PLANT GROWTH AND GAS EXCHANGE

MIDDLE/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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Contents

Overview 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.

The major focus of the unit is to engage students in the questions:

1. Where does dry plant matter come from? (i.e. not from soil or water, but from the air),
2. What is the main component of plant matter? (Carbon-based).

These activities will lay a foundation for tracing carbon through organisms and ecosystems, improving student understanding of the global carbon cycle.

The key observations students need to make are:

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 macroscopic scale, students will need to connect their observations with processes occurring at the microscopic and atomic-molecular scales—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

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 1 (p. 6).

Instructional Aides

We have built two particular instructional aides into multiple portions of this unit in the hope of better scaffolding for students the learning that we are aiming for. The first is a recurring formative assessment theme, built around the learning of a "typical" student, Adrienne (i.e. **The Story of Adrienne**). Her experiences and thinking are highlighted throughout with hashed boxes, which you can also consult for useful questions that can help you to diagnose your students' thinking as you begin new portions of the unit (see also questions marked with stars throughout this guide). Adrienne's story (and those of her classmates) begins with a simple question:

- Little acorns can grow into big, heavy oak trees. Where does all the mass of an oak tree come from?

Here are three answers to this question:

- **Adrienne:** (Level 2 reasoning; see Appendix A) *The mass of an oak tree doesn't really "come from" anywhere. The tree makes the wood itself. The tree uses some things as it makes the wood: sunlight, water, air, and minerals or nutrients in the soil. Those things are not wood, though. So the tree uses them to make its mass. It uses sunlight and soil nutrients for energy. It "drinks" by soaking up water from its roots, and it "breathes" the air (it breathes in carbon dioxide and breathes out oxygen, the opposite of people).*
- **Beatrice:** (Level 3 reasoning) *I agree that the tree makes its own wood, but the MASS of the wood—the atoms that it is made of—has to come from somewhere. I think that water and soil nutrients are the "ingredients" that the tree uses to make wood, so the mass of the tree comes mostly from water and soil. The tree also uses sunlight for energy and carbon dioxide in the air for breathing, but they don't contribute much to the mass of the tree.*
- **Carla:** (Level 4 reasoning) *I agree with Beatrice that the mass of the wood has to come from somewhere, but I don't think that the mass comes mostly from water and soil nutrients. I think that the mass comes mostly from carbon dioxide in the air.*

The second set of repeated aides are the **Tools for Reasoning**, which are designed to embody three key principles that are essential for reasoning about environmental processes: SCALE, MATTER, and ENERGY. These tools are designed to support student thinking about these processes by providing visual cues for both the teacher and the learner.

- 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 Matter[1], 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 (see Table 2; p. 7)

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. See **Appendix B** for a sequence of questions that show the key steps in constructing the arguments 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 the goal practices described in Table 1 below. A concept map (Table 3, p. 8) is available to illustrate how each lesson ties in with the big ideas.

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[1] 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.

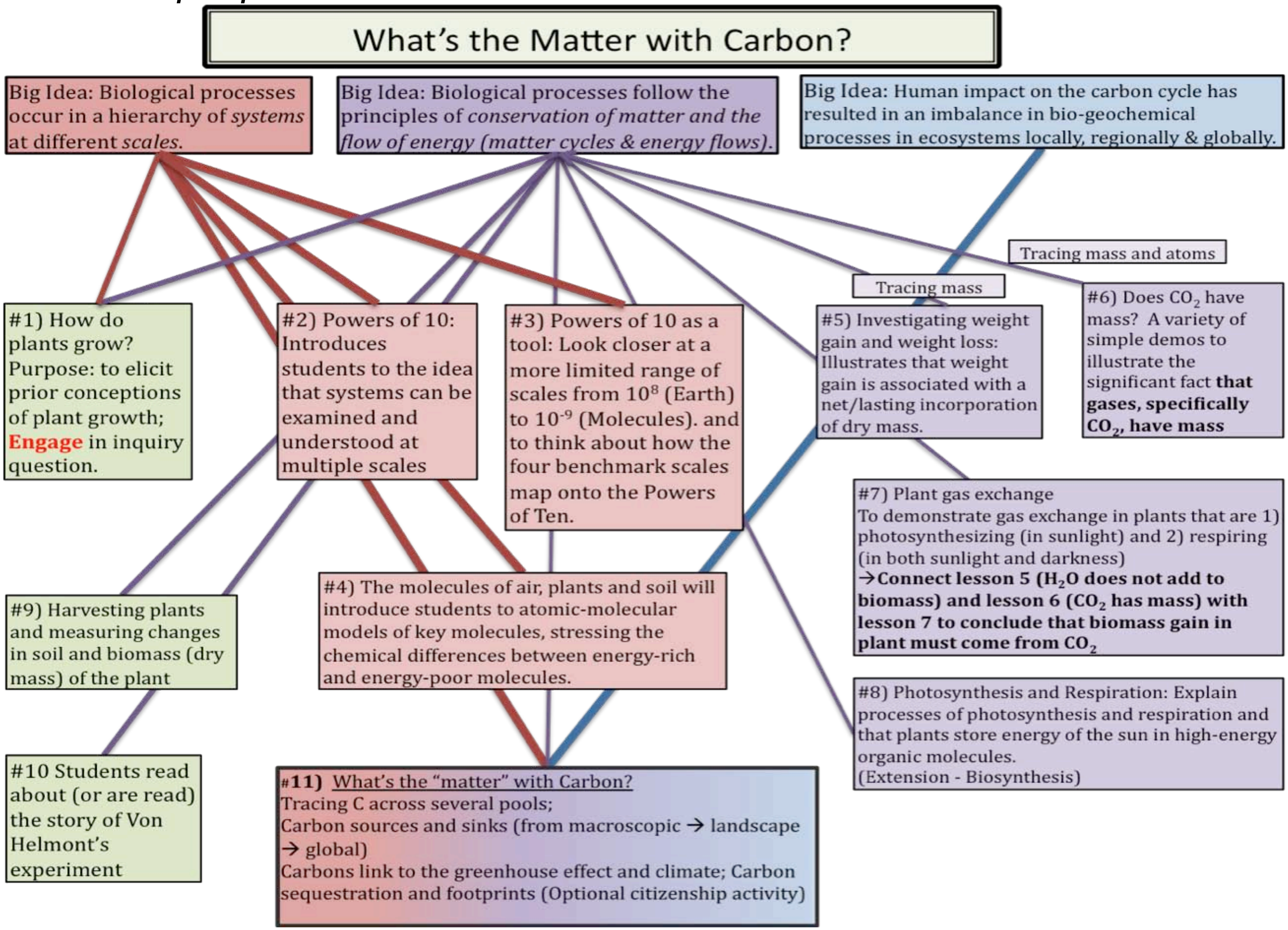
Table 1: Unit Goals as Changes in Student Inquiry Practices and Accounts

Practice	***Typical Entering Student Practices***	***Goal Practices***
	Inquiry or Investigating Practices (finding patterns in data and constructing arguments from evidence)	
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.
	Accounting Practices (explanations and predictions): Core goals	
Identifying material reactants and products	Describe plants as actors capable of two types of actions: • 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: • Photosynthesis in leaves converts CO_2 and H_2O to glucose and O_2 • 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_2O
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_2O to biomass and back again Recognize soil minerals and water as essential to plant growth but making up a small portion of biomass
	Accounting Practices (explanations and predictions): Secondary goals	
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

Table 2: Summary Table of Unit Activities

	Activity	Purpose	Time	Comments
Engage	**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 2-3 weeks)	This activity finishes by harvesting the seeds, which is described in activity 9
Engage / Explore	**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	Activity can be done at any point before the unit as well; does not have to follow #1.
Explore / Explain	**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	Activity can be done at any point before the unit as well; does not have to follow #1.
Explain	**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	
Engage	**5. Investigating weight gain and weight loss**	To illustrate that weight gain is associated with a net/lasting incorporation of dry mass.	70 minutes (over 2 days)	Best if run over 2 days to allow materials to dry back out
Explore	**6. Does CO_2 have mass?**	A variety of simple demos to illustrate the significant fact that gases, esp. CO_2, have mass	60 minutes	Classroom demos
Explore / Explain	**7. Plant gas exchange**	To demonstrate gas exchange in plants that are 1) photosynthesizing (in sunlight) and 2) respiring (in both sunlight and darkness)	50 minutes	Classroom demos
Explain	**8. Photosynthesis and Respiration**	To build fuller accounts of these two processes using the process tools	55 minutes	
Elaborate	**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
Elaborate / Evaluate	**10. Von Helmont and explaining changes in mass**	To complete the discussion integrating photosynthesis w/ cell maintenance (biosynthesis) and respiration	45 minutes	
Evaluate	**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	55 minutes	Possible matter & energy process tool extension (15 min.)

Table 3: Concept Map of Unit Activities



Materials List

This is a general list – see activities for details.

Activity 1: Vermiculite (or other inert soil amendment), soluble fertilizer, large shallow trays, full-spectrum lighting or well-lit window, dehydrator or drying oven, radish, lettuce, bean, and/or pea seeds (non-heat treated), growing containers ("Grow cups"), digital balance or pocket scale (300g x 0.01), weigh boats, graduated cylinder or beaker, masking tape, permanent marker, paper towels or other wicking material

Activities 2 & 3: Powers of 10 video and class chart, laminated Powers of 10 item cards, magnets

Activity 5: Per group: tin or plastic cup, vermiculite, small square of sponge, small bowls, water, digital scale, beaker or graduated cylinder

Activity 6: Per group: carbonated soda, small cups, digital scale; Per class: Vernier CO_2 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), 2-3 small candles, plastic (sealable) 20oz soda bottle, water, baking powder

Activity 7: Vernier CO_2 probe (O_2 probe -optional), Vernier Go-Link interface cable (LabQuests or LabPros will also work), aquarium and stopper (or tape), Potted bean plants from activity 1, Very fresh leaves (e.g. spinach), aluminum foil, sunlight or full spectrum light source

Activity 9: Oven or dehydrator, small paper lunch bags or aluminum foil, Digital pocket scales, plastic weighing boats, tweezers/forceps/small paint brushes (optional), Parchment/waxed paper or baking tray, Plant Growth Grapher and Sample Data.xls (optional)

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 CO_2 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 7: Probe Difficulties

Activity 8: Plants and Photosynthesis; Plants and Respiration

Activity 10: Matter-tracing Process Tools

Activity 11: Atmospheric Carbon Process Tool

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.

The Story of Adrienne checkpoint

Refer to the 3 responses representing Learning Progression levels by Adrienne (Level 2), Beatrice (3) and Carla (4) in the introduction to this unit. Keep those in mind as you formatively assess your students' responses to the first 3 questions of activity 1. This should give you a rough idea of the percent of your class at each level.

Materials

General

- Soil or soil amendment. For this experiment, it is preferable to work with inert amendments such as perlite or vermiculite (or a mixture of both).[2] If not supplied by your university partners, these amendments are currently available in garden centers or stores.
- Large, shallow trays (such as rimmed baking sheets) for students to place cups on to facilitate moistening plants from below, so as not to disturb the (very light-weight) vermiculite.
- Full-spectrum fluorescent lighting, if sunlit area unavailable
- Crystallized, soluble fertilizer (we recommend something with a full suite of micronutrients, Miracle Grow only has N, P & K and may not be as effective over time periods >3 weeks compared to fertilizers that includes Ca, Mg, S etc; vermiculite does not have any mineral nutrients for the plants to aid plant growth – adding will allow the plants to sustain healthier growth for a longer time).
- Dehydrator or drying oven. Regular home/kitchen oven can work if necessary.
- 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. Placed in an envelope.
- 2 Growing Containers (these should be able to withstand a dehydrator or drying oven; aluminum cups work well)
- 1 Digital Balance, 300g (x0.01)
- 1-2 Weigh Boats
- Graduated cylinder or beaker for pouring water

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[2]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.

- Masking tape
- Marker
- Paper towels, muslin cloth, or other wicking material

Advance Preparation

- Make copies of *How do Plants Grow?* Student Worksheets (1 per student)
- Prepare seed packets containing 20 romaine lettuce or radish seeds and 4 bean/pea 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 group 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 9, Harvesting Plants).

Procedures

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

Pass out worksheets to your students, and ask them to complete the first three questions briefly on their own (keeping in mind that these responses can be very valuable for assessing where your students are on the learning progression at the start of the unit).

Then divide the students into groups of 4 for the experiments, and start the activity by asking the students about the things that plants need for growing and the materials that contribute to plants' mass increase. Use the blank matter and energy process tool to facilitate the discussion of how plants gain mass in terms of identifying what goes in and out. At this point in the unit, it is sufficient to have students discussing the process of photosynthesis/plant growth at the level of factors needed rather than of mass changes or other more detailed levels. The process tool will reappear in later lessons where these deeper discussions are likely to be more useful.

1. Explain that plants are, similarly to all living things, made of carbon-based materials.
    a. If no one has identified it after a while, ask where plants could get that carbon from.
    b. 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.
3. Have the students carefully read through the procedures before passing out the materials.
    a. Check for students' sense of the size by asking what unit of measure makes sense. Should they use grams, kilograms…?
4. Have students complete the procedures for planting their seeds (see Appendix C for photographs of experimental set-up), then have them make predictions and answer the questions below the table in their handout.
    a. You may wish to walk less experienced students through the experimental set-up, demonstrating each step before your students do it on their own, so they don't skip steps and so you can reiterate the importance of taking careful measurements.
    b. Have students predict what materials they believe will add to the mass of their plants as they grow, and in what proportions.

    i. Students will likely predict soil, water, even sunlight. The proportion of mass due to each variable will give an indication of student understanding.

5. Make sure cups are placed in a well-lighted place (by sunlight or full-spectrum fluorescent lighting), being careful to avoid drafty areas if possible. When placing bean seed 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 through 8 of the unit. In 14-18 days, radish or lettuce plants are likely to be ready for harvest. Bean or pea plants will normally require closer to three weeks to show consistent gain in mass, since they are able to survive off of the starches stored in their seeds for so much longer. You may allow more time for observing growth, depending on your unit plans.

1. In the next 14-18 days, select 5-7 times for students to register their observations (in Table).

   Upper level student observations could include tracking change in height of plants as a function of time. They may even display the data in a graph and track trends in the graph, including rate of growth between time intervals where height was measured.

2. 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 growing 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 (see Appendix C).
3. About once per week (plus initial watering), add the recommended amount of fertilizer to the water being used on the plants to insure that adequate minerals are available for the plants. It might be easiest not to draw students' attention to this added material, but if they do ask, you could weigh a dose of the fertilizer for comparison to the final growth measurements in Lesson 9.
4. 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 seeds 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 trees can grow from small seeds. What do you think plants need to grow?

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

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

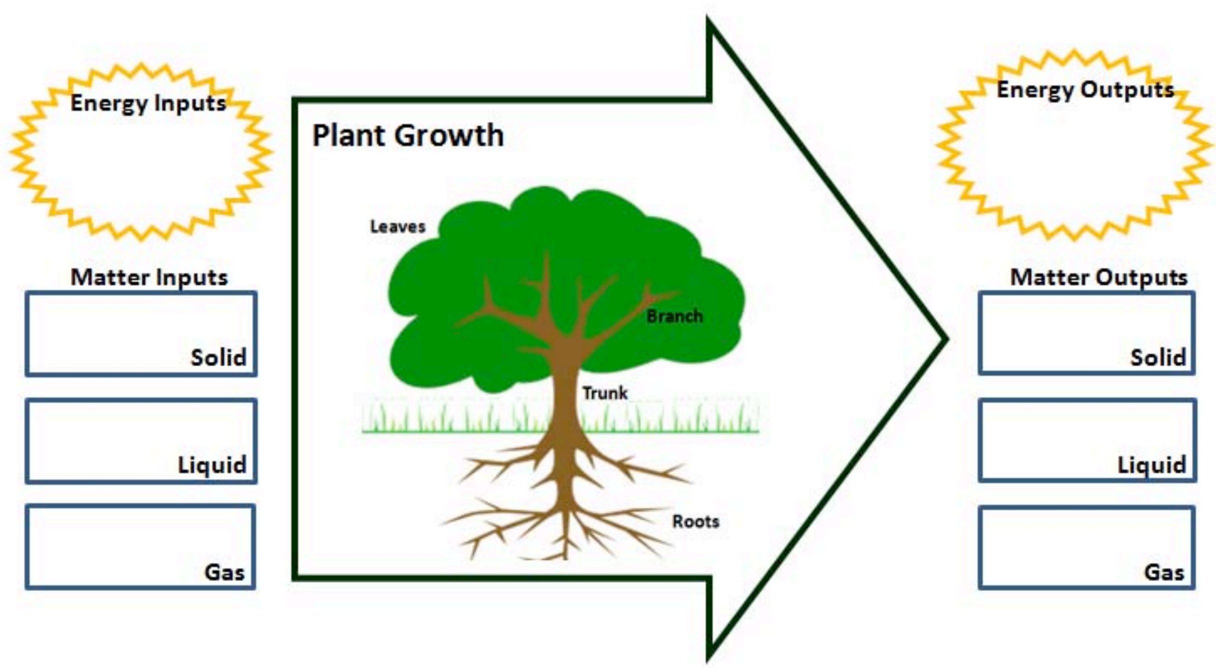
Plants die if they don't get enough water or are kept in the dark too long. Don't usually see plants growing without their roots in the soil. Most students have no direct evidence of trees taking up carbon dioxide, but have often heard it throughout earlier grades.

How do you think plants use these things they need to grow?

I think the water helps their cells stay hydrated, like ours. The 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 "stores" energy for later use by the plant. Soil minerals help, in smaller quantities, with other essential life processes of the plants.

Use the matter and energy process tool below to illustrate your thoughts about what plants need to grow:

Matter and Energy Process Tool



Introduction

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.

1. We will grow lettuce or radishes in soil (actually vermiculite, a mineral used in potting mixtures)
2. We will grow beans or peas in soil (again, vermiculite)

Methods

Lettuce or Radishes

1. **Make a 1-cm long cut** in the bottom of your growing cup with scissors, then **feed a small piece of wicking cloth** (strip of re-usable, industrial-strength paper towel folded length-wise approximately 7 by 12cm depending on height of grow cup) through the cut, with about half the length in and half out the bottom of the dish.
2. **Label** your cup with your group name and/or class period.
3. **Weigh** your empty cup and **record** its mass in row A of the table below.
4. **Fill** the cup ¾ full with vermiculite.
5. Use the table below to record the following measurements for the lettuce seeds:

Lettuce: Cup Number __________			
	Mass of:	**Before growing** (Lesson 1)	**After growing and drying** (Lesson 9)
A	cup		
B	cup + soil		
C	soil (subtract B - A)		
D	seeds		
E	cup + soil + seeds		
	number of seeds:		

6. Plant your seeds in the soil after you have weighed them – do not put all the seeds in the same spot
7. Answer the following questions:

   ○ Your prediction: What will happen to the mass of your plants as they grow?

      It will increase.

   ○ Reason for your prediction:

      We expect students to connect growth with mass gain, but not necessarily with adding on materials from outside the plant.

8. Water the growing containers carefully, according to your teacher's directions.

9. Place your cup in the light near a window, if possible.

Beans or Peas

10. Follow the same steps for bean/pea seeds as for lettuce/radish seeds. Use the table below to record data about your bean seeds.

Beans: Cup Number __________			
	Mass of:	**Before growing** (Lesson 1)	**After growing and drying** (Do later: Lesson 9)
A	cup		
B	cup + soil		
C	soil (subtract B - A)		
D	seeds		
E	cup + soil + seeds		
	number of seeds		

11. Water the seeds as you did for the lettuce and place the cup in the growing area.

Track the progress of your seeds

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 following data table about every 2-3 days. Note the general health and growth patterns of the plants: Have all survived? Are all producing healthy green leaves? and so forth. Be complete and accurate in your notes.

Date							
Lettuce: number of shoots							
Lettuce Observations							
Beans: number of shoots							
Additional Observations:							

Activity 2: Powers of 10

Note: Activities 2 and 3 could be done at anytime in your course before the unit begins – they do not necessarily have to follow Activity 1. There will be some lag time between planting seeds and available plants to do Activities 4 and following, and this Powers of 10 approach is one way to use that time well.

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 2nd 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 in Activity 3.

The Story of Adrienne Checkpoint:

Lessons 2 and 3 introduce Adrienne to the key idea of SCALE. Air and water are so obviously different from wood that it doesn't make sense to Adrienne that wood could be made from air and water. She can understand how this is possible only if she recognizes the existence of a "hidden world" of systems and processes too small for her to see. In particular, it is important that she come to think of gases as very much a state of matter like liquids and solids. In other words, as something that has mass. Lesson 2 introduces Adrienne to this hidden world, while Lesson 3 centers around the key Tool for Reasoning (Powers of 10 Chart) that will help her to use the idea of scale to interpret and explain the world—to use the idea as a tool rather than just a fact. The first step in this process is to understand the relative sizes of objects and systems that she is familiar with and to compare them with molecules in particular (the key systems she will need to understand how carbon dioxide and water can become wood). The activity of placing objects on the Powers of 10 chart will help her to do this.

Materials

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

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). The Cosmic Voyage excerpt is also good (http://www.youtube.com/watch?v=qxXf7AJZ73A).

There are also some interactive sites that allow students to navigate among images at different scales you may wish to tinker with:

- Scale of universe: http://primaxstudio.com/stuff/scale_of_universe.swf
- Cell size and scale: http://learn.genetics.utah.edu/content/begin/cells/scale/
- "The Universe Within": 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 on screen

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 eco*system*)
        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

1. 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**

2. Pass out the *Zooming In and Out* student worksheet.
    a. Read the instructions with students and tell students that the list of items at the beginning of the worksheet are different systems or components of systems that were included in the video.
    b. 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 see[3]), microscopic/cellular (we cannot see but can use a microscope to see), macroscopic (things we can see with our eyes), and large-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)[4].
    c. Encourage the students to dissect the words, for example, discussing what "scopic," "micro," and "macro" mean and develop a set of working definitions for each of these benchmark scales.
    d. 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**

3. 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.

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

[4] 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 in biological systems.

Name: ______________________________________ Period: _______ Date: __________________

Activity 2: Zooming In and Out

We generally use four different scales to group systems and parts of systems:
1) atomic-molecular (things we cannot see even with a microscope),
2) microscopic/cellular (things 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.

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. Complete the table below.

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.

The Story of Adrienne Checkpoint:

Here are the key things that Adrienne will need to notice as she works with her classmates to place objects on the Powers of 10 chart:

- *The exact Power of 10 is not particularly important. What is important is for Adrienne to notice which of the four Benchmark Scales (the four different colored regions of the chart) each object belongs in. These are:*
    1. *Atomic-molecular (atoms and molecules)*
    2. *Microscopic (cells, bacteria)*
    3. *Macroscopic (objects that we can see easily around us, plants and animals)*
    4. *Large scale (systems much larger than us)*
- *As in Lesson 2, Adrienne also needs to see that the SAME SYSTEM can be described at many different scales (a tree is made of cells, which are made of molecules, and is part of an ecosystem).*

If Adrienne makes sense of these ideas, then she will be well prepared for later lessons when she will tell the story of the SAME PROCESS at different scales (a tree grows—macroscopic scale—because its cells grow and divide—microscopic scale—because atoms in air, water, and soil are rearranged into new molecules—atomic-molecular scale).

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

- 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)*
- NOTE: This activity can be significantly shortened by not using the introductory slideshow and moving straight to the introduction to the wall chart and placement of objects. This may be especially desirable for high school or other advanced students.

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.

1. 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.
2. 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**

3. 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.

4. 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**

5. 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^{-10})
   - Microscopic (10^{-6} through 10^{-3})
   - Macroscopic (10^{-5} through 10^{2})
   - Large Scale (10^{2} through 10^{5})

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

6. 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.

Formative Check:

Discuss with your class.

1. Which of the objects placed on our Powers of 10 chart have mass?

   Students should realize that ALL of the objects have mass because they are all made of matter.

   Typical Level 2 response: Will vary, but could state that only objects big enough to be seen w/ naked eye will have mass.

   Typical L3: All have mass, but not the same *kind* of mass (i.e. – molecules don't add up to enough mass to be comparable to macroscopic objects).

   Typical L4: All have mass, and the amount of mass tends to be proportional to the size of the object, since larger objects are just aggregations of many, many smaller ones.

2. Why didn't we have a picture of sunlight to include on our chart?

   Sunlight is not matter, it is a form of energy and one does not measure energy by spatial size.

   L2: We can't say for sure how big it is.

   L3: Sunlight has mass when it's connected to something else, like leaves during plant growth.

   L4: Pure light has no mass, and no distinct spatial boundary.

3. An additional formative assessment could be to ask your students to complete the following table comparing a single carbon atom with an average leaf:

	Carbon Atom	Leaf
Power of 10	10^{-9}	10^{-1}
Scale	Atomic molecular	Macroscopic

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?*

The Story of Adrienne Checkpoint

This check focuses on Adrienne's ability to transfer the big ideas in the systems and scale activities specifically to air, plants and soil. Adrienne should be able to take what she sees on the macroscopic scale and identify how that substance is made of smaller microscopic particles (smog and smoke), and even smaller particles (atoms and molecules). An important aspect for Adrienne to realize is that very small things (i.e. atoms) have mass that is much smaller than her level of perception. When these very small things are put together, they eventually can add up to a very large mass. Drawing connections to the just-completed Powers of 10 activities can help her to see that because atoms are so much smaller than familiar macroscopic objects, like wood, it takes time for the mass to add up enough to make a perceptible difference.

Though the Carbon Unit's primary focus is not on energy as much as it is on conservation of matter; it cannot be dismissed that energy flow is an integral component of the carbon cycle. Lesson 4 provides an opportunity to introduce the idea that energy from the sun has been transformed into chemical energy and is now being stored in the bonds of organic molecules in the plants, especially glucose. The plant can then use the glucose molecules in the production of more complex organic molecules, such as starch, cellulose, fats, and so forth.

Adrienne knows that sunlight is an energy source for plants as they grow, but it is not clear to her that it is the ONLY energy source and that the other things she listed (water, air, soil) are matter but not energy. The reading and quiz for this lesson will help her identify that materials making up a plant (cells, large molecules) are synthesized from smaller materials taken in from the air and (soil) water. In addition, she will see that some energy is being transferred from the sun to specific molecules, and bonds, within the plant.
The table that concludes the exercise is a crucial piece for underlining two major concepts:
1) Not all molecules can be useful sources of chemical energy for plants and eventually other organisms; only those with C-C and C-H bonds are useful in this way. The simpler molecules which make up most of those taken in by plants are not rich in these kinds of bonds.
2) The material which makes up plants (and other organisms) is synthesized from simpler molecules, beginning with the key process of photosynthesis.

The lessons in the remainder of the unit will focus on this latter point.

Materials

- Classroom Powers of 10 Poster
- 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* (embedded in the reading)
- Optional Graphic Organizer to accompany reading
- Molecular modeling kits (optional)

Advance Preparation

Make copies of student readings and quiz

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.)
    c. To assist your students with the reading you may want to provide them with a graphic organizer similar to the one below. This immediately helps them connect this activity to the four benchmark scales introduced with the Powers of 10 tool.
2. Have students take the Molecules Quiz. For less advanced students, you may want to limit them to just a couple questions (for example questions 1 and 2).
    a. 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.
3. (Optional) If you have molecular modeling kits and a little extra time, you could use models of the molecules talked about in the reading to compare relative complexity, sizes, etc.

Activity 4: *Molecules of Air, Plants and Soil* Graphic Organizer

Material	Atomic-Molecular Scale	Microscopic Scale	Macroscopic Scale	Key Facts / Questions
Air				
Plants				
Soil				

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**	**N_2, O_2, H_2O, and CO_2**	**No**
Plants	**Mostly C, H, O, and N (and P, etc.)**	**H_2O, 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**	**H_2O, with dissolved minerals like nitrate (NO_3^-) or phosphate (PO_4^{---}).**	**No**

2. 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 from somewhere? (also remember the contrast between Adrienne, Beatrice and Carla in the question they answered initially)

3. Based on your answers in the last column above, if you answered "yes" to any of the materials storing energy; identify the material and explain where the stored energy comes from.

Check to see that students understand energy flow from sunlight to the molecules in plants.

Typical Level 2 response: identifies energy in plants and soil minerals

L3: may state that sun's energy becomes some of the material in the plant

L4: some of the absorbed light is retained as chemical energy, and some leaves the plant as heat

Activity 5: Investigating Mass Gain and Mass Loss

Overview

Day 1

Introduction ~10 minutes

Initial measurements of selected objects ~15 minutes

Day 2

Final measurements of selected objects ~10 minutes

Does water make people and plants grow? ~20 minutes

Estimated Time: 55 minutes split over two class periods (Day 1: 25 mins, Day 2: 30 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 affect 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 CO_2 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 mass.

The Story of Adrienne Checkpoint:

When pressed to account for the mass increase in a growing tree, Adrienne may point to the large amount of water that plants take up as they grow. Although water does of course have (a lot of) mass, it is not mass that contributes to the structure of growing plants. For this, plants need to build mass using the molecules introduced in lesson 4 (starches, cellulose, etc).

By watering and then drying out a number of objects, starting from simple physical systems like a sponge and then moving to more complex situations like living organisms, Adrienne should make the connection that adding water to a system is a process that does not involve an incorporation of the water molecules into the structure of the object. After working with each object, check to see how Adrienne is dealing with the distinction between water weight and structural weight. Using the mass process tool for multiple examples she should see the transient nature of water within systems (e.g.10 g in as liquid water = 10 g out as water vapor).
(Note: these concepts are exactly analogous to those being discussed in the water experiment, except focusing more on transpiration than simple evaporation.)

The end of lesson 5 sets up the inquiry question -- how could we tell whether plants are gaining dry mass (not just water) when they grow? You will return to actually conduct this inquiry in activity 9.

Materials

PowerPoint to facilitate discussion: *Activity 5 - Mass Gain and Loss*

Copies of *Investigating Mass Gain and Mass Loss* handout

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

- 2 tins or plastic cups
- 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
- 300g digital pocket scales
- Beaker or graduated cylinder

Advance Preparation/ Safety Considerations:

- Decide which of the physical systems you would like to work with – sponge, vermiculite or both. They are substantially redundant, and many classes will get the point after just one exercise or demonstration. Be sure to remove any slides from the PowerPoint that you are not using (i.e. sponge or vermiculite).
- Make copies of *Investigating Mass Gain and Mass 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, or identify an oven to use
- Figure out how you will keep track of which sponges belong to each group. Label the sponges, or label tape on the cups. Using the aluminum growing cups will allow you to put cups directly into an oven.

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.
2. Divide students into groups of 3-4 for the experiments, then pass out the handout and have them work in their groups to respond to the first three questions. Lead a whole class discussion based on the groups' responses, making sure that the following key idea comes up:
   a. 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.
   b. The terms mass and weight are sometime misused. Have students discuss the difference between weight (measurement of pull of gravity on object, force of gravity on an object) and mass (amount of matter in object) and how each is measured.
   c. **Formative Check**: this is a good opportunity to see how your students are handling the issue of water in living things, as one of many aids to successful growth (L2) or as a necessary component of many reactions that has mass but is often not incorporated into the structure of the plant (L4).

NOTE: The role of water in organisms' mass is certainly complex, since protons (H^+) relatively easily dissociate from the oxygen present in water, and can subsequently be used in a variety of molecules inside of cells. In the specific case of photosynthesis being discussed in this unit, the carbon and oxygen in glucose both come from carbon dioxide molecules, while the hydrogen comes from other sources of available protons in the cell. In terms of location within the cell, as well, the light (where water is split) and dark (where glucose is made) reactions of photosynthesis are in distinct parts of the chloroplast. In other words, in terms of molecular mass, 168 of 180 AMUs (93%) in a glucose molecule come from carbon and oxygen, so the role of water in permanent structural mass is minimal.

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). In this case, being specific about masses of reactants and products is a key new distinction to make sure students are aware of. 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. Be sure to remove any slides that you are not using (i.e. sponge or vermiculite).

Does water make a sponge or vermiculite "grow?" **~25 minutes**

4. Instruct students to complete the sponge and/or vermiculite activities in their groups, as described on their worksheets (remember that both are not necessary unless you would like your students to spend more time on these). A discussion of appropriate units to use for mass (why grams?) and of measurement accuracy, precision, and error could be had again here.
5. 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.
6. Then let the groups complete the process of wetting the materials and take measurements on the revised masses of each. Be sure students do not use too much water, or the sponge will not soak it all up. 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 2-3 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 or vermiculite and to discuss the associated questions on the worksheets. Use slides 11-13 for a concluding discussion.

Does water make plants 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, their radish or bean plants. Using slide 14, have students make predictions for the mass changes they would expect to see.
2. 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 slide 15 to discuss their predictions.
3. Using slide 16 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 adding water produced a change in mass, but not in size. If time allows, have students weigh their plants again the next day. Did they lose mass? Where did the water go? In addition to evaporation, you could introduce the concept of transpiration here.

   The final question on Slide 16 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.

Does water make you grow? **optional**

Some students find it interesting to explore how water affects their own weight. Ask for volunteers (or have students explore on their own) to weigh themselves before and after drinking a large glass of water? Is this mass gain permanent? Weigh students again the next day, where did the water go?

Name: ______________________________________ Period: _______ Date: __________________

Activity 5: Investigating Mass Gain and Mass Loss

Warm-up Questions

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 mass? Try filling out the table below.

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

Does water make materials gain mass?

Materials:

1 plastic cup

1 dry sponge or small amount of dried vermiculite

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 or vermiculite** before and after you add water. This means you will:
    - **Weigh** the dry sponge or vermiculite.
    - **Weigh** a cup, then add some water and weigh the cup filled with water.
    - Figure out the **mass of just the water**. How can you do that?
    - **Predict the mass** of moist material after it soaks up the water.
    - **Weigh** the moist material to see how well you predicted.
- Your teacher will dry out the material overnight
- On the second day, you will **predict and measure the mass of the dried material**.

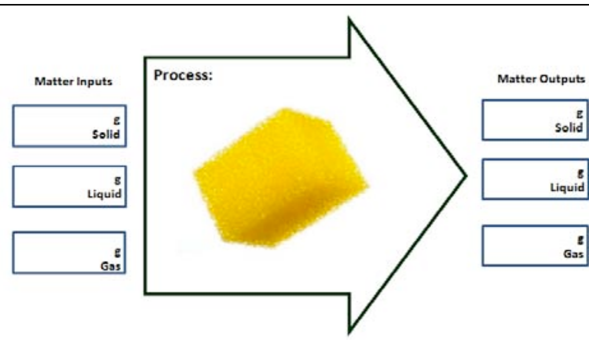
You can use the table below to record your measurements and predictions:

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

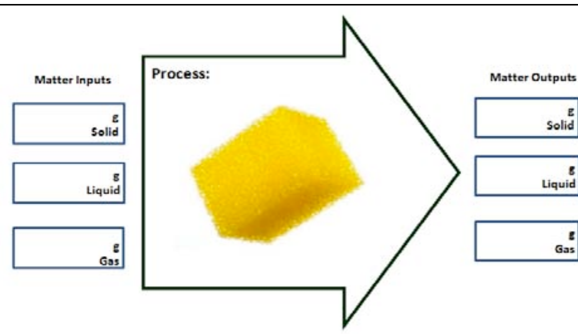
When we added water, did the material gain mass? Explain your reasoning.

The material-and-water system did, although the material 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 material.



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



Drying material: 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.

Do Plants Gain Mass When You Water Them?

Materials

1 small digital balance (300-g capacity)
Your Plant
Small plastic cup
Water

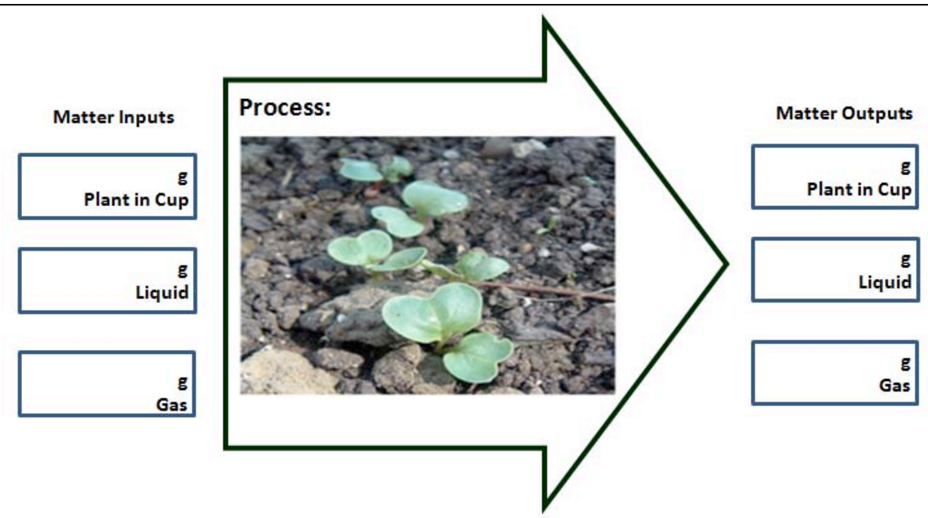
What to do:

- **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 mass** of just the water. How can you do that?
- **Predict the mass** of your plant after you have watered it.
- **Weigh** your plant to see how well you predicted.

Use the table below to record your measurements and predictions:

Mass of your plant in its cup:	
Mass of empty cup:	
Mass of cup with water:	
Mass of just the water:	
Your hypothesis: What will your plant weigh after it is watered?	
Reason for your hypothesis:	
Actual mass of your watered plant:	

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



Watering Plants: Fill in the masses that you measured. Did the plant gain mass when you watered it?
The plant's overall mass changed, but not the plant's (non-water) biomass.

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 mass when you watered it? Explain your reasoning.
Again, only temporarily. Not necessarily a structural change.

One final question: You can see that the measured mass 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 mass 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 CO_2 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 CO_2 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 (% O_2, ppm CO_2).

You may decide to not conduct all of the demos in this activity if you wish to save a little time, or if you are confident that your students understand the concept.

The Story of Adrienne Checkpoint:

The purpose of lesson 6 is to show students that gases do, in fact, have mass. In lesson 5, Adrienne made the distinction between water weight and structural weight, and observed that water from the soil was not significantly contributing to the actual growth of her plant. Over the next couple lessons, Adrienne will explore the possibility that gases from the air are contributing to growth, but to do this, she must believe that "air" has mass. This is the focus of lesson 6.

First, Adrienne will need to become familiar with the CO_2 probe and learn to interpret its measurements. Adrienne is already familiar with the concept of "breathing," so the demonstration of exhalation increasing CO_2 in the chamber should make her comfortable with information given by the probe.

To observe mass lost as gas, carbonated soda is a familiar system for Adrienne, as most students have experience with soda going flat and losing its fizziness. Throughout the class period, Adrienne will observe bubbles rising in her cup along with a measurable decrease in its mass. She will also observe a decrease in mass of the burning candle and the baking powder fizzing in water. In combining the scales with the CO_2 probes in these two processes, Adrienne should connect the mass lost on the scale to the CO_2 increase measured by the probe. The matter and energy process tool will help Adrienne to trace the masses through these changes.

Through these demonstrations, it should become clear to Adrienne that smaller, simpler compounds like water and CO_2 can be chemically combined with each other to make larger and heavier compounds that have a different nature all together. This is how the mass of water and carbon dioxide can actually become the mass of the tree's structure, not just help the tree to create mass. You should help her make the connection to herself as well; that she too loses mass when she exhales CO_2. This lesson will lead Adrienne to see in future lessons that absorption or release of CO_2 affects biomass.

Materials:

Copies of *Does CO_2 Have Mass?* student handout

Per student group

- Approx. 50 ml of carbonated soda beverage (or small 8 oz. cans of soda work well)
- Small cups (one per group; approx. 50 ml capacity)
- 300-g digital pocket scales

Per class

- Vernier CO_2 probe
- #10 size glass aquarium w/ Lexan or plexiglass lid, or 2000-mL biochamber from Vernier
- 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 CO_2 Have Mass? student handout.
2. Make sure you are familiar with how to use the Vernier CO_2 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 if you download the program. 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 CO_2 probe is set to read high levels of CO_2 (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 (or each group can weigh small can of soda initially, then open the soda).
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. Alternatively, you may wish to use the 2000-mL biochamber available from Vernier, or other large, sealable container.
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.

Your students may find it interesting if you track the loss in weight for the soda over a school day (a typical soda will release carbon dioxide for about a day before going completely flat). Weigh the soda and container before school, open it, and then record the weight of the soda and container in each class. You may have each class plot the data on a graph of time by weight of soda. A 16 ounce bottle of soda will release approximately 2.2 grams of carbon dioxide.

Measuring CO_2 before and after exhaling **~10 minutes**

1. Have students make their predictions regarding [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. Wait for CO_2 levels to stabilize, and discuss how the probe works, by measuring the absorption of infrared radiation by carbon dioxide molecules inside the shaft of the sensor.
4. 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.
5. Quickly remove straw and replace the tape securely over the hole.
6. Watch the data output respond to the influx of CO_2 into the chamber and interpret the graph. What does the horizontal axis represent? Time in seconds from when the probe begins collecting data. What does the vertical axis represent? Amount of CO_2 in ppm, or parts per million; a measure of very dilute concentrations of substances. Just as per cent is out of a hundred, parts per million is out of a million.
7. Have students complete the appropriate cells in the table on p. 2.
8. You could also put a cup of the soda in the chamber to observe what is happening with CO_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 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 CO_2 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 CO_2 concentration, but even a single candle will work. If using the Vernier biochamber or other plastic container, only one tea light should be used to minimize risk of melting the lid). 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 CO_2 into the chamber from the candle.
7. Read for approximately 5 minutes, or until candles go out (if you are using a smaller chamber).
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 CO_2 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 CO_2 in chamber with baking powder and water ~10 minutes

1. Immediately after the previous demo, remove the lid from the chamber 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 CO_2 in the chamber should also remain stable at the background level. (This reaction is releasing CO_2 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 CO_2 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 chamber and how did it affect the mass of the remaining materials? Where do they think the CO_2 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. Again, mass is the key feature to ensure in their discussions here.

Formative Check: While your students are working with the process tools, circulate to see if they are using the idea that some of the masses are leaving the system (candle, baking powder), either in an unspecified way or as energy. Remind them that they must explicitly conserve mass when using the tool, and that matter can not be converted to energy, or vice versa.

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 CO_2 and lose mass when they release CO_2, and this DOES affect their biomass.

Name: ______________________________________ Period: _______ Date: __________________

Activity 6: Does CO_2 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 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.

Warm-Up Questions:

<table>
<tr><td>Do you think the air around you has mass?</td><td>Yes

No</td><td>Explain your answer
Answers will vary.</td></tr>
<tr><td>After we pour the soda and let gas escape, will the mass of the cup + soda increase, decrease or stay the same?</td><td colspan="2">Explain your answer
Answers will vary.</td></tr>
</table>

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.

<table>
<tr><th>Time</th><th>Minutes since start</th><th>Weight of soda + cup</th><th rowspan="2">Weight of gas lost since start</th></tr>
<tr><td>At Pouring</td><td>0</td><td></td></tr>
<tr><td rowspan="3">After pouring</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

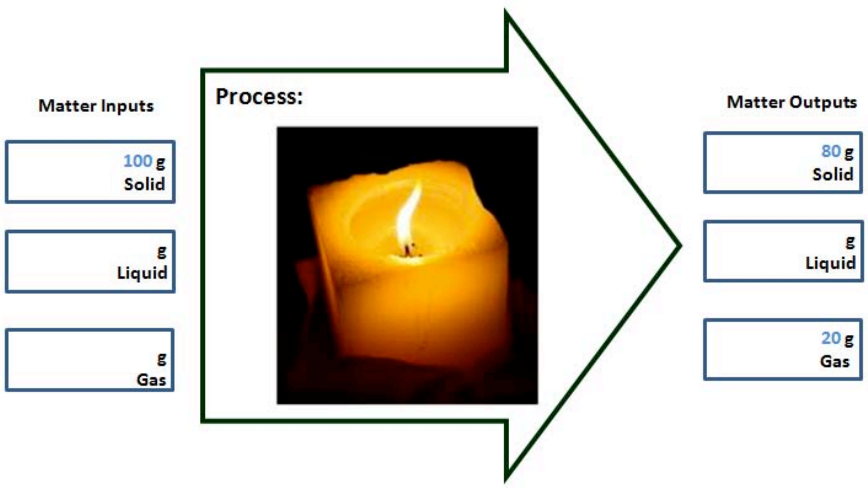
The next three experiments will be done as classroom demonstrations.

As your teacher prepares each of the three demonstrations:

- Observe the concentration of CO_2 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 CO_2 and mass, and record a final concentration and mass.

	Concentration of CO_2 before activity	Concentration of CO_2 after activity	Mass before the activity	Mass after the activity
Exhalation				
Candle Burning				
Baking Powder + Water				

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

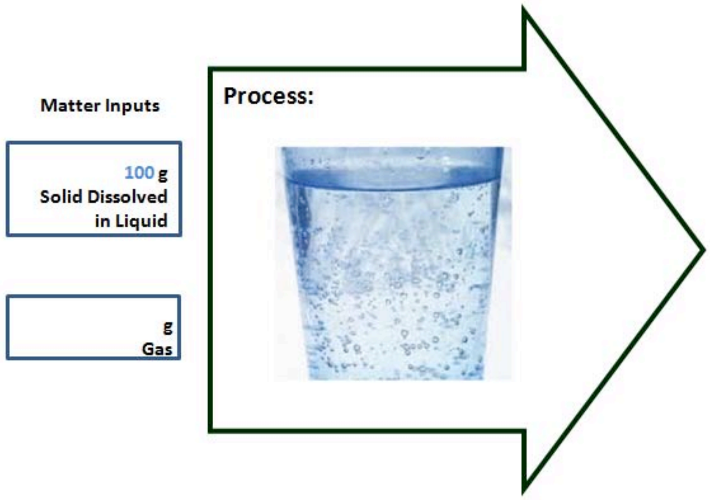


Candle burning

What did you observe happening to the mass and CO_2 concentration as the candle was burning? Should show an increase in concentrations of CO_2, and a decrease in mass.

Explain what you think happened to the mass of the candle as it burned?

Some of the solid wax (and oxygen) was converted to carbon dioxide and water.



Baking powder in water

What did you observe happening to the mass and CO_2 concentration as the baking powder and water fizzed? Should show an increase in concentrations of CO_2, and a decrease in mass.

Explain what you think happened to the mass of the baking powder and water mixture when it fizzed?

Some of the solid-liquid mixture is becoming carbon dioxide gas. (If the water is evaporated, it will show that the mass is actually being lost by the baking powder.)

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

Overview

Introduction and overview of probe set-up	~5 minutes
Measuring CO_2 for plants in the light	~20 minutes
Measuring CO_2 for plants in the darkness	~15 minutes
Discussion: Gas exchange in plants	~15 minutes

Estimated Time: 55 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 CO_2 moving in and out of plants with the pattern of weight loss when CO_2 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.

The Story of Adrienne Checkpoint:

In this lesson, Adrienne will have the chance to observe first hand her initial conception of the plant "breathing." This lesson also provides a quick check of her inquiry abilities regarding gas concentration measurements and making claims based on evidence. She should be able to predict what will happen to CO_2 concentrations when the plants are in the light and in the dark, and complete the data table with appropriate measurements. Interpretation of the measurements combined with experiences in the last two lessons should all be incorporated into the discussion questions at the end of the lesson.

Check point: At the end of the activity all students will consider three questions about the implications of their observations (Note: It is important that the distinction between mass and biomass be reiterated here.):

Based on your other experiments with CO_2 (e.g. soda pop, candle burning, person breathing), what do you think might be happening to the biomass of plants in the dark? Explain your reasoning. What might be happening to the biomass of plants in the light? Explain your reasoning. How could this be happening? What are your ideas about what the plants are doing in the light and in the dark?

Formative check:
Create a question and/or visual that will ask students to explicitly connect the observation that CO_2 in the chamber went down with a destination: where did it go? [the plant] From Lesson 6 students know that CO_2 has mass, so where did the mass of that CO_2 gas go? [the plant!] What does this mean for the plant's biomass? [it goes up]

For Adrienne, it is not as important that she use scientific terms of photosynthesis and respiration here, since they will be highlighted in Lesson 8. What is important for her to comprehend is that the "breathing" process of plants involves a gain of mass when they absorb CO_2, and a loss of mass when they release CO_2, and this does affect their biomass. Adrienne should be forced to confront that plants do "breathe" like we do (as witnessed in the dark), and that there are two separate processes going on.

NOTE: For an additional discussion of possible probe reading difficulties (w/ example Vernier readings), please see the PowerPoint "Lesson 7 – Probe Difficulties" in the supplementary materials. These may provide useful discussion starters for your students if the readings do not go as planned (or even if they do!).

Materials

- Vernier CO_2 probe (a Vernier O_2 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 or Vernier biochamber
- 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.
- ***In addition:*** Very fresh spinach leaves or leaves taken off of an outside tree or plant. Small vial of algae or aquatic plants, open to gas exchange with the larger chamber.
- Copies of student handout: *Gas Exchange in Plants*
- Heavy gauge aluminum foil or dark plastic bag to create darkened chamber
- Full spectrum light source (i.e.- growth or laboratory lamps)
- 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 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. *Results will be clearest if you can access direct sunlight (not filtered through a window), but fluorescent grow lights should also work indoors. Regular incandescent or fluorescent bulbs may not work – be sure to test them before trying this with your classes!* Sample results can be found in Appendix D. You may also familiarize yourself with the PowerPoint *Probe Difficulties*, in case you need to refer to it during class. Alternative data sheets that allow for simultaneous measurement of both carbon dioxide and oxygen can be found in Appendix E.

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. (NOTE: some trials have reported clearer measurements if the plants are observed in the dark and then moved to the light. Feel free to try it either way, but in any case test out the set-up the day before, when students aren't around!)

Procedures

Overview of probe and chamber set-up **~5 minutes**

1. Pass out the *Gas Exchange in Plants* handout to students.
2. Place CO_2 probe into one hole of chamber, and rubber stopper into the other. (Or use O_2 probe in the other hole. See Appendix C for a photo.)
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 CO_2. 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 CO_2 for plants in light **~15 minutes**

1. Place enough bean plants in chamber to cover the bottom of chamber. Insert the probe and close the 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 CO_2 level. Begin recording data when CO_2 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 CO_2 inside the chamber? (It is taking up CO_2)
   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 CO_2 for plants in the darkness **15 minutes**

With the plants still in the chamber, cover chamber with heavy aluminum foil or a dark plastic trash bag.
Wait at least three minutes for probe to adjust to new conditions. Monitor CO_2 level. Begin recording data when CO_2 level starts to rise.
Take readings and have students fill in data table on handout
While taking readings, engage students in discussion.
   a. What is the plant doing with CO_2 inside the chamber now? It is increasing the amount of CO_2 in the chamber
   b. Why, what process might be going on? respiration, releasing carbon from sugars.
Save results in LabQuest file (see Vernier manual)

Discussion: Gas exchange in Plants **~15 minutes**

Project both sets of results on the classroom screen (see Vernier manual) as you discuss the questions at the end of the handout. This discussion should be tailored to the level of your students. Keep it simpler for younger students.

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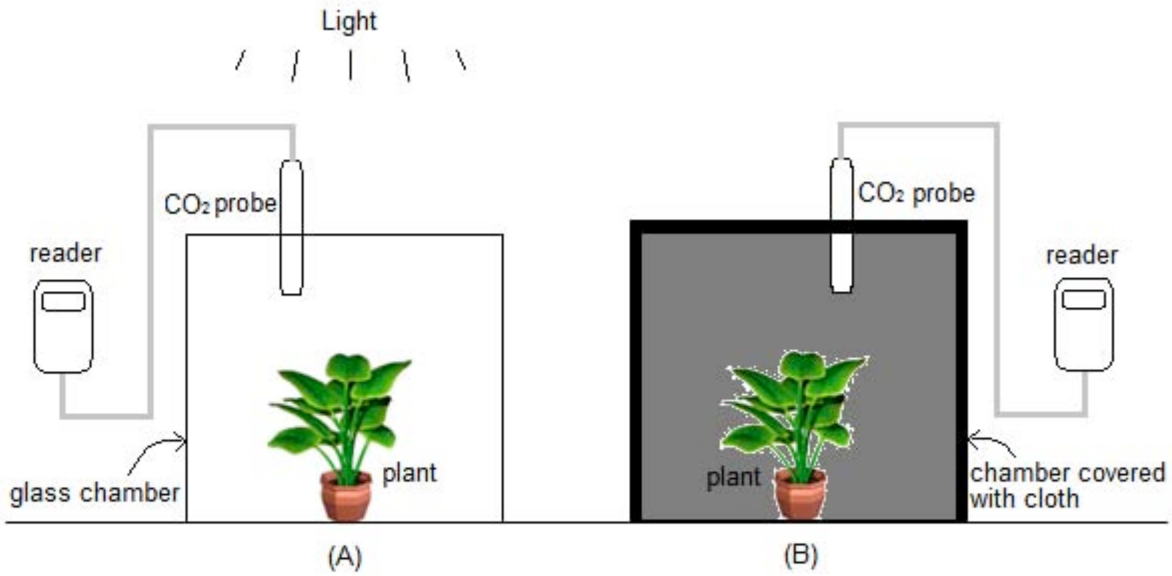
Activity 7: Gas Exchange in Plants

In this activity, we will use probes to study how plants affect levels of CO_2 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.



Warm-Up Question: What do you predict will happen to the amount of CO_2 in each chamber?

	In the light	In the dark
The amount of CO_2 will…	☐ increase ☐ be the same ☐ decrease	☐ increase ☐ be the same ☐ 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

1. Record your observations:
   a. What happened in the light?

   b. What happened in the dark?

2. Based on your other experiments with CO_2 (e.g. – candle, person breathing, etc), what do you think is happening to the biomass of plants in the dark? The plant is losing weight as it releases carbon dioxide to the air.

3. What might be happening to the biomass of plants in the light? The plant is gaining weight as it incorporates carbon dioxide into its body structure

4. Explain what you think is happening to produce these results. Students are likely to understand that the plants take up CO_2 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 stops, 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!

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 CO_2 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.

The Story of Adrienne Checkpoint:

As we saw in her initial answer about growing trees, Adrienne describes trees as growing when they have the things they need for life (water, air, sun, soil). The tree uses these things to make their matter as they grow, while sunlight and soil minerals are used for energy. The readings and discussion in this lesson will provide a chance for Adrienne to understand much more explicitly the parallel-but-different roles of matter and energy in the process of plants growing and living.

The previous lessons have helped Adrienne to see that gases have perceptible mass and that carbon dioxide in particular is exchanged in and out of plants in the light and in the dark. But she may still be confused about how these two ideas are connected, or what they have to do with other concepts she knows about growing plants. The reading will help her to connect these ideas to the notion that plants make their own food, which she probably holds from her earlier learning. Specifically, the initial product of photosynthesis, glucose, is made of several CO_2 molecules joined together inside the plant into a molecule that contains many high-energy bonds. Knowing from lesson 6 that gases have mass, and from lesson 7 that plants take up CO_2 under light conditions, she is then able to account for the increased dry mass of a growing plant: it comes mainly from the carbon atoms incorporated into glucose during photosynthesis.

(Optional depending on level of class)
But what about the energy that is in the high-energy bonds of glucose? Well, Adrienne already mentioned that plants get their energy from sunlight and soil minerals. The first is true, since some of that light energy is transferred to chemical potential energy in the bonds of glucose, but the latter is less accurate. While plants do need small amounts of materials like nitrogen and phosphorus (remember lesson 4), it is to build other molecules within their cells (proteins, DNA, etc) and not as a source of energy for plants. The additional materials provided with this lesson, such as the PowerPoint presentations, go into much greater detail about the fate and use of chemical energy in plants, but before trying to impress those upon Adrienne and her classmates, it is important to make sure that they understand the more fundamental distinction between forms of matter and energy.

At the molecular-level, cellular respiration is essentially the reverse process to photosynthesis, in that glucose is broken down to carbon dioxide and water, releasing stored energy in the process. Adrienne may not think of plants as needing to use this process, but all living cells need to use some variation on this basic plan in order to carry out their life process, and plants are no exception. Thus, when they can't photosynthesize (in the dark), plants release CO_2 into the air just as animals and other organisms do. They are still respiring in the light, but the release of CO_2 is generally overshadowed by the larger amount of CO_2 being taken up for photosynthesis.

After Adrienne and her classmates have finished the reading and discussions, close the period by drawing their attention back to the plants they have been growing. In lesson 9 they will measure the dry mass of their plants, and see for themselves the effect of a growing plant consuming carbon dioxide over a few weeks in terms of adding mass to the plant.

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 CO_2 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 CO_2 for plants to breathe in and then emit O_2. 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 $\leftrightarrow$ 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.
14. See Lesson 9 (Advance Preparation) if you have time to prepare your plants for drying.

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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.

1. What happened to carbon dioxide levels near the plant in the *dark*? What biological process was mainly responsible for that change?

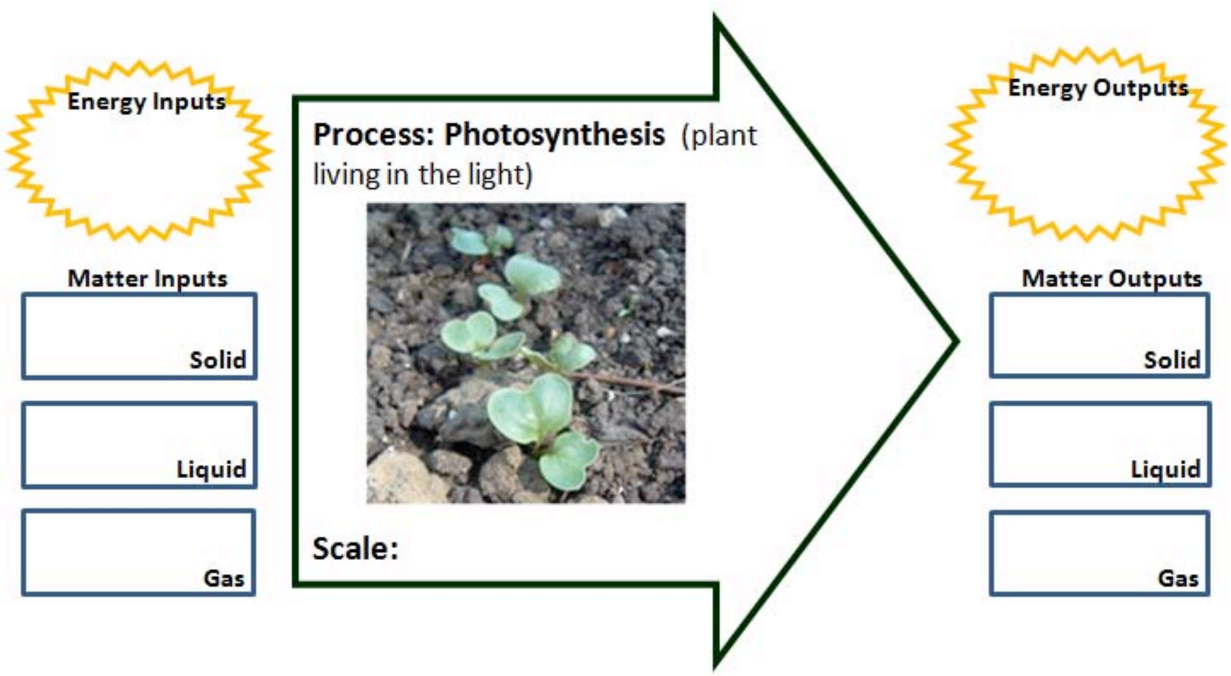
CO_2 levels increased; respiration

2. What happened to carbon dioxide levels near the plant in the *light*? What process was responsible for the change in CO_2 concentrations in this case?

CO_2 levels decreased; photosynthesis

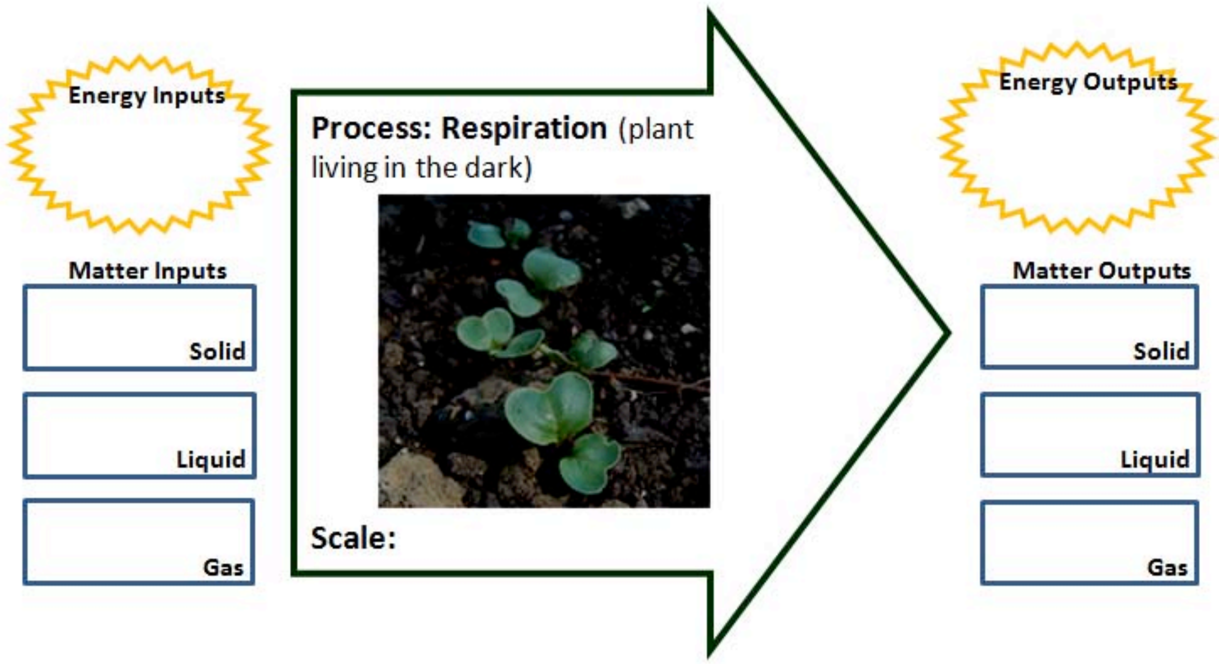
Now let's consider those processes a little more fully. Working with your lab group, fill in the following process tools for photosynthesis and respiration as completely as you can. They will be more complicated than any of the others that you have completed so far, so check that you include all the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

Plant living in the light



Energy input = solar/light energy; Energy Output = chemical energy, heat
Matter input = CO_2 (gas), water (liquid);
Matter output = O_2 (gas), glucose (solid – although dissolved in solution within cells)

Plant living in the dark



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/lettuce plants that you have been growing.

3. How do you predict your plant's biomass will have changed?

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

4. How do you think that this happened? 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.

The Story of Adrienne Checkpoint:

The purpose of this lesson is to once and for all challenge Adrienne's initial conception of the tree "using things" to help it grow, but not grasping the conception that plants grow and gain mass from the contribution of atoms of carbon from carbon dioxide. Teachers must be aware that even small amounts of miscalculation/experimental error could sway Adrienne's results and thus not provide the evidence she needs to change her thinking. Additionally, a very small mass gain, though measurable, may be insufficient to overcome the skepticism of Adrienne and many of her classmates. A quick QR (quantitative reasoning) lesson on atomic mass units (i.e. atoms on the periodic table do have masses, albeit very, very small ones) might do the trick, or reminding students of the gas molecules they placed in the Powers of 10 chart. More likely, providing additional experimental evidence from numerous classes (see discussion question 4) can highlight the overall trend of mass gain in radish plants due to CO_2 from the air. This is essentially what the von Helmont experiment (Lesson 10) does as well, and you could highlight that finding using a potted plant from your classroom, etc.

Formative check:
It might be helpful to have a discussion on what contributes to the mass of the plant and what students attribute the mass to, before summary questions or in helping them complete Q1.

- *Water does not actually form the structure of the plant, but it does provide an aqueous solution for cells (lesson 5)*
- *Carbon dioxide has mass (lesson 6), is consumed by the plant during photosynthesis and converted to glucose (lesson 7,8), and is the main contributor of dry mass to the plant*
- *Soil minerals contribute to plant proteins / DNA, but N, P and K are present in much smaller amounts than C, H, and O*
- *Seeds have even smaller contributions; again N, P, and K are used up, but add minimal mass.*

After allowing students to complete the summary questions it will be important to highlight (make visible) exemplar student responses (specifically Q1 and the discussion section). Ideally, Adrienne's answer could be shared with classmates, or you may remember that you have students like Beatrice and Carla in your class who had pre-conceptions that started with level 3 and level 4 reasoning. One way or another, highlighting the correct scientific understanding of carbon sequestration is essential for typical students like Adrienne to adjust their thinking upwards on the learning progression.

Materials

- Oven or dehydrator for drying samples
- Paper lunch bags (aluminum foil also works)
- Parchment/waxed paper or baking tray (for a sorting surface)
- Digital pocket scales
- Large plastic weighing boats (optional)
- Copies of *Harvesting Plants* Student Worksheet (1 per student)
- Tweezers or forceps (optional)
- Small paint brushes (optional)
- Plant Growth Grapher and Sample Data.xls (optional)

Advance Preparation (before lesson) ~ 20 minutes

1. Use the radish plants started in Activity 1, **as long as they have been growing for at least two weeks or so.** Using plants that are not very old (e.g. less than 8-10 days) is likely to yield unclear results for students. The more time plants have had to "put on biomass" the better. This is another reason for adding small amounts of fertilizer at several points; it helps encourage robust growth.
2. Make sure that the students don't water their plants for about 2 days before drying.
3. Gently dump the entire contents of each growing 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 onto their paper or plastic sorting surface, after removing the cup (see Appendix C for pictures). 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 (including any unsprouted seeds), setting them into the 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 (if used) from the final mass measurement in that set. They can also just weigh both the vermiculite and plant parts separately in the cup.

Discussion **~20 minutes**

3. Still working in their groups, students should now respond to the summary questions.
4. 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? How much mass did the vermiculite lose?
    a. Possible extension: generate a graph to compare data across groups and classes. You may create your own, or an excel template has been provided (Plant Growth Grapher and Sample Data.xls). Students should enter their class period, group name, and starting and end plant and soil masses into the table and the spreadsheet will calculate and graph the average changes in mass (pretty cool!).
    b. Possible extension: 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.
    a. The Plant Growth Grapher and Sample Data.xls offers some sample data for comparison to your own class data, if desired.
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

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Activity 9: Harvesting plants

In the last several weeks, 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 mass.

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

1. Copy your measurements from the data table in lesson 1 into the "Before Growing" column in the table below.
2. Find the mass of your weigh boat and record in row F.
3. Gently remove the growing cup from your bag, weigh it, and record in row G.
4. Pour the remaining contents of your bag onto a paper or plastic sorting surface.
5. Using your fingers or tweezers, gently pick out all of the plant material (roots, shoots, potentially even seeds) from the soil and set them in the weigh boat.
6. Dump the soil into the cup, weigh it, and record in row H.
7. Subtract the mass of the cup to calculate the dry mass of the soil. Record in row I.
8. Weigh the plants in the weigh boat and record in row J.
9. Subtract the mass of the weigh boat to calculate the dry mass of the plants. Record in row K.
10. Calculate the change in mass over the experiment. Subtract the mass in Lesson 1 from the mass in Lesson 9 to find the difference.

Lettuce: Cup Number _________							
	Mass of:	**Before growing** (copy from Lesson 1)		**Mass of:**	**After growing and drying** (Lesson 9)		**Compare Before and After** (Lesson 9 – Lesson 1)
			F	weigh boat			
A	cup		G	cup			
B	cup + soil		H	cup + soil			
C	soil (B - A)		I	soil (H - G)		L	
			J	weigh boat + plants			
D	seeds		K	plants (J - F)		M	
E	cup + soil + seeds						
	number of seeds						

Summary questions

1. Let's compare!
   a. Did your soil mass change (see row L)? How? Can you explain why?

   b. Did your plant mass change (see row M)? How? Can you explain why?

2. What materials contribute to plant mass?

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

3. What does "dry mass" mean? Why is it important to measure when looking at plant growth?

Dry mass 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, and not water weight.

4. Is a plant's source of energy related to its dry mass? 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.

5. 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 CO_2 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.

The Story of Adrienne Checkpoint:

Lesson 10 is meant to bring together all the mass-transforming processes from the unit to help Adrienne form a more complete understanding of the mass gain in her plants. Plants gain mass through photosynthesis, break apart and reorganize glucose molecules to create more complex molecules through biosynthesis, and lose mass through cellular respiration.

Adrienne thinks that water, minerals and nutrients from the soil play a huge role in creating mass in the plant and providing energy for the plants' processes. von Helmont's results should challenge Adrienne's strong reliance on soil for mass and energy. It will be important to check that Adrienne understands the reading by reviewing her table at the end of the handout and confronting any lingering misunderstandings. Revisit the discussion from Lesson 9 in the context of an experiment that has been around for a long time and provides more evidence to the conclusion that structural plant mass comes from the carbon in carbon dioxide. Check to be sure she believes von Helmont's conclusions about soil, and the class's conclusions about carbon dioxide.

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 CO_2, 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: Von Helmont's Willow Tree Reading Guide

Where does a plant's mass come from? As you read, use the left column to record passages that help you answer this question. In the right column, write down what the passage tells you about the answer to the question.

Info from the text	What this tells you about the question
He waters the tree regularly, but does not add any more soil	*Von Helmont thought soil might not be food for plants and did an experiment to test the idea*
Von Helmont found that the soil lost a little weight while the willow tree gained a lot of weight	*The mass must have come from somewhere other than the soil*

Info from the text	What this tells you about the question

Name: ______________________________________ Period: _______ Date: __________________

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 mass. Think about whether the soil is food for the plant.

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

   YES NO

2. Do you think the mass 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 mass of the tree and the soil.

MASS CHANGE OF TREE	MASS 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.

6. What process describing plant growth was unknown to him and other scientists of the time? **photosynthesis!**

7. 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.

8. What are some other molecules that make up a plant's dry material, and where within the plant or its cells might those molecules 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, complete the following table:

	Gaining Mass	Transforming Mass	Losing Mass
Which process is responsible?	**Photosynthesis**	**Biosynthesis**	**(Cellular) Respiration**
What happens to the amount of CO_2 around the plant?	**Decreases**	**No effect**	**Increases**
What is the main product(s) of the process?	**Glucose**	**Starch, cellulose, lipids, proteins, etc**	**CO_2 and H_2O**

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

General Overview

Introduction	~ 5 minutes
Carbon and the 4 Benchmark scales	~ 15 minutes
The Carbon Cycle: Tracing Carbon through Systems	~ 20 minutes
CO_2 is a Greenhouse gas	~ 20 minutes
CO_2 "Process tool"	~ 20 minutes
Stabilization Wedges game (optional)	~ 50 minutes
What's the "matter" with Carbon? assessment	

Estimated Time: ~130 minutes (including Optional game) + assessment if using class time

Purpose

How are humans impacting the Carbon Cycle, and what can we do about it?

This lesson reinforces the importance of carbon by showing students that carbon is present in all living things at various scales. The teacher expands on learning from previous lessons with a focus on carbon at a global scale. Initially, the lesson reintroduces the 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 activities 2 & 3 were already done). Next, focusing on a carbon cycle diagram students will explicitly connect carbon to processes that relate matter and energy at different size scales. The class will develop a variety of pathways showing how processes like plant growth, cell respiration, digestion, combustion, and decomposition move carbon atoms across the different benchmark scales.

Next, the lesson focuses on the Greenhouse effect, specifically on CO_2 as a greenhouse gas. Using an online simulation, teachers can demonstrate again, at the molecular level, how CO_2 responds to long-wave radiation.

Using a modified box diagram or "bathtub" analogy students will account for the annual net production of CO_2 that is being released into the atmosphere on a global scale. Teachers then have the opportunity to introduce the Stabilization Wedges concept and game to their students. This optional activity provides students with ideas for how to stabilize Carbon emissions over the next 50 years; economic, social and ecological factors must all be considered.

Lastly, for an assessment the students will be required to reflect on the big question - What's the "matter" with carbon? and various sub-questions through a written project.

The Story of Adrienne Checkpoint:

This capstone lesson provides Adrienne and her classmates a chance to explicitly tie together their ideas about scale developed in Lessons 2 & 3 with the measurements and observations they have been making in the intervening lessons. By applying scale in this way, this lesson focused on carbon issues at a global scale, can also provide a springboard to any number of other units you may wish to pursue.

For Adrienne, who has only recently begun to use the idea that various forms of matter are sources of matter for growing plants (rather than the plant somehow just making this mass during photosynthesis), it is important to stretch this idea into a couple of new applications. This lesson asks her to continue to think discretely about movements of carbon and its consequences on a global scale. Following carbon from plants into other organisms, and then into still more organisms or back to the atmosphere in respired CO_2 will help her to see that there are numerous ways in which carbon moves through the environment. With some additional scaffolding from you, she should also be able to conclude that these movements have consequences for the amounts and masses of materials in these various ecosystem parts.

Materials

- Class Powers of 10 class poster or PowerPoint slide
- Item images, magnets or paper
- PowerPoint slides of: landscape image of carbon containing items, the Carbon cycle, and the Greenhouse effect
- Activity 11 PowerPoint - Atmospheric Carbon process tool
- Stabilization wedges game: http://cmi.princeton.edu/wedges/game.php
- 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 poster.
- Make item cards to include on poster. You can print images to affix on magnets 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 greenhouse effect simulation, Activity 11 PowerPoint and Stabilization Wedges game and website.
- Prepare materials for game: Activity board and wedges

Procedures

1. Introductory discussions:

   What's the "matter" with carbon? ~ 5 minutes

   a. Introduce that this lesson will tie together information from the previous lessons, challenging students to expand their understanding of carbon specifically out to the global scale. Students will culminate the unit by reflecting on the big question - What's the "matter" with carbon? and various sub-questions through a written project.

Carbon and the four benchmark scales ~20 minutes

a. Ask the students to generate a list of as many carbon containing items as they can from viewing the projected slide or overhead image of a landscape scene. The possibilities are many, but hopefully you can find a picture with fairly obvious carbon items. Students should compile their list and complete the table on the *What's the "matter" with carbon?* worksheet. The teacher can also use the large Powers of 10 poster and either blank magnetic pieces or post-it notes, have students assign one of their objects to its appropriate scale on the classroom poster.

2. The Carbon cycle: 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 and in PowerPoint).

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 CO_2; 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. Ask the students: are all of the transitions in a given example actually possible? Have we unsuccessfully conserved matter at any point? Watch out for common mistakes, such as moving carbon from decomposing organisms into the soil, and from there into plants via uptake by roots. Remember that students tend to neglect the role of gaseous forms of carbon.

c. Ask students what the blank, un-named arrows represent (burning, cellular respiration, and photosynthesis). Then a brief introduction to next slide can occur using these arrows. Ask students what it would mean if the two arrows entering the atmosphere added up to more carbon than the arrow with the carbon leaving the atmosphere, and vice versa. Adding the amount of carbon from burning and cellular respiration and subtracting the carbon from photosynthesis will give the net flux. If this number is positive, then there is more carbon from the two arrows entering the atmosphere than the arrow exiting it, so there is more carbon entering the atmosphere than leaving it. If this number is negative, then there is more carbon from the arrow exiting the atmosphere than the two entering it, so there is more carbon leaving the atmosphere than entering it. This can lead to a deeper understanding of the relations between the processes that release carbon into the atmosphere and the processes that take carbon out of the atmosphere back to earth and will be built upon later in this lesson.

3. CO_2 is a Greenhouse gas ~20 minutes

Background information: The most abundant gases in the atmosphere—nitrogen, oxygen, and argon—neither absorb nor emit infrared radiation (heat). Clouds, water vapor, and some relatively rare greenhouse gases such as carbon dioxide, methane, and nitrous oxide in the atmosphere can absorb and re-emit radiation. Greenhouse gases in the atmosphere will radiate heat energy both to space and back towards Earth. This back-radiation (to Earth) warms the planet's surface.

The greenhouse effect is important. Without the greenhouse effect, the Earth would not be warm enough for humans to live. However, as the greenhouse effect becomes stronger, it will make the Earth warmer than usual. Even a little extra warming causes problems for humans, plants, and animals.

a. For this part of the lesson you can choose whether to do a class demonstration or allow the students to work through the online simulation demonstrating how "normal" air warms compared to air that has an increased concentration of CO_2. Depending on the availability of computers you may choose to have your students perform this lab independently. *The greenhouse effect diagram (below and in PowerPoint) would be useful as a static reference if you wish to save time or to wrap up your discussion of the online simulation*.

For static reference:

What do the arrows in the solar radiation model represent?

-Arrows represent the amount of solar radiation that comes from the sun and hits the earth, then is either (1) reflected by the earth back into space; or (2) absorbed by the earth by passing through the clear atmosphere. The amount that is reflected by the earth can then (a) pass through the clear atmosphere into space again, or (b) be reflected again by greenhouse gas molecules.

b. Navigate to (or direct your students to) the following link: http://phet.colorado.edu/en/simulation/greenhouse Clicking on the "Run Now" button will open a window (Java needs to be installed) with the simulation. Begin with the "Photon Absorption" page, which models how various molecules absorb (or don't) both infrared and visible radiation. When you fire infrared through the molecules of greenhouse gases (CH_4, CO_2 and H_2O), some of the photons are absorbed and then reemitted in random directions. Other gas molecules (N_2, O_2) don't absorb any infrared, nor do any molecules absorb visible light if you switch to that. Students can also build their own "atmospheres" and see the effect of different combinations of gases on the retention of infrared in the system. Remind your students that this simple simulation reflects the physical realities of how these molecules interact with radiation of different wavelengths, and that the bouncing around of infrared photons is at the heart of the greenhouse effect.

c. After your students have gotten the point of the photon page, switch tabs to the "Greenhouse Effect," where you can directly change the overall concentrations of greenhouse gases using the slider, and watch the effect on the average global temperature over some time. You can also add clouds to the picture, which will further increase heat retention in the atmosphere. Make sure your students realize that although the individual gas molecules are not seen in this larger model of the atmosphere, it is because of their presence that infrared radiation (heat) is held inside the atmosphere. This can be seen in the way that some photons "bounce" back towards the earth.

4. CO_2 "Process tool", or CO_2 box diagram 20 minutes + 50 minutes (optional)

a. For this part of the lesson you will go through the PowerPoint (Activity 11 - Carbon "Process tool") to introduce and explain global carbon emissions and resulting concentrations (ppm) over the next 50 years. The point to make is that in order to hold carbon dioxide levels steady in the atmosphere, human emissions of carbon need to be reduced to the levels that natural systems can take up each year, and no more. Currently we are above those levels, and as a result, CO_2 concentration continues to climb. Students will work through a net flux problem on their handout.

b. Have students play the Stabilization Wedges game as described, for example, here: http://cmi.princeton.edu/wedges/pdfs/teachers_guide.pdf The Stabilization Wedges game is an innovative activity that puts the students in the shoes of citizens and policy makers deciding how our society should best act to reduce emissions in time to prevent as many harmful effects of climate change as possible. Developed by researchers at Princeton University, the game asks students to decide which "wedges" of policy they would implement in order to first slow, and potentially decrease the amount of carbon emitted on an annual basis by human society. *If you choose not to do the game, you could also have a discussion around some of the wedge ideas without actually playing the game, focusing on why each choice would act to change carbon balances* (see PowerPoint and questions below).

i. What happened to the amount of carbon emissions between 1950 and 2000?
   -The amount of carbon emission increased from 1.6 billion tons of carbon to about 8 billion tons of carbon.
ii. What does the vertical yellow dotted line represent?
   -It represents the year 2010.
iii. How and why was the dashed line named current path="ramp" created?
   -Students need to look at the rate of change between 1950 and 2010. Assuming that the increase in the amount of carbon remains constant, they can then give a prediction for the next 50 years.
   Rate from 1950−2010 $= \dfrac{\text{8 billion tons} - \text{1.6 billion tons}}{\text{50 years}} = \dfrac{\text{6.4 billion tons}}{\text{50 years}}$
   So the rate of change can be interpreted as 6.4 billion tons of CO_2 being added every 50 years.
iv. How and why was the orange line at 2010 created?
   -This line represents a rate of no change, meaning the graph becomes constant. It represent no increase in CO_2 concentrations, but not yet a decrease.
v. How can students relate the box diagram from earlier to this graph? How do gigatons relate to billions of tons?
   -They can compare the net flux they calculated on their handout to verify an increase of CO_2 in the atmosphere. One gigaton is one billion tons.
vi. What effect will increasing concentrations of carbon dioxide have on the earth's average temperature? How does CO_2 cause that effect?

5. Final Assessment: ask the students to address the first question – What's the "matter" with carbon and at least two of the additional questions and present it in a genre of their choice (brochure, PowerPoint slide, newspaper column, rap, etc). Students should be provided with a rubric that corresponds with the four levels on the carbon learning progression. (See Appendix A for sample rubric)

1. What's the "matter" with carbon? **Carbon in its basic atomic form…**
2. Why is carbon so important? **Common in all forms of life...**
3. What do we hear about carbon on the news? **May come up in reference to greenhouse gases (CO_2, CH_4, CFCs), carbon offsets or carbon footprints**
4. Why do scientists talk about carbon? **Tracing carbon through ecosystems is essential to tracing the flow of material as a whole**
5. What does the term carbon footprint mean? **Refers to the total greenhouse gas effect that a lifestyle or individual decision has**
6. What is your carbon footprint and what are ways you are willing to reduce it?

Optional review activities for this unit:

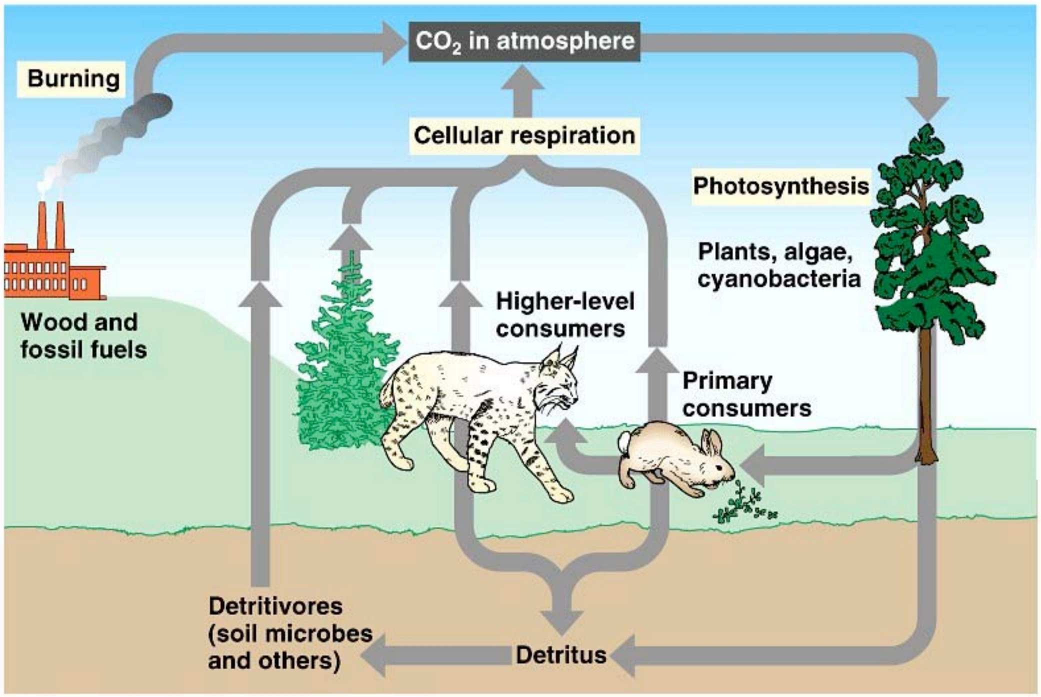
1. The Powers of 10 *(if not already discussed in lessons 2-4) **~15 minutes**
    a. What does the word “scale” mean to you? (try to cue students to move beyond measuring scales, such as weight scales).
    b. Using the responses of your students, guide the discussion to the following possible definitions.

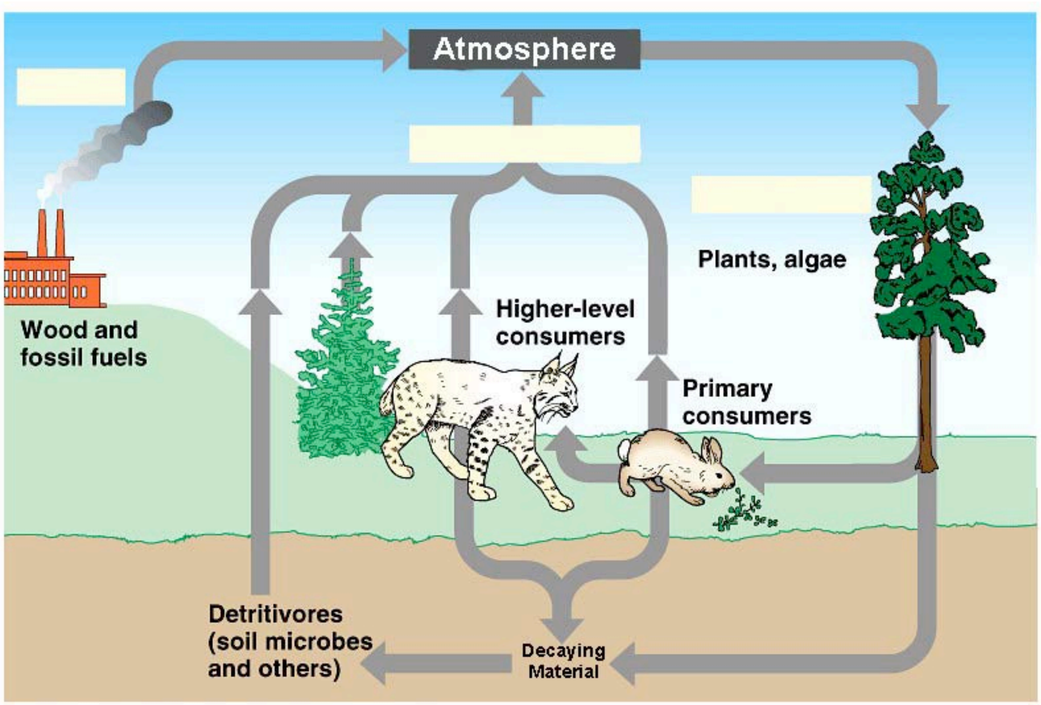
        Possible definitions

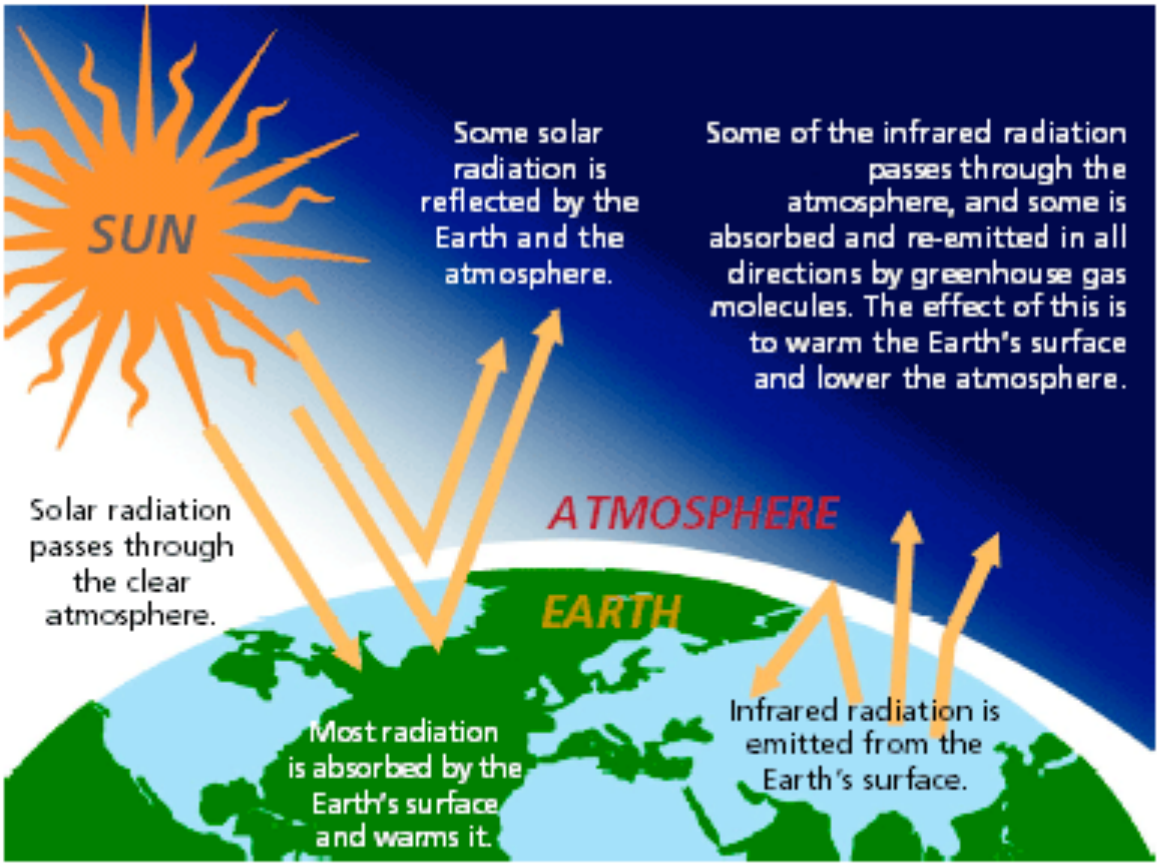
        i. Scale: the size or range of measurement used for describing a particular system. You can use scale and measurement to compare the relative sizes of systems.
        ii. Atomic-Molecular (list a few examples)- these are things we can not see with our eyes or microscopes
        iii. Microscopic (list 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.

2. 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)

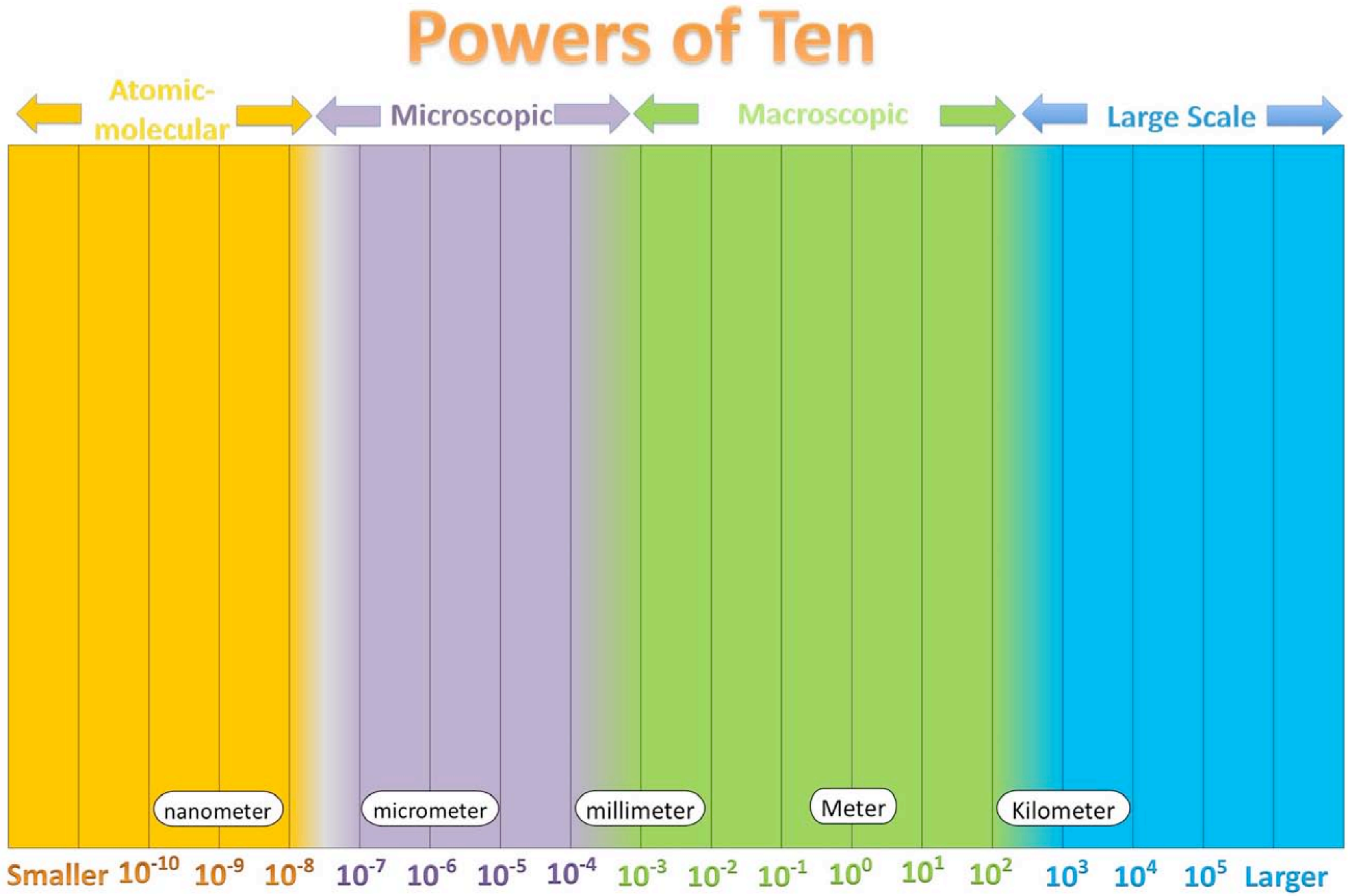




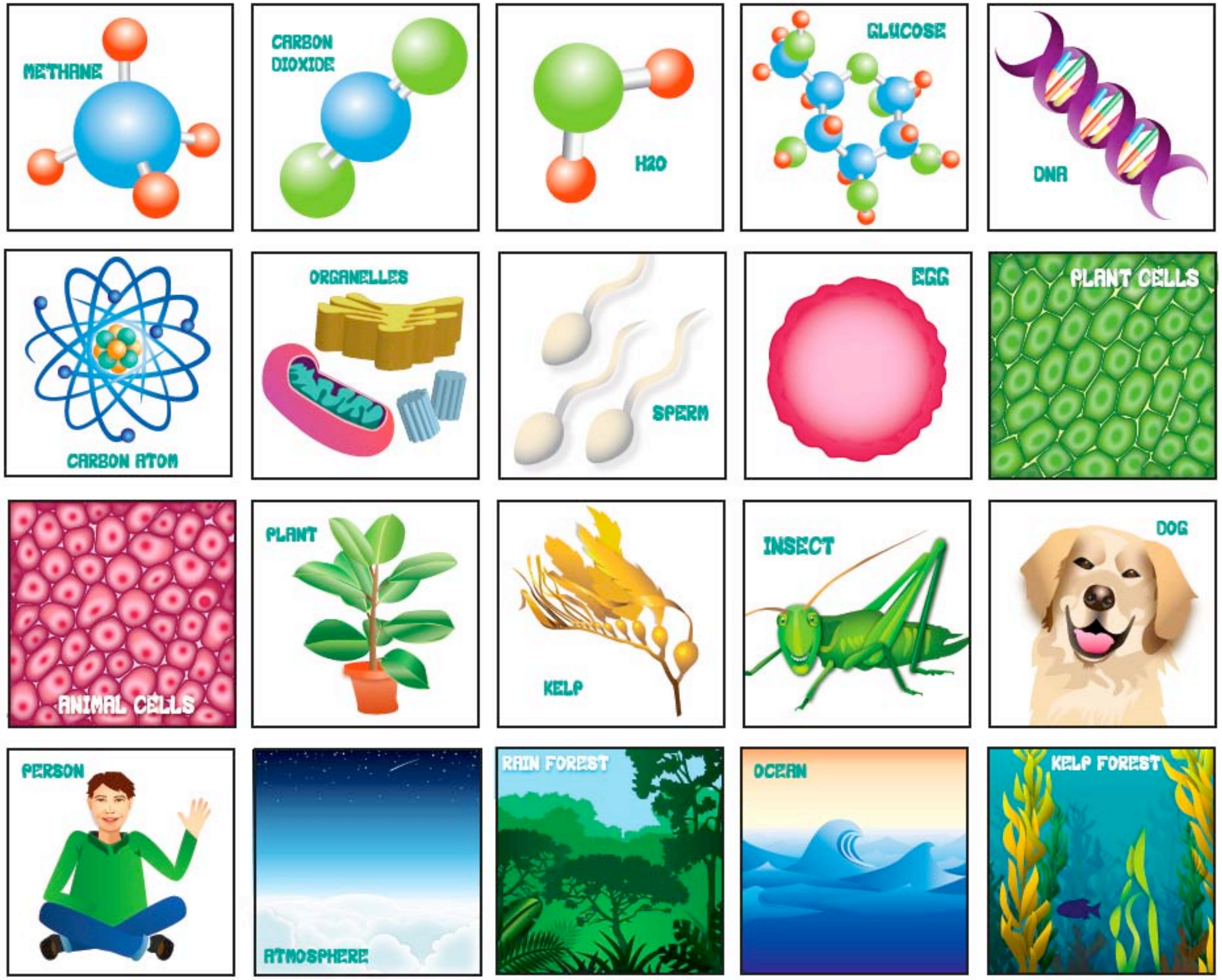


SUN
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and lower the atmosphere.
Solar radiation passes through the clear atmosphere.
ATMOSPHERE
EARTH
Most radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

Example Board



Example Item Cards



Name: ______________________________ Period: _______ Date: _______________

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

1. Using the diagram your teacher projected, identify objects that contain carbon (at least two for each of the benchmark scales).

Atomic Molecular	Microscopic	Macroscopic	Landscape or Global

2. Using the carbon cycle diagram your teacher projected, describe two possible routes that a carbon atom could take through the ecosystem:

1st Location	Process →	2nd Location	Process →	3rd Location
CO_2 in atmosphere	**photosynthesis**	**glucose in pine tree**	**burning**	**CO2 in atmosphere**
glucose in decomposer organism	**biosynthesis**	**chitin in decomposer**	**death**	**chitin in decaying material**

many other routes possible

Atmosphere Box Model:

3. What is the net flux presented in the box model?

U $_{\text{Amount of CO2 going into atmosphere}}$ = 121 gt/yr + 7 gt/yr + 90 gt/yr = 218 gt/yr

D $_{\text{Amount of CO2 coming from atmosphere}}$ = 122 gt/yr + 92 gt/yr = 214 gt/yr

Net Flux = U – D = 4 gt/yr

Thus, the amount of carbon being release into the atmosphere exceeds the amount coming back from the atmosphere.

Stabilization Wedges:

4. What happened to the amount of carbon emissions between 1950 and 2000?

-The amount of carbon emission increased from 1.6 billion tons of carbon to about 8 billion tons of carbon.

5. What does the vertical yellow dotted line represent?

-It represents the year 2010.

6. How and why was the dashed line named current path=”ramp” created?

-Students need to look at the rate of change between 1950 and 2010. Assuming that the increase in the amount of carbon remains constant, they can then give a prediction for the next 50 years.

Rate from 1950−2010 = $\dfrac{\textit{8 billion tons} - \textit{1.6 billion tons}}{\textit{50 years}} = \dfrac{\textit{6.4 billion tons}}{\textit{50 years}}$

So the rate of change can be interpreted as 6.4 billion tons of CO_2 being added every 50 years.

7. How and why was the orange line at 2010 created?

-This line represents a rate of no change, meaning the graph becomes constant. It represent no increase in CO_2 concentrations, but not yet a decrease.

8. What effect will increasing concentrations of carbon dioxide have on the earth’s average temperature? How does CO_2 cause that effect?

In general, more CO2 in the atmosphere will lead to higher average temperatures on earth, due to the absorption and re-emittance of heat caused by carbon dioxide molecules in the atmosphere.

Unit Assessment: Pick two or more of these questions and respond to them using everything you have learned 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’s 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

General Learning Progressions

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 following have been identified as the Learning Progression levels of achievement for accounts (explanations and predictions:

Level 4: Coherent scientific accounts: Students successfully apply fundamental principles such as conservation of matter and energy and genetic continuity to phenomena at multiple scales in space and time (generally consistent with current national science education standards and with the draft framework for new standards).

Level 3: Incomplete or confused scientific accounts: Students show awareness of important scientific principles and of models at smaller and larger scales, but they have difficulty connecting accounts at different scales and applying principles consistently.

Level 2: Elaborated force-dynamic accounts: Students' accounts continue to focus on actors, enablers, and natural tendencies of inanimate materials, but they add detail and complexity, especially at larger and smaller scales.

Level 1: Simple force-dynamic accounts: focus on actors, enablers, and natural tendencies of inanimate materials, using relatively short time frames and macroscopic scale phenomena.

Carbon Learning Progressions

While researching Carbon similar patterns emerge. The figures below illustrate what 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.

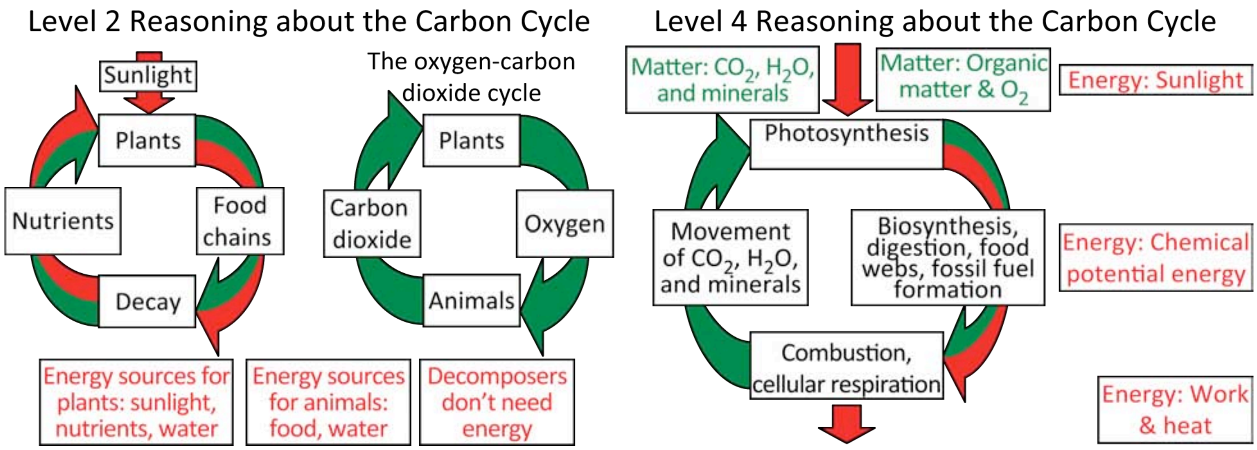


Figure 1: Comparing typical student understanding and scientific understanding of the carbon cycle

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.

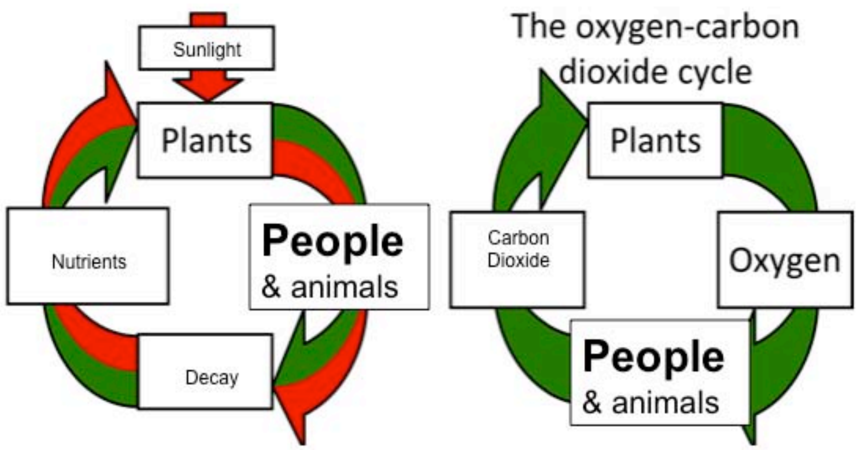


Figure 2: A better representation of most students' understanding

Figure 2 shows that it might be better to ***think*** of students as speaking a different "language" (what educational researchers call a *discourse)* from scientists. 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

<table>
<tr><td rowspan="2">Level 4 general categories</td><td colspan="4">Matter</td><td rowspan="2">Energy: Heat, chemical, etc.</td><td rowspan="2">Conditions: Temperature, care, etc.</td></tr>
<tr><td colspan="2">Organic matter (including organic gases)</td><td colspan="2">Inorganic matter (including inorganic gases)</td></tr>
<tr><td>Linking states</td><td colspan="3">Solids and liquids</td><td>Gases</td><td colspan="2">Not matter</td></tr>
<tr><td>Linking material kinds</td><td>Plants, animals</td><td>Dead plants and animals</td><td>Water, soil</td><td>Air</td><td>Light, heat</td><td>Temperature, care</td></tr>
<tr><td>Level 1 general categories</td><td>Living things</td><td colspan="2">Dead and inanimate things</td><td colspan="3">Insubstantial kinds: gases, conditions, energy</td></tr>
</table>

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 I 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.[5] 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.

[5] 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.

- 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 a sort of 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."

Appendix B. Activity Summaries

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 CO_2 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 sponges and wet and dry soil. 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 CO_2 concentration and changes in mass for three processes: baking powder in water, candle burning, and person breathing. They will see that, like water, CO_2 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 CO_2?*

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 CO_2 concentration for the bean plants that they have been growing in the light and in the dark, observing that the plants absorb CO_2 in the light and emit CO_2 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.

Appendix C. Photos of Experimental Design

Lesson 1: Planting Seeds

Fig. 1. Illustrating the placement of wicking material through slit in bottom of tin growing cup, and arrangement of multiple growing cups on a cookie sheet to facilitate watering.

Lesson 7: Plant Gas Exchange Measurements

Fig. 2. Illustrating measurement of CO_2 and O_2 (optional) concentrations in both light and dark conditions. These measurements were taken in a 2000-mL biochamber available from Vernier Instruments, but could be taken in any reasonably airtight container large enough to hold a number of photosynthesizing plants.

Lesson 9: Drying and Separating Plant Biomass

Fig. 3. Separating the plant biomass from the growing medium (vermiculite), using a flexible plastic cutting board as a work surface.

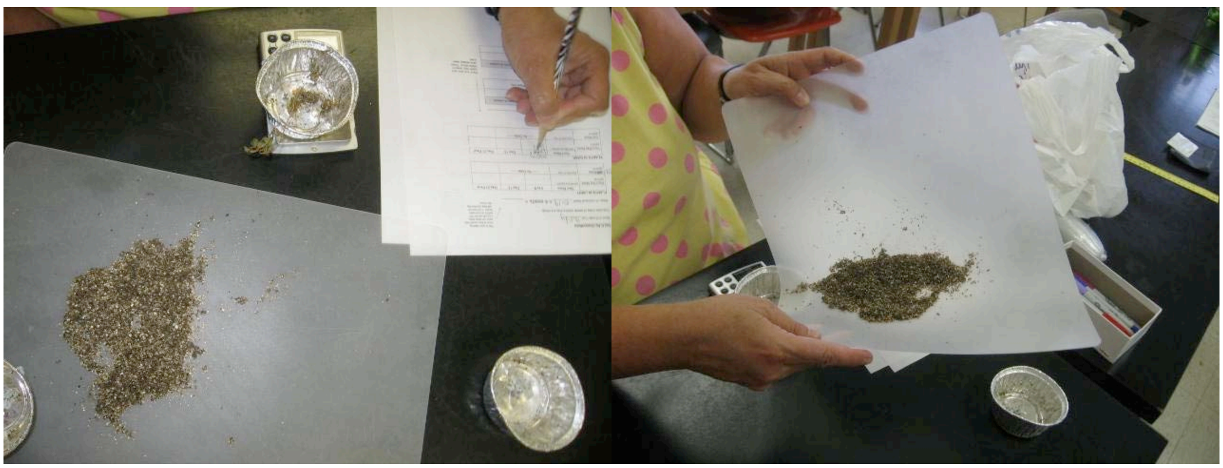
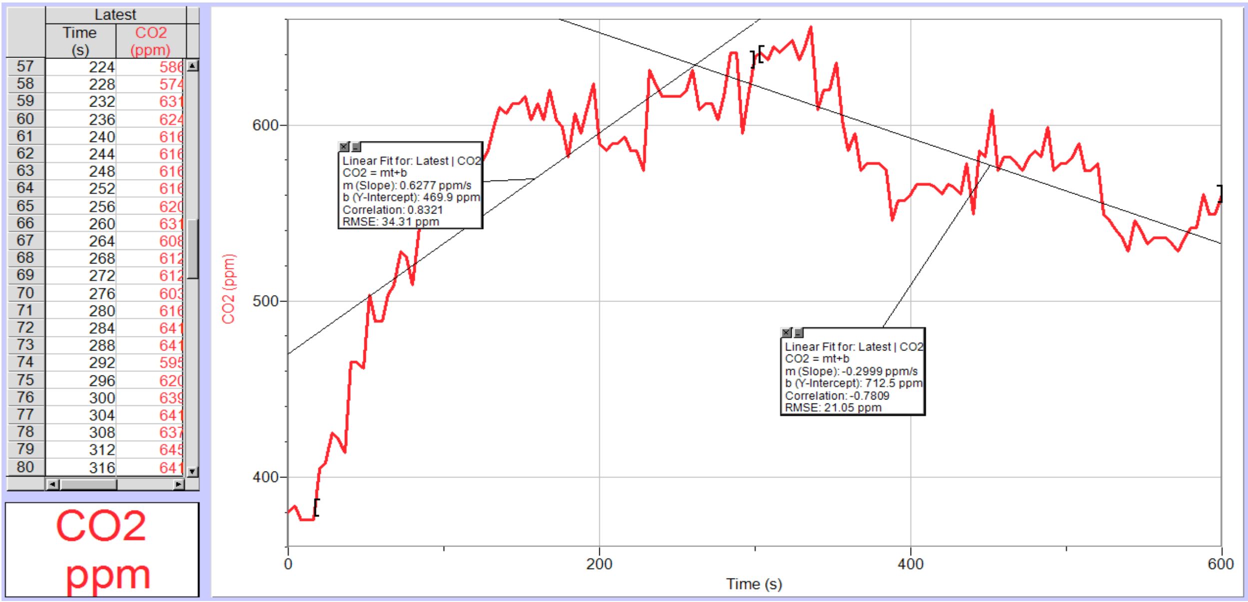


Fig. 4. Weighing the plant biomass (left) and vermiculite (right) separately upon completion of sorting.

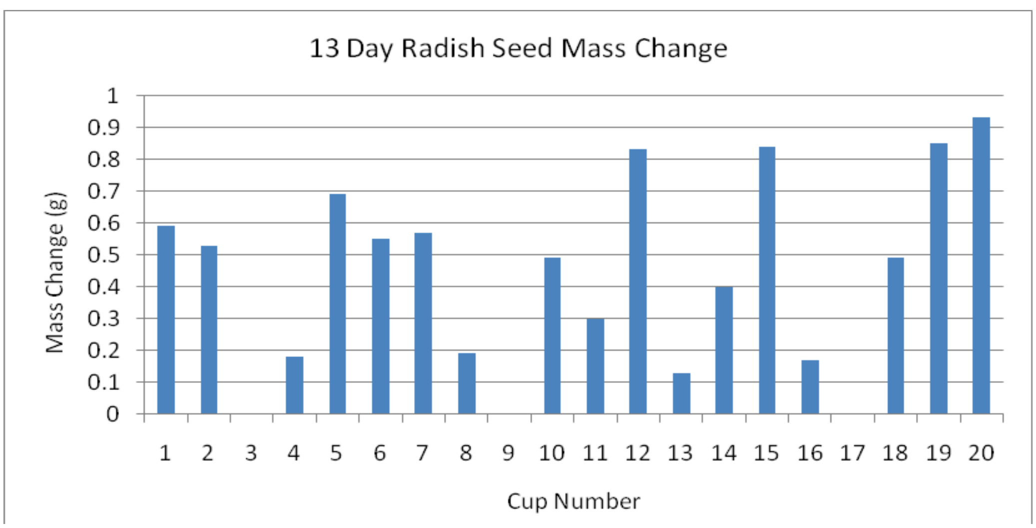
Appendix D. Sample Data Sets for Gas Exchange & Growth

Sample output from Vernier Data Logger (Lesson 7)

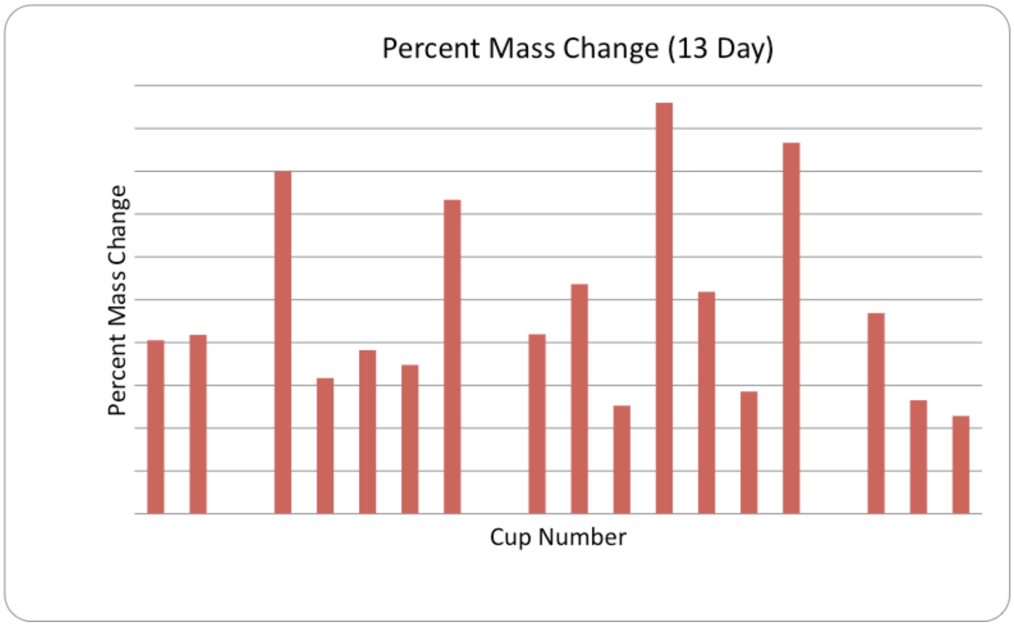


The first 200 seconds or so of this trial were recorded with radish plants in the dark, after which the cover was removed and they were again exposed to light, allowing them to photosynthesize. Notice the lag time before a distinct uptake of CO_2 by the plants began; it takes a while for the photosynthesizing cells to begin utilizing the incoming light.

Sample radish growth data (dried after 13 days)



This chart details the absolute mass increase for plants from a number of sampled cups. Cups 3, 9, & 17 had no surviving plants to measure after 13 days.



This chart presents the same data, but expressed as a percentage change from the original mass of the planted radish seeds.

Cup #	7/29 seed mass (g)	7/29 vermiculate mass (g)	8/10 seed mass (g)	8/10 vermiculate mass (g)	Seed-Plant Biomass Change (g)	Number of Plants	Vermiculite Biomass Change (g)	Percent Change
Avg	**0.13**	**10.88**	**0.64**	**10.58**	**0.51**	**13.13**	**-0.3**	**24**
Median	**0.13**	**10.725**	**0.67**	**10.51**	**0.53**	**13**	**-0.2**	**21**
1	0.15	10.37	0.74	10.06	0.59	14	-0.31	20
2	0.14	11.1	0.67	10.9	0.53	14	-0.2	21
3	0.12	10.2						
4	0.12	11.71	0.3	9.88	0.18	13	-1.83	40
5	0.13	10.31	0.82	9.87	0.69	12	-0.44	16
6	0.13	13.01	0.68	12.61	0.55	13	-0.4	19
7	0.12	13.18	0.69	12.85	0.57	13	-0.33	17
8	0.11	10.76	0.3	10.9	0.19	14	0.14	37
9	0.12	11.74						
10	0.13	11.15	0.62	11.02	0.49	15	-0.13	21
11	0.11	12.31	0.41	12.42	0.3		0.11	27
12	0.12	9.14	0.95	8.5	0.83	13	-0.64	13
13	0.12	10.7	0.25	10.93	0.13	13	0.23	48
14	0.14	11.49	0.54	11.55	0.4		0.06	26
15	0.14	9.31	0.98	8.79	0.84	14	-0.52	14
16	0.13	10.14	0.3	10.1	0.17	9	-0.04	43
17	0.14	10.75						
18	0.15	10.12	0.64	10.1	0.49	13	-0.02	23
19	0.13	10.6	0.98	10.51	0.85	13	-0.09	13
20	0.12	9.45	1.05	8.94	0.93	14	-0.51	11

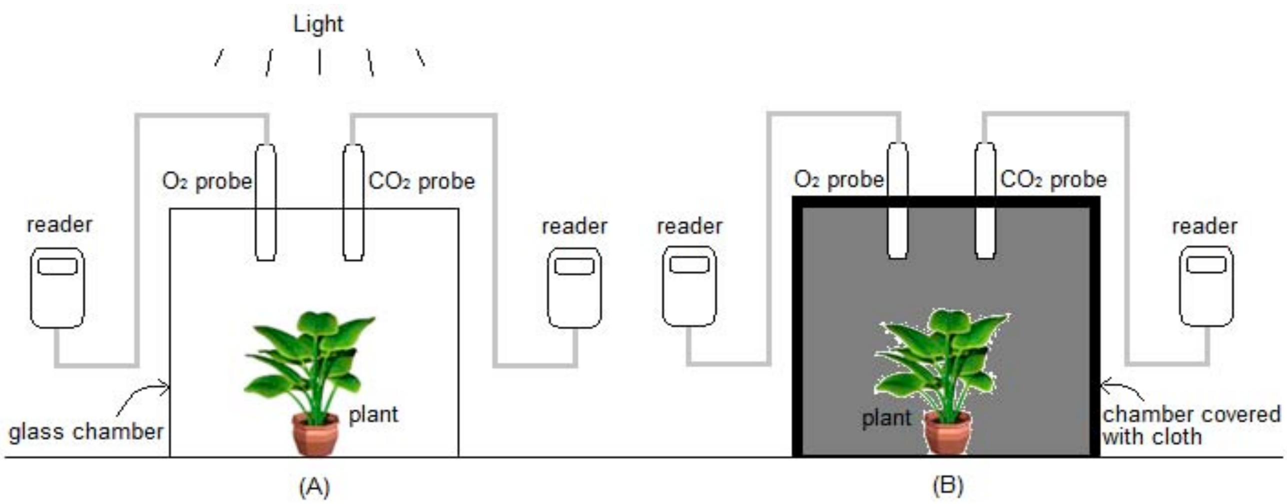
Raw data for the two graphs referenced above.

Appendix E. Alternative Data Sheet for Gas Exchange Lesson (#7)

Name: ________________________________Period: ______ Date: ____________

Gas exchange in plants

In this activity, we will use probes to study how plants affect CO_2 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 O_2 and CO_2 in each chamber?

	In the light	In the dark
The amount of CO_2 will…	☐ increase ☐ be the same ☐ decrease	☐ increase ☐ be the same ☐ decrease
The amount of O_2 will…	☐ increase ☐ be the same ☐ decrease	☐ increase ☐ be the same ☐ decrease

Record Data in the table below:

	In the light			In the dark	
Time (seconds)	Level of CO_2 in the chamber	Level of O_2 in the chamber	Time (seconds)	Level of CO_2 in the chamber	Level of O_2 in the chamber

Appendix F. National Science Content Standards

Unifying concepts and processes in science.

- M.U.1. Systems, order, and organization, 2. Evidence, models, and explanation, 3. Change, constancy, and measurement
- H.U.1. Systems, order, and organization, 2. Evidence, models, and explanation, 3. Change, constancy, and measurement

Science as inquiry.

- M.A.1. Abilities necessary to do scientific inquiry, 2. Understandings about scientific inquiry
- H.A.1. Abilities necessary to do scientific inquiry, 2. Understandings about scientific inquiry

Physical science.

- M.B.1. Properties and changes of properties in matter
- H.B.2. Structure and properties of matter, 3. Chemical reactions, 5. Conservation of energy and increase in disorder

Life science.

- M.C.1. Structure and function in living systems, 4. Populations and ecosystems
- H.C.1. The cell, 4. Interdependence of organisms, 5. Matter, energy, and organization in living system

Science in personal and social perspectives.

- M.F.5. Science and technology in society
- H.F.6. Science and technology in local, national and global challenges