for wrapping aquarium to create darkened chamber
- Full spectrum light source (i.e.- shop or laboratory lamp)
- Standard laboratory thermometer (optional)

Advance Preparation/ Safety Considerations

Make sure you are familiar with how to use Vernier probes and GoLink interface (see manuals or go to <http://www.vernier.com>). The real-time data output can be projected to a screen from a laptop computer. This will probably be the best way to do these activities as demonstrations in front of a class. Set-up, calibrate and test probes, interface, computer and projection system in advance of class. You may also verify that the light source you have chosen will induce photosynthesis in the bean plants with a trial the day or evening before.

Also insure that the plants are in a lighted environment throughout the day before using them in observations. With potted plants it is best to have the plant in a well lit environment where the experiment will be performed for at least 30 minutes so that the plant does not have to adjust to new conditions when placed in the aquarium.

Procedures/Suggestions

Overview of probe and chamber set-up

~5 minutes

1. Pass out the *Gas Exchange in Plants* handout to students.
2. Place CO₂ probe into one hole of chamber, and rubber stopper into the other. (Or use O₂ probe in the other hole.)
3. Allow students to see chamber and probe set-up.
4. Explain how the probes work and what they can measure. It's not necessary to get into the mechanical intricacies of the probes, but if students ask, you can explain that it essentially works by reflecting infrared light out of the air sample and looking for the particular wavelength signature of CO₂. For the really curious...[CO2 Probe Explanation](#)
5. Explain that you will set up two treatments (light,dark). Ask them what might be different for the plants under those two conditions and what biological processes they would expect to be active in each case.
6. Have the students fill in their predictions on their worksheets.

Measuring CO₂ for plants in light

~15 minutes

1. Place at least 2-3 bean plants in chamber with probe inserted and close chamber. (Feel free to use more plants if you'd like – more plants will generate a quicker, larger response).
2. Wait at least three minutes for probe to adjust to new conditions. Monitor CO₂ level. Begin recording data when CO₂ level starts to decrease.
3. Take readings at regular intervals and have students fill in data table on handout
4. While taking readings, engage students in discussion about the results they are seeing.
 - a. What are the plants doing with CO₂ inside the chamber? **(It is taking up CO₂)**
 - b. Why, what are they using it for? **(To build sugars inside its cells, w/ light & water.)**
5. Save results in LabQuest file (see Vernier manual)

Measuring CO₂ for plants in the darkness

15 minutes

1. With the plants still in the chamber, cover chamber with heavy aluminum foil.
2. Wait at least three minutes for probe to adjust to new conditions. Monitor CO₂ level. Begin recording data when CO₂ level starts to rise.
3. Take readings and have students fill in data table on handout
4. While taking readings, engage students in discussion.
 - a. What is the plant doing with CO₂ inside the chamber now? **It is increasing the amount of CO₂ in the chamber**
 - b. Why, what process might be going on? **respiration, releasing carbon from sugars.**
5. Save results in LabQuest file (see Vernier manual)

Discussion: Gas exchange in Plants

~15 minutes

(This discussion should be tailored to the level of your students. Keep it simpler for younger students. Questions 6-10 on student handout can also be used as group discussion questions.)

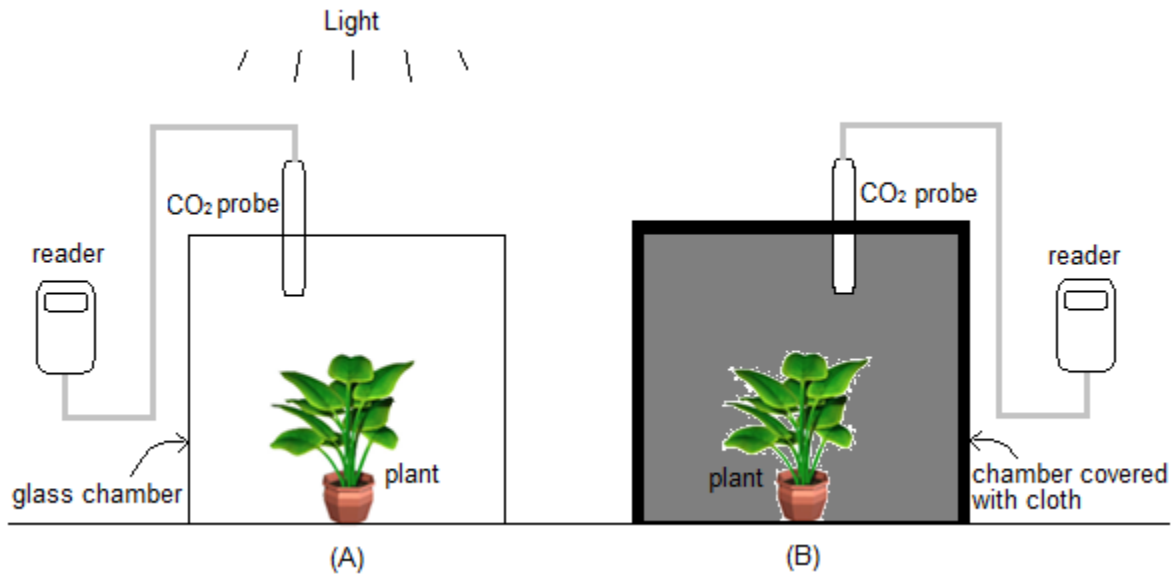
1. Project both sets of results on classroom screen (see Vernier manual).
2. Ask students to explain what they think accounts for the results. (This may be a recap of their earlier points)

3. Based on your other experiments with CO₂ (e.g. – candle, person breathing, etc) , what do you think might be happening to the biomass of plants in the dark? **The plant is losing weight as it releases carbon dioxide to the air.**
4. What might be happening to the biomass of plants in the light? **The plant is gaining weight as they incorporate carbon dioxide into its body structure**
5. How could this be happening? What are your ideas about what the plants are doing in the light and in the dark? **Students are likely to understand that the plants take up CO₂ in the light because of photosynthesis, but they will probably not know that plants are also respiring at all times, which is most easily observed in the dark. You may note that the carbon taken up by plants during photosynthesis more than compensates for the carbon released by respiring plants, but once photosynthesis is stopped, the signature of respiration quickly shows up. If students scoff at that possibility, remind them that respiration is simply part of all cells' life maintenance processes, and they are still alive while they photosynthesize!**

Name: _____ Period: _____ Date: _____

Activity 7: Gas Exchange in Plants

In this activity, we will use probes to study how plants affect levels of CO₂ in the air around them. We will test the plants under two different conditions: 1) When the plant is in the dark, and 2) when the plant is in the light.



What do you predict will happen to the amount of CO₂ in each chamber?

	In the light	In the dark
The amount of CO ₂ will...	<input type="checkbox"/> increase <input type="checkbox"/> be the same <input type="checkbox"/> decrease	<input type="checkbox"/> increase <input type="checkbox"/> be the same <input type="checkbox"/> decrease

Record Data in the table below:

	In the light		In the dark
Time (seconds)	Level of CO ₂ in the chamber	Time (seconds)	Level of CO ₂ in the chamber

Activity 8: Photosynthesis and Cellular Respiration

Overview

Introduction and Reading	~20 minutes
Slideshows and discussion of PS and CR with process tools	~ 30 minutes
Predictions for biomass measurements	~ 5 minutes

Estimated Time: 55 minutes

Purpose

Although your students have been discussing the requirements and effects of photosynthesis (PS) and respiration (CR) for the last few lessons, this is the first point at which the unit is designed to have them explicitly discuss these pivotal biological processes. More advanced students will likely bring the concepts up before this point, and feel free to work them into earlier discussions if that happens, but for many students this will be the first point at which the implications of PS and CR become apparent. For instance, most secondary students will associate PS with the process of plants growing, but that does not always mean that they understand that mass is actually built into a plant's structure when glucose is made, or that this will be accompanied by a drop in CO₂ levels in the air immediately around the plant. In other words, they have often not thought fully through conservation of matter and energy within these processes. This lesson uses matter and energy process tools to guide student predictions of the next step in the unit, which deals with the connection between PS and biomass.

Materials

Student copies of the reading (in their packets): *Photosynthesis and Respiration*

Student copies of the handout: *Photosynthesis and Respiration*

Slideshows: *Plants & Photosynthesis*; *Plants & Respiration*

Advance Preparation

Prepare copies of the handout and check that your projection system will be ready.

Procedures

Introduction and Reading

20 minutes

1. Remind students briefly of the work they have done in recent activities – they have identified that mass is always conserved, although water weight can sometimes obscure deeper changes in mass (Activity 5); they have verified that gases have mass, allowing for conservation of mass when solids or liquids are turned to gases or vice versa (Activity 6); and they have seen that plants can change the concentration of gases, particularly carbon dioxide, in the air around them while they grow in the light and in the dark (Activity 7). Then focusing them onto the latter point, ask if they can think of any biological processes that could change CO₂ concentrations in the way that they observed.

2. Now give them time to work individually through the reading: *Photosynthesis and Respiration*. This reading is largely designed to provide a background summary of these two processes. Be flexible with the amount of time you allow your students to spend here. With older students that have more familiarity with these ideas, they may be better served by moving more quickly to the slideshows and discussion around those.
3. If your students have questions about the reading, allow them to bring them up and discuss as a whole class before moving on to the process tool activity.

Slideshows and discussion of PS and CR with process tools

30 minutes

4. Next, project the slideshow *Plants & Photosynthesis*. Your students should recognize the first 8 pictures, as they are the same as those in the *Powers of 10 – Plant* show used in Activity 3 (and are seen again in the *Plants and Respiration* show). You can move quickly through them, as they are simply intended to help the students orient themselves in terms of location.
5. At slides 10 and 11 the focus moves into the chloroplasts, the specific site for photosynthesis within leaves. You'll notice that there are a good number of details you could discuss about the structure of thylakoids and so forth. Feel free to only dwell on those which would be helpful for the level of your students.
6. Next project the macroscale process tool (slide 12) and guide the students in completing it (answers on slide 13). Note that there are multiple ways in which reactants and products can be identified, and more of these will be suggested on the following slides. When the class has come to consensus, switch to the 'answer' slide and compare it to the class consensus. You may wish to point out that not all of the products remain in the plant, and you may want to discuss that further. As you progress through slides 14-17, help your students see that the matter and energy are the same in each case, but moving to smaller and smaller scales allows one to understand photosynthesis in richer ways. At the atomic-molecular scale in particular, the animation makes clear why mass and matter is conserved. For an additional animation option, consider the video found at this website (use segment between 51:07 and 53:16 on the video):
<http://www.learner.org/vod/login.html?returnurl=/workshops/energy/workshop5/&pid=1712>
7. Ask your students: Now that the plant has made glucose, what can it do with it? Many students will likely focus on using it in cell respiration or for "powering cell functions" in general. Probe the students to see if they can think of any other uses for this glucose, in particular looking for any tracing of that glucose into other molecules that make up the structure of the plant (The reading will have primed this pump for them).
8. Next walk your students through the *Plants & Respiration* slideshow. The scale orientation images have been compressed on this slideshow onto one slide to save a little time. Slide 3 introduces students to a diagram of a mitochondrion, where you could note that it is about the same size as a chloroplast and also has an interior structure with abundant surface area for facilitating chemical reactions. Work through slides 4-7 as with photosynthesis. Note that the animation on slide 7 allows students to trace atoms of glucose back out to the molecules that were used as reactants in photosynthesis, which is what students often cite when they discuss animals breathing out CO₂ for plants to breathe in and then emit O₂. In this case, importantly, both of these occur in plants. Slide 8 summarizes the formulae involved in both photosynthesis and respiration.
9. (optional) For upper-level students, it may be useful to discuss in more depth *how* exactly respiration provides energy for cellular activities. Namely, the importance of the ADP + Pi ↔ ATP reaction. Slides 9-13 explore this issue with several diagrams and formulae that you should feel free to use if you gauge your students to be ready for them.

10. Now divide the students back into their lab groups and give them time to discuss PS and CR, including time to complete the respective process tools on their handouts.
11. As group discussions wind down, bring the class back together to compare their answers. Do groups agree on the correct depictions using the tools? How should any disagreements be reconciled?

Predictions for biomass measurements

5 minutes

12. Next, focus class discussion on the idea of biomass, and how they would expect CR and especially PS to affect the biomass of plants. If students answer quickly, ask them to explain why they think their answer is correct given the process tool for photosynthesis that the class decided upon.
13. Finally, ask the students how they would design an experiment or observation to test their predictions about biomass and PS using the plants they've been growing. Make sure they keep in mind the importance of separating wet from dry biomass! This discussion could lead immediately into having the students prepare their plant samples for drying if you desire.

Name: _____ Period: _____ Date: _____

Activity 8: Photosynthesis and Respiration

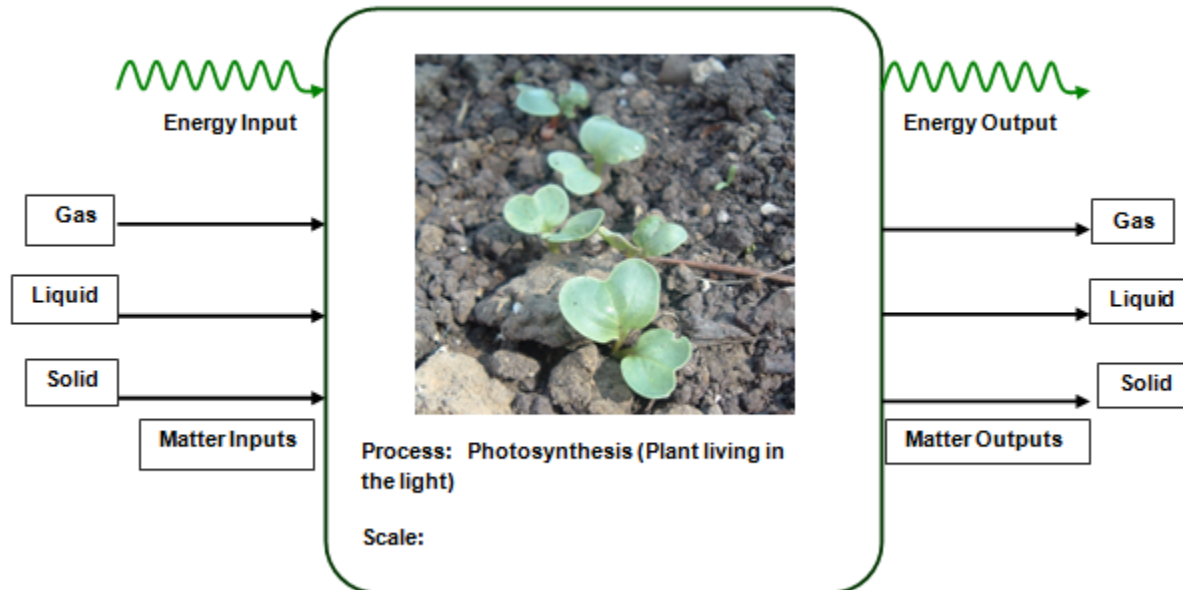
In the last activity you observed plants living in the light and the dark, and recorded the changes in concentration of carbon dioxide gas in the air around the plants over time. Just to refresh everyone's memory, what happened to carbon dioxide levels near the plant in the dark? What biological process was mainly responsible for that change?

CO₂ levels increased; respiration

How about CO₂ levels near the plant in the light? What process was responsible for the change in CO₂ concentrations in this case?

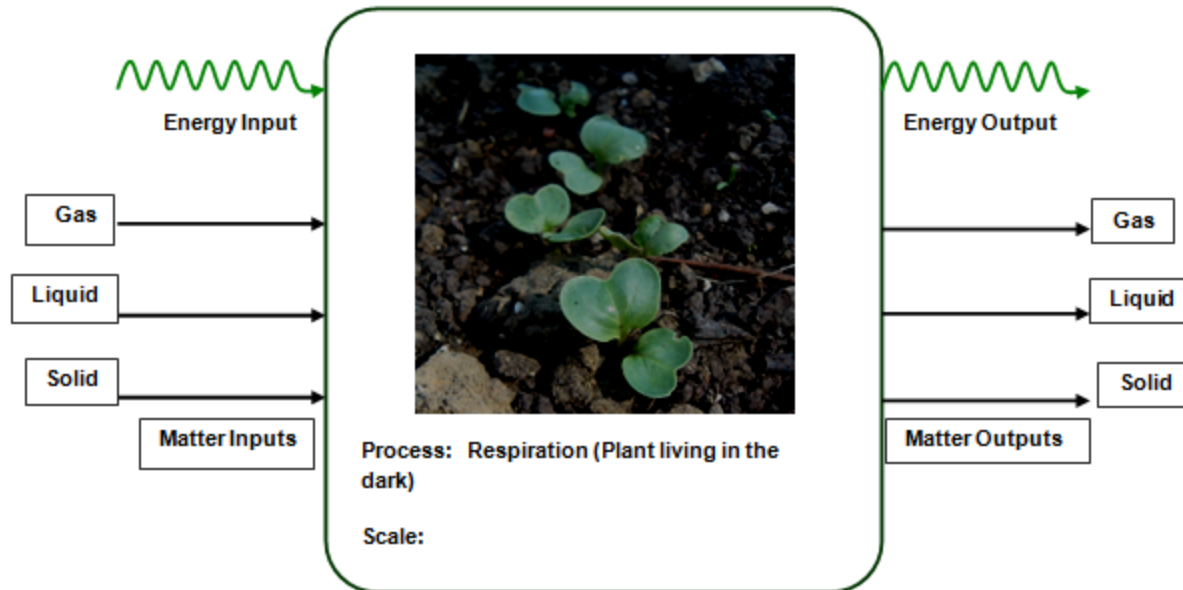
CO₂ levels decreased; photosynthesis

Now let's consider those processes a little more fully. Working with your lab group, fill in the following process tools for photosynthesis and respiration as completely as you can. They will be more complicated than any of the others that you have completed so far, so check that you include all the inputs and outputs of both matter and energy.



Energy input = solar/light energy; Energy Output = chemical energy, heat

Matter input = CO₂ (gas), water (liquid); Matter output = O₂ (gas), glucose (solid – although dissolved in solution within cells)



Energy Input = chemical energy; Energy output = motion energy (at molecular level), heat
Matter input = O₂ (gas), glucose (solid, although aqueous); matter output = CO₂ and H₂O (gas)

In the next activity you will measure the changes in biomass (the dry mass of the plants that is not water) in the radish plants that you have been growing. What do you predict that you will find?

Students should predict correctly that the dry mass of the plants will have increased.

How do you think that this is happening? How did the plants change their mass?

Some students should explain that plants are producing new biomass through photosynthesis. You can check their responses to this question to see how heavily you will need to emphasize these ideas in activities 9 and 10.

Activity 9: Harvesting Plants and Measuring Changes in Soil and Biomass

General Overview

Advance preparation (before lesson)	~ 20 minutes
Plant harvest and measurement	~ 20 minutes
General discussion	~ 20 minutes

Estimated Time: 35 - 40 minutes

Purpose

This lesson continues the experiment which began in activity 1. Since planting, students have observed and registered the growth of radish plants and considered how similar plants (beans) are growing by direct measurement of gas exchange. In this lesson, students will harvest their radish plants and discuss their results. The key conceptual point that you should make with your students is that the increased mass of plants after growing is due primarily to the contribution of atoms of carbon from carbon dioxide, incorporated into the tissue of the plants. By thoroughly drying the plants and their growing medium before taking measurements, you will be able to distinguish this growth from simple water gain (as in Activity 5). If all goes well, mass loss from the vermiculite should be minimal, and certainly not enough to match the increased dry mass of the plants. This should give students some tangible evidence to revise a common initial conception – that plants' mass comes largely from soil – which will be discussed in more detail in the next activity. Throughout this lesson keep alert for opportunities to point students back to their conclusions from earlier activities: gases do have mass and are being exchanged as plants photosynthesize.

One final note: there is no reason you could not also try this activity with the bean plants the students have grown, except that we did not see as consistently reliable results for growth with the beans in our trials over the summer. Since they store much more food in their seeds than radishes, most of their growth in the first two weeks or so is not due to photosynthetic uptake of carbon, but rather mobilization of the stored carbon. If you and your students are interested, though, feel free to go for it. It would simply require doubling the number of materials for drying and weighing.

Materials

- Oven or dehydrator for drying samples
- Large envelopes or paper lunch bags
- Digital pocket scales
- Large plastic weighing boats
- Copies of *Harvesting Plants* Student Worksheet (1 per student)
- Tweezers or forceps (optional)
- Small paint brushes (optional)

Advance Preparation (before lesson)

~ 20 minutes

1. Use the radish plants begun in Activity 1.
2. Make sure that the students don't water their plants for about 2 days before drying.
3. Gently dump each tin cup into a correspondingly labeled paper bag or envelope. Try not to be too rough with the plants, but the objective is for the contents of the cup to separate enough to increase drying efficiency. Leave the cup in the bag as well. (Note: this step can alternatively be carried out by the students on the day before you intend to complete the lesson at a minimal cost of time.)
4. Put the bagged materials in the dehydrator or oven (set to as low heat as possible) overnight.

Procedures

Plant Harvest and Measurement

~20 minutes

1. In their lab groups, have your students gently pour the contents of their dried bag into their weighing boat (after removing the cup). Make sure they have noted the weight of the boat first. If there is vermiculite stuck to the sides of the cup, they should use their fingers or a small brush to whisk that material into the weighing boat. Then have them carefully pick through the vermiculite to remove any and all parts of the dried plants, setting them into the tin cup. Tweezers/forceps may help with this step.
2. Once all of the plant material has been separated from the vermiculite, students should weigh the cup and subtract its mass (printed on side), thus giving them the final dried mass of their plants. They can do the same for the vermiculite by subtracting the mass of the weighing boat from the final mass measurement in that set.

Discussion

~20 minutes

3. Still working in their groups, students should now respond to the summary questions.
4. Finally, guide a discussion about the results of the experiment. Did all groups indeed see that their radishes gained dry mass compared to the mass of the seeds initially? And how much mass did the vermiculite lose? Another possible extension would be to have groups calculate the mass gain of their plants by percentage, and then compute an average percentage mass gain for the entire class (or even across classes).
5. It will probably be necessary and helpful to bring up the topic of experimental error at some point. What sources of error might affect their measurements? A common one is likely to be dropped/lost vermiculite or plant material at some stage of the process.
6. By the end of the discussion, it is important that your students recognize that:
 - the weight increase of plants does not come from the soil.
 - an important part of the plant mass is water and carbon-based materials.
 - the increase in carbon-based materials is a result of the process of photosynthesis

Name: _____ Period: _____ Date: _____

Activity 9: Harvesting plants

Within the last week or two, you set up an experiment to observe plant growth. Meanwhile, you have learned about the requirements plants have for growth and the role of gases, particularly carbon dioxide, in that growth. You've also discussed the differences between wet and dry weight.

Now you will harvest your radish plants and measure dry weight to see how things have changed.

1. Either follow your teacher's instructions as to how to prepare the samples for drying, or, if this step has already been completed, take out the bag with your dried samples.
2. Gently take out the tin cup from your bag, set it aside, and pour the remaining contents of your bag into the weighing boat provided (first note the mass of the empty weighing boat). Check that no soil material is stuck to the inside of your tin cup.
3. Using your fingers or tweezers, gently pick out all of the plant material (roots, shoots, potentially even seeds) from the boat and set them in the cup. Now weigh both the boat/soil system and the cup/plant system separately. Subtracting the known masses of the weighing boat and cup, you should be able to calculate the dry mass of both the soil and your radishes. Enter those numbers in Table 1.

Table 1: Dry masses of soil and plants

Total mass of container and contents	Mass of container	Dry mass of contents
Boat + Soil:	Weighing boat:	Soil:
Cup + Plants:	Tin cup:	Plants:

Summary questions

1. What are the materials that contribute to plant mass?

Water, carbon dioxide gas, soil minerals, some materials from seed

2. What is the meaning of "dry weight"? How is it related to plant growth?

Dry weight means the mass of an object after any water has been dried out of it. It is important to measure the true mass of other components of the object, in this case the matter added by growth of a plant.

3. Is a plant's source of energy related to its dry weight? Why?

Yes; since plants use stored chemical energy in the sugar they make during photosynthesis, it's also related to dry weight since more sugar being made = greater dry mass.

Students could also legitimately answer "No" if they point out that sunlight, the original source of energy, has no mass.

4. Summarize the process observed during the experiment, from seed germination to the harvest. Include the factors that affect plant growth.

The seed germinated upon contact with sufficient moisture, and then proceeded to grow towards the soil surface using stored energy. After reaching the surface, the leaves began to photosynthesize, taking in water from the soil and carbon dioxide from the air to generate sugars in the presence of sunlight.

At the end of the experiment, we stopped growth by drying out the plants (and soil) to remove water weight.

Discussion

Write the main ideas you can conclude from this activity. Remember the purpose of growing the plants was to examine the requirements of plants for growth...

Plants do gain more mass during growth than the soil alone provides, even after water has been dried out of the plants.

Thus it makes the most sense to say the majority of the dried plant biomass comes from CO₂ taken up during photosynthesis and incorporated into glucose.

Activity 10: von Helmont and Explaining Changes in Mass

General Overview

Gaining, Moving and Losing Plant Mass

~45 minutes

Total Estimated Time: 45 minutes

Purpose

This lesson is designed to help students connect the various mass-transformation processes that have come up at various points in the unit: photosynthesis, biosynthesis and cellular respiration. In doing so they will be able to much more fully explain changes in a plant's mass, as well as mass changes in the system around the plant (e.g. air, soil). The lesson begins by providing students with the story of von Helmont's plant growth experiment from the seventeenth century, and moves to a summarizing discussion.

Materials

Student Reading: *von Helmont's Willow Tree*

Student Handout: *Gaining, Transforming and Losing Plant Mass* (1 per student)

Remaining living plants from the experiment (beans, extra radishes)

Slideshow: *General & Mass Tracing Process Tools*

Advance Preparation

Gather remaining bean and radish plants.

Make copies of reading and handout for students.

Procedures

Gaining, Transforming and Losing Plant Mass

~45 minutes

1. Review results from the previous activity. Where did the students conclude the majority of a plant's dry biomass comes from? And what process is responsible for that increase?
2. Then have students read and answer questions 1 and 2 of the handout. Students may also want to look at their own plants during this lesson.
3. Read together the section of the handout labeled "An experiment from long ago". The point of this reading is to present a study analogous to theirs, done over a longer time scale and at a pivotal stage in the history of biology as a science. Hopefully your students will work through it quite easily at this point, but find some excitement in seeing their results shared by a seventeenth-century biologist.
4. Have students answer questions 3, 4 and 5, then discuss their answers as a class. Try to help students understand how their measurements on gas mass and gas exchange done earlier in the unit connect to von Helmont's evidence.
5. Give the students time to read through the text on the handout about biosynthesis (or read it together as a class), and include some time to discuss the biosynthetic pathway map, which the students will likely have questions about. If you'd like them to see it in more detail, the link is <http://www.genome.jp/kegg/pathway/map/map01010.html>. Again, reassure them that the details are not important to try and remember, but rather the big

idea that the more complex molecules are made by breaking apart and reorganizing glucose molecules. In addition, all of the reactions are reversible (although not all are energetically favorable), which explains how starches can be broken back down to glucose molecules for use in respiration, for instance.

6. Move to a discussion of cell respiration, which they are likely more familiar with. The key idea to focus on here is that plants do lose mass when they emit CO₂, as do all other living organisms. The difference for plants and other producers is that they can also gain mass whenever they photosynthesize.
7. Finally, use the slideshow *General & Mass Tracing Process Tools* to lead a summary discussion on the mass implications for photosynthesis, biosynthesis and respiration.

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Activity 10: Gaining, Transforming and Losing Plant Mass

Look at this young tree planted in a bucket of soil. As the tree grows it gains weight. Think about whether the soil is food for the plant.

1. Do you think the weight of this tree came mostly from materials the plant took from the soil?

YES NO

2. Write down in the box whether you think the weight of the soil in the pot will “increase”, “decrease”, or stay the “same” as the plant grows:

WEIGHT CHANGE OF SOIL



*****Read the first part of this lesson’s reading, *von Helmont’s Willow Tree*, before proceeding.*****

3. Write down the changes in weight of the tree and the soil.

WEIGHT CHANGE OF TREE	WEIGHT CHANGE OF SOIL
+164 lbs	- 1 lb

4. How would you explain the results that von Helmont found? Where does the majority of a plant’s mass come from if not the soil?

From either the water he added or from the air, in the form of carbon dioxide gas.

5. Why did the soil lose some mass? What components of the soil might now be somewhere else?

Some of the minerals within the soil might have been taken up by the plant for its use, such as nitrate or phosphate.

Although von Helmont was able to show that plants didn't simply take mass from the soil for all of their growth, he believed that instead the plant's material was somehow composed of water, the only thing that he had added to the bucket other than soil. Why is that idea incomplete? What process describing plant growth was unknown to him and other scientists of the time that we now take for granted? **photosynthesis!**

What is the main product of this process that contributes to plant mass? **_glucose**

As you consider any plant, though, it is obvious that although it has both water and this product, it is more complex than either of those things. Can you think of any other molecules that make up a plant's dry material, and where within the plant or its cells those molecules might be found? (for hints, look back over your reading from activity 4)

Lipids – cell membranes; starch – storage organs like tubers; cellulose – cell walls; proteins – cell 'machinery;' etc.

*****Return to the reading to complete the section *Plants: Even more complex than von Helmont knew!******

To summarize all that we've discussed, please complete the following table:

	Gaining Mass	Transforming Mass	Losing Mass
Which process is responsible?	Photosynthesis	Biosynthesis	(Cellular) Respiration
What is the effect on CO ₂ around the plant?	Decreases	No effect	Increases
What is the main product(s) of the process?	Glucose	Starch, cellulose, lipids, proteins, etc	CO₂ and H₂O

Activity 11: What’s the “matter” with Carbon?

General Overview

Introduction: What’s the “Matter” with Carbon?	~ 15 minutes
The Powers of 10 (optional)	~ 15 minutes
Carbon and the Powers of 10	~ 15 minutes
Discussion: Tracing Carbon through Systems	~ 15 minutes
Matter and Energy Process Tool Extension (optional)	~ 15 minutes

Estimated Time: 40 - 55 minutes (70 Minutes with extension)

Purpose

This lesson reinforces the importance of carbon by showing students that carbon is present in all living things at various scales. The teacher reintroduces four different size scales (atomic-molecular, microscopic, macroscopic, and large scale) and again asks students to think of items they are familiar with that might fit into the different scale categories (it is a reintroduction if scales activities were already done). Students are then asked to think about the plant growth unit and list the items that contain carbon and where these might fit on the Powers of 10 board. The teacher can then utilize the Powers of 10 board, cards and *Matter and Energy Process Tool* to highlight the importance of scale and help trace matter and energy in a growing plant. This discussion will help students to explicitly connect carbon to processes which relate matter and energy at different size scales (i.e. photosynthesis, respiration, biosynthesis, decomposition). Lastly, the class develops a variety of pathways showing how processes like plant growth, cell respiration, digestion, and decomposition can move a carbon atom across the scales in examples of simple carbon cycles.

Learning Outcomes

- Students increase their understanding of atomic-molecular, microscopic, macroscopic, and large scales.
- Students realize the overall importance of carbon and begin to understand how to trace matter and energy in biological systems

Materials

- Class Powers of 10 class poster or PowerPoint slide
- Item Cards, magnetic or paper
- *Matter and Energy Process Tool* poster or PowerPoint
- Student copies of *What’s the “Matter” with Carbon?* (1 per student)

Advance Preparation:

- Powers of 10 class poster or Projector with PowerPoint slide of Board.
- Make item cards to include on Board. You can print cards on magnetic cards or use tape and paper. The items should include at least the following: carbon atom, carbon dioxide, macromolecule (glucose), plant cells, leaf, entire plant, and a forest. You can also include cards that may be relevant to local ecosystems that students may be familiar with.
- Review *Matter and Energy Process Tool* from systems and scales unit.

Procedures

Introductory discussions: What's the "Matter" With Carbon?

~15 minutes

1. Begin by reviewing plant growth, the gas exchange and mass change activities and organic materials. Have students share key concepts they learned throughout the unit such as what materials contribute to plants' mass increase, how matter and energy are used in photosynthesis and respiration, where the mass for plant growth comes from and what organic matter is. Next, ask the students to complete at least two of the following questions on their worksheets:
 - a. Why is carbon so important? **Common in all forms of life...**
 - b. What do we hear about carbon on the news? **Mostly comes up in reference to greenhouse gases (CO₂, CH₄, CFCs)**
 - c. Why do scientists talk about carbon? **Tracing carbon through ecosystems is essential to tracing the flow of material as a whole**
 - d. What does the term carbon footprint mean? **Refers to the total greenhouse gas effect that a lifestyle or individual decision has**
 - e. What's the "matter" with carbon?

Although these questions cover material above and beyond the unit to this point, they are largely included to begin students thinking about the broader importance of carbon to the earth's systems. Why have we spent so much time learning about it in this unit? It's not only to better understand plant growth. The key ideas are that carbon is the backbone of the molecules that make life as we know it possible, and that as it moves through the atmosphere in gaseous form it can have a dramatic greenhouse gas effect. If you wish, have some students volunteer their responses to the whole class (although be cautious as some of the topics could spur long side conversations).

2. The Powers of 10 *(if not already discussed in lessons 2-4) ~15 minutes

- a. What does the word "scale" mean to you? (try to cue students to move beyond measuring scales, such as weight scales).
- b. Using the responses of your students, guide the discussion to the following possible definitions.

Possible definitions

- i. Scale: the size or range of measurement used for describing a particular system. You can use scale and measurement to compare the relative sizes of systems.
- ii. Atomic-Molecular (list a few examples)- these are things we can not see with our eyes or microscopes
- iii. Microscopic (list a few examples)-these are things we cannot see with our eyes; we must use Microscopes.
- iv. Macroscopic (list a few things)- these are things we can see with our eyes
- v. Large scale (list a few things)-these are things too large to see in their entirety with our eyes

- c. If your students have already worked through lessons 2 & 3, you may simply want to have them resupply their definitions of systems and scales.

3. Carbon and the Powers of 10 Activity

~20 minutes

- a. Using the classroom Powers of 10 poster or overhead slides, have the class agree again on the placement of the following items containing carbon: carbon atom, carbon dioxide and glucose.
- b. Next, ask the students to generate as many other items that have carbon as they can from their experiences in this unit. The possibilities are many, but hopefully they will arrive at a list including plants, people, starch or cellulose, seeds, etc...Then using either blank magnetic pieces or post-it notes, have students assign each object to its appropriate scale on the classroom poster.

4. Tracing Carbon Through Systems

~15 minutes

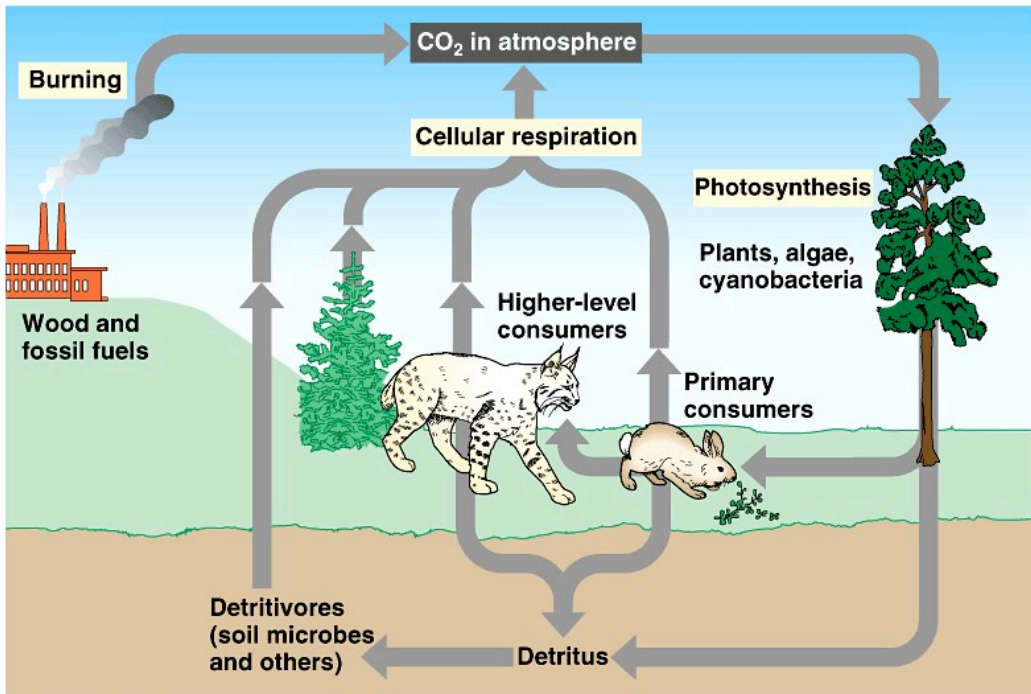
- a. Point out to your students that most of the objects they have identified are connected to each other through biological and chemical processes that we often refer to as the carbon cycle. Project a slide or overhead of the Terrestrial Carbon Cycle (below).
- b. Tracing Matter – Pick any point in the diagram, say, the lynx, and ask where carbon from a molecule in the lynx's body could go next (**respired as CO₂; moves into decaying material if lynx dies, where it could then be respired; moved within the lynx's body by biosynthesis**). Then allow the students to describe other possible routes on their handouts. Encourage the students to make mental use of the arrows in their pathways. After everyone has had a chance to think of a couple, bring the class back together and solicit volunteers to share their ideas. Ask the students: are all of the transitions in a given example actually possible? Have we unsuccessfully conserved matter at any point?
- c. Follow up with questions about the importance of carbon, the different scales where it is found and why.

5. (Optional) Matter and Energy in the Growing Plants

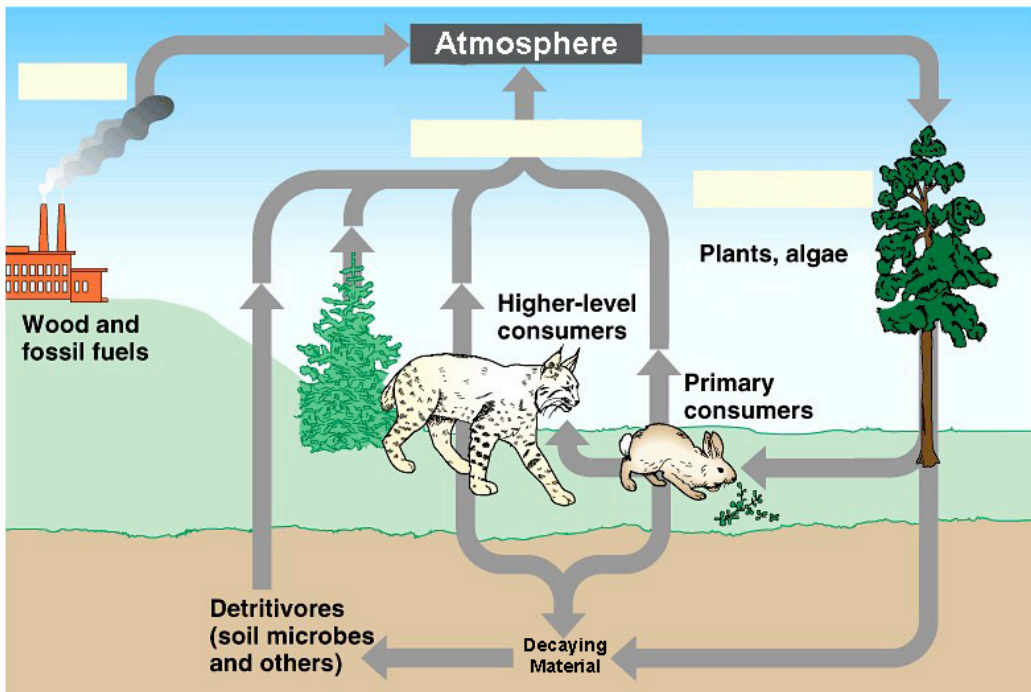
~15-20 minutes

- a. If your students did not complete activity 8, this is an opportunity to use the *Matter and Energy Process Tool* to describe changes occurring during photosynthesis, biosynthesis and respiration.
- b. Use this tool to help the students understand how matter and energy transform during photosynthesis.

Terrestrial Carbon Cycle (with and w/o processes)

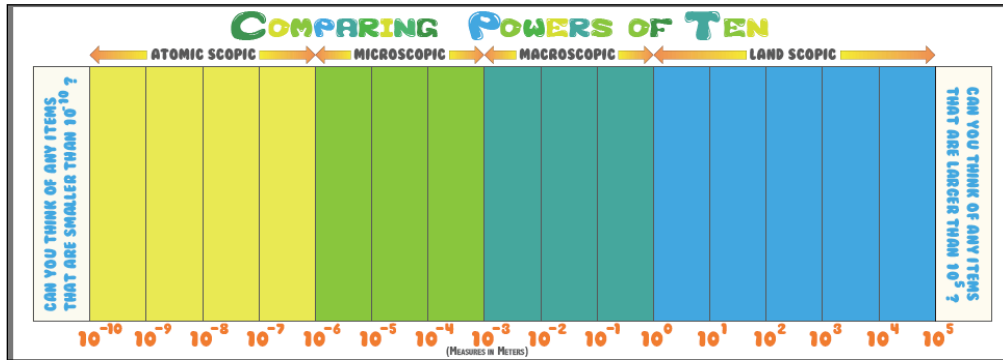


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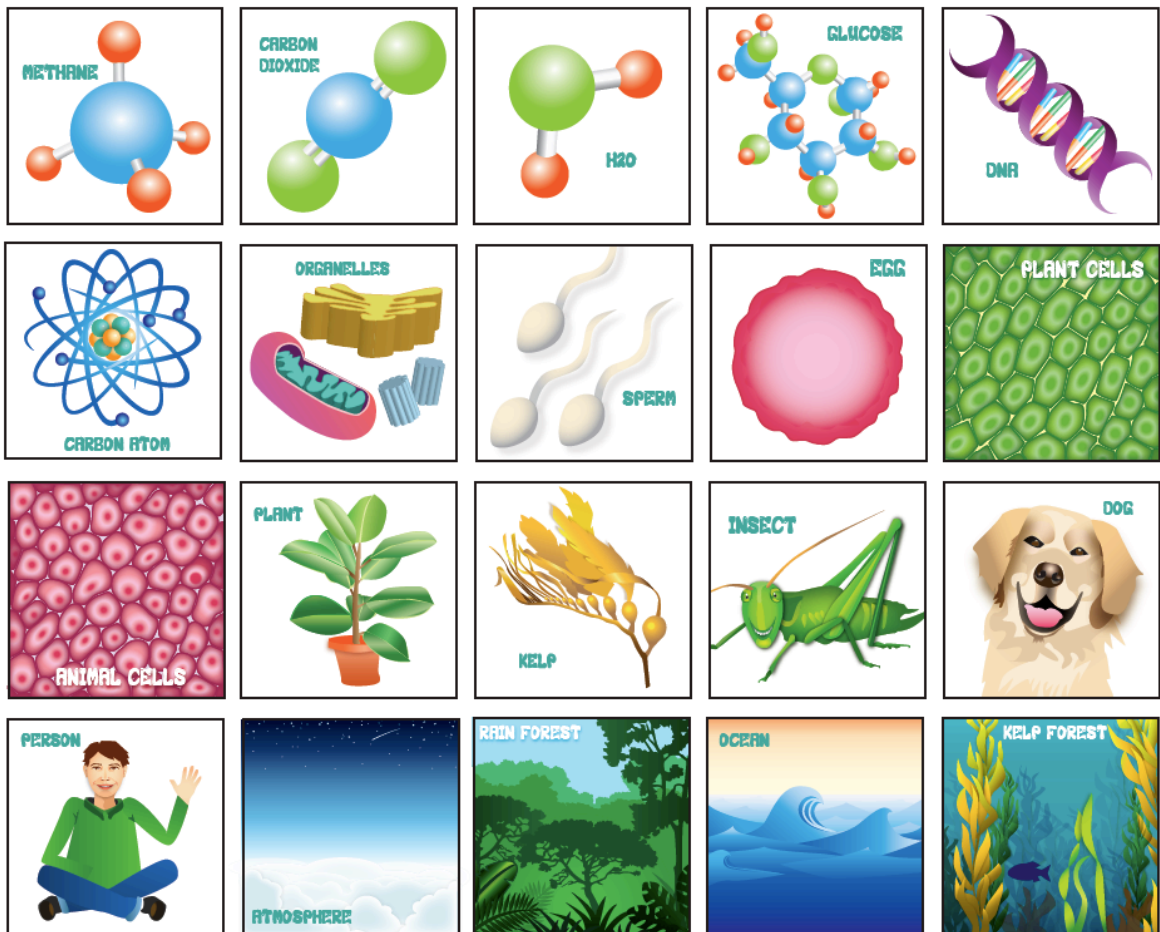


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Example Board



Example Item Cards



Name: _____ Period: _____ Date: _____

Activity 11: What's the "Matter" with Carbon?

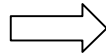
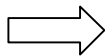
1. What do you know about carbon?

Pick two of these questions and respond to them using your previous ideas about carbon

What is carbon?
 Why do we think carbon is so important?
 Why do scientists and environmentalists talk about carbon?
 What is the meaning of a "carbon footprint"?
 What is the big deal about carbon?
 What's the "matter" with Carbon?

many possible answers here; make sure discussion stays focused on importance of carbon to all life, and that large changes in carbon's location on the global level is creating problems for human society

2. Using the carbon cycle diagram your teacher projected, describe two possible routes of at least three links each that a carbon atom could take through the ecosystem:



1 st Location	Process	2 nd Location	Process	3 rd Location
CO ₂ in atmosphere	ps	glucose in pine tree	burning	CO ₂ in atmosphere
glucose in decomposer organism	biosynthesis	chitin in decomposer	death	chitin in decaying material

many other routes possible