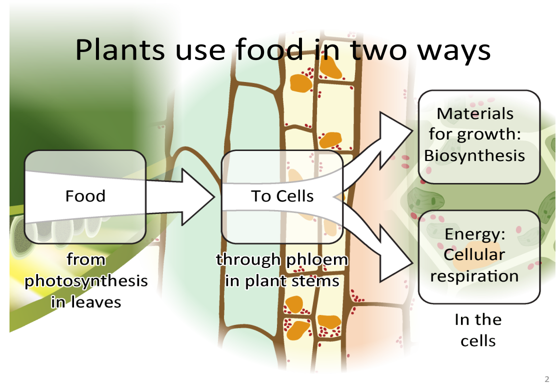
Student Challenges and Teacher Choices in the Plants Unit

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



Observations and Patterns: Students investigate plants growing and gas exchange in the light and dark. Key patterns in their observations:

- **When plants grow, they gain more dry mass than the soil loses.**
- Plants absorb CO_2 in the light.
- Plants emit CO_2 in the dark.

Models (and Explanations): Students explain Photosynthesis, Biosynthesis, and Cellular Respiration by connecting macroscopic and atomic-molecular scales, and by answering the Three Questions:

- Matter Movement: The dry materials that plants are made of come mostly from CO_2 entering through leaves. Only a small portion of the dry materials in plants come from water and minerals from the soil.
- Matter and Energy Change:
  - **Plant cells get the materials they need to grow and divide through photosynthesis and biosynthesis.**
  - Plant cells get the energy they need to move and function through photosynthesis and cellular respiration.

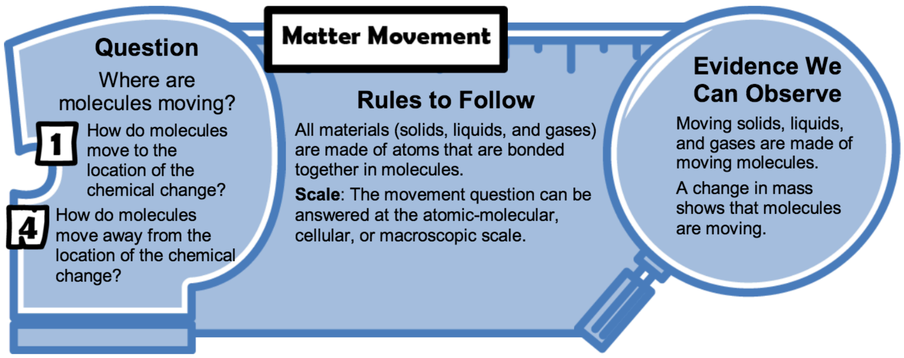
The key findings from the *Plants Unit* investigations and the key points that students need to include in explanations are summarized in the table above from the *Carbon TIME* Instructional Model. The two ideas in bold are especially difficult for students in this particular unit. For each of these difficult points, the pilot version of the *Plants Unit* includes different approaches that teachers need to choose among. This working paper aims to explain the challenges, and then discuss the advantages and disadvantages of the different choices.

Investigation Challenge: Measuring Changes in Dry Mass

Core idea: Using mass changes to answer the Matter Movement Question

We want students to measure mass changes and to recognize that they can use these measurements to answer the Matter Movement Question in the Evidence-Based Arguments (EBA) Tool, with the support of the Three Questions. Here's the relevant row in the tool and the associated Three Questions prompt:

	Class Evidence What patterns did we find in our class evidence about each of the Three Questions?	Conclusions What can we conclude about each of the Three Questions using this evidence?	Unanswered Questions What do we still need to know in order to answer each of the Three Questions?
The Matter Movement Question			



The EBA tool 'Class Evidence' column is especially important and especially difficult for some students. Students reasoning at learning progression Level 2 have trouble understanding how mass changes provide evidence for movement of atoms. These students know, for example, that children have to eat in order to grow, but they think of growth as an action that food enables rather than believing that "you are what you eat"—that the additional matter in our bodies *must* have come into our bodies from somewhere. They lack a *sense of necessity* about conservation of mass. So this is the really important core idea that students need from the investigation: Plants gain more dry mass than the soil (or paper towel, or plant gel) loses, so the atoms in the plant *must* have come from somewhere other than the soil.

The challenge: Plants are mostly water

Our measurements show that growing radish plants are about 93% water. The materials we use to grown plants, including the plant gel crystals (98.6%) and the brown paper towel can absorb a lot of water. Dry soil can absorb more than its weight in water. So if we try to answer the Matter Movement Question just measuring the mass of plants and soil, we will mostly measure the movement of water. We really want to know about the movement of carbon atoms, and for those purposes we will have to measure changes in *dry mass.*

This is a challenge because all of the materials involved in the plant investigations—the plants themselves, the seeds, the substrate, and the water with fertilizer—are *mixtures* of water and solid materials. So measuring changes in dry mass requires measuring or estimating the amount of dry mass in those mixtures. However we do this, it will be challenging to students for several reasons:

- Understanding the nature of mixtures and the logic of the investigation: students reasoning at Level 2, in particular, may have trouble thinking of "solid" materials like plants and plant gel crystals as mostly water and understanding why and how we want to measure the solids in the mixtures but not the water.
- Complicated procedures: It will be easy for students to take a "cookbook" approach to measuring and calculating through multi-step procedures without keeping track of why they are taking the steps that they are taking.
- Difficulties with measurement and calculations: Students will need to measure and calculate to 0.01 gram accuracy and use percentages to calculate dry mass.

- False precision and “too small to measure:” Radish seeds and the solids in fertilizer mixtures turn out to have tiny masses—less that 0.01 grams. Here are a couple of ways to deal with these tiny amounts for the dry mass of a seed planted with one of the protocol options (Gel protocol - plant gel crystals hydrated with water and Ionic Grow fertilizer):

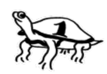
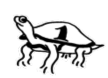
Bad science (false precision)	**Good science (recognizing limits of precision)**
0.24 g (dry mass of crystals) + 0.007 g (dry mass of radish seed) + <u>0.0001 g</u> (dry mass of ionic grow) 0.2471 g (total dry mass in test tube)	0.24 g (dry mass of crystals) + too small to measure (dry mass of radish seed) + <u>too small to measure</u> (dry mass of ionic grow) 0.24 g (total dry mass in test tube)

Even though the scales show 0.01 g precision, they aren’t really that accurate, so the best way to deal with masses less than 0.01 g is to treat them as 0: too small to measure

Choices for responding to the challenge

There is a new reading, Estimating the Mass of Solids Mixed with Water that we recommend for all students. The concepts are reinforced in the “Measuring Plant Growth” video embedded within the curriculum. *The new version of the Plants Unit includes two different protocols with different approaches to measuring the dry mass of these mixtures.* These strands correspond with the *Carbon TIME* Turtle Trails designations. The **1 Turtle Trail** approach contains procedures and learning goals appropriate for all students. The **2 Turtle Trail** approach considers calculations of dry mass in more detail and is appropriate for more advanced middle school or high school students. The two choices are as follows (note that while recommendations are provided, choices should be made by districts and/or teachers):

Pre-Lesson (1-2 hr)	**Gel Protocol** 0.1GL: Keeping Track of Water in Solids and Liquids (60 min + overnight or several days) **AND** 0.2GL: Plant Growth Investigation Setup (45-60 min over one or two days) **OR** **Paper Towel Protocol** 0.2PT: Plant Growth Investigation Setup	 	*When to plant radish seeds:* Students should plant their radish seeds before beginning the *Plants* Unit so that plants will grow big enough for the Lesson 3 investigations. Allow at least 2-4 weeks from the Pre-Lesson to Lesson 3, depending on which Turtle Trail you choose. *How to plant radish seeds:* Decide whether to follow a paper towel (PT or 1-Turtle Trail) a plant-growing gel protocol (GL or 2-Turtle Trail). Both versions give students the invaluable experience of watching plants grow, then analyzing plant gas exchange and mass change data. The Gel Protocol is more complex and rigorous, and there are more things that can go wrong. Two other differences include **growing materials** (paper towel vs. gel) and **time** (the gel protocol has two additional activities; some 2-Turtle activities may take longer, and the plants will need longer to grow).
1 (50 min)	For the 1-Turtle Trail, wait at least one week after planting radishes before beginning Lesson 1. For the 2-Turtle Trail, wait at least three weeks after planting radishes before beginning Lesson 1.		
2 (2 hr 5 min)			
3 (2 hr 40 min)	3.1 Predictions and Planning about Radish Plants Growing (50 min) **Gel Protocol** 3.2GL: Observing Plants' Mass Changes, Part 1 (30 min)		To be ready, your plants should have at least two sets of leaves open and well developed (two cotyledons and two true leaves).

	OR **Paper Towel Protocol** 3.2PT: Observing Plants' Mass Changes, Part 1 (30 min)	 	• If plants are ready, you can begin with the Mass Change investigation. While plants are drying, use extra radish plants (or another leafy plant such as a houseplant) for the light and dark investigation. • If plants are not ready, we recommend using another leafy plant such as a houseplant for the Light/Dark investigation, giving your plants a little more time to grow. This will mean teaching the two Mass Change Activities (3.2 & 3.4) consecutively, but you will need **<u>time</u>** in between them for plants to dry! In this case, we recommend that you (a) partially complete the Evidence-Based Arguments tool after the Light/Dark investigation in Activity 3.3, (b) harvest the radish plants in Activity 3.2, (c) move on to Lesson 4 to teach Cellular Respiration and Photosynthesis, and (d) return to complete Activities 3.4 and 3.5 after plants have dried.
	3.3: Observing Plants in the Light and Dark (60 min)		
	Gel Protocol 3.4GL: Observing Plants' Mass Changes, Part 2 (45 min) **OR**		
	Paper Towel Protocol 3.4PT: Observing Plants' Mass Changes, Part 2 (45 min)		
	3.5: Evidence-Based Arguments about How Plants Grow (50 min)		

Choice 1: Paper Towel protocol (1 Turtle Trail). Students measure changes in dry mass of radish plants and (optional) paper towel. This is the least rigorous approach, but also the least time consuming and the approach that burdens students with the fewest procedural and mathematical details. This approach also requires the least amount of materials (disposable tins & paper towel), grows plants in bulk- making individual measurements less critical, and is adaptable to most classroom situations. This approach is appropriate for most middle school classes. This choice includes:

- Pre-Activity 0.2PT: Plant Growth Investigation Setup
- Activity 3.2PT: Observing Plants' Mass Changes, Part 1
- Activity 3.4PT: Observing Plants' Mass Changes, Part 2

The worksheets and PowerPoints for this choice guide students through all the steps in measuring the dry mass of bulk seeds and the resulting plants throughout the investigation.

Choice 2: Gel protocol (2 Turtle Trail). Students measure changes in the dry mass of individual radish plants, the clear gel substrate they are grown in, and (optional) the nutrient solution. This is the most rigorous approach, but also the most time consuming and the most challenging for students. Distinct advantages of this choice include: ability to track most inputs to and growth of individual plants, the ability to see the roots as the plants grow, more student engagement and 'ownership' of experiment plants. Disadvantages include more rigorous setup (test tubes and gel preparation) and more precise measurements/calculations. This choice includes:

- Pre-Activity 0.1GL: Keeping Track of Water in Solids and Liquids
- Pre-Activity 0.2GL: Plant Growth Investigation Setup
- Activity 3.2GL: Observing Plants' Mass Changes, Part 1
- Activity 3.4GL: Observing Plants' Mass Changes, Part 2

The worksheets and PowerPoints for this choice guide the students through all the steps in measuring and calculating the dry masses of seeds, plant gel, and the plants themselves throughout the investigation.

Pedagogical Challenge: Being Responsive to Students

Core idea: We want students to answer their own questions

Asking Questions is a Science and Engineering Practice, and it is important for students to have opportunities to answer their own questions. Without such opportunities, engaging in the practice of Asking Questions can feel inauthentic to students when they recognize that their teacher's instruction proceeds as planned without regard to the questions they posed. With such opportunities, students' curiosity about science can be nurtured, their enthusiasm for learning can increase, and their learning gains can improve.

In the *Plants* Unit, students are prompted to consider what questions are left unanswered after conducting the *Plants* investigations as they complete the EBA Tool in Activity 3.5. After discussing the EBA Tool, students begin answering these questions in Lessons 4 and 5 with the activities surrounding the carbon-transforming processes.

The challenge: Deciding on an order to teach the carbon-transforming processes

The challenge is that the order of the carbon-transforming processes in Lessons 4 and 5 may or may not adequately respond to your students' questioning, which may leave students missing the connections between their questions and the learning goals in Lessons 4 and 5. Designing instruction that is responsive to students' questions is nearly impossible for curriculum designers. Rather, you as the science teacher will need to use your professional judgement about which processes might make most sense to teach in which order. You will also need to use your professional expertise to guide students to understand how Lessons 4 and 5 are answering their unanswered questions from their EBA Tools.

Carbon TIME should serve as a tool kit rather than a script in your classroom. In addition to the curriculum, you will want to consider other variables when making decisions about instructional sequencing. You should consider what you know about your school and district, including standards, pacing expectations, and academic calendar. Perhaps more importantly, you should consider what you know about your students, including their cultural resources, academic levels, outside of school experiences, interests, and questions.

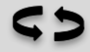
Choices for responding to the challenge

One way to teach the three processes is in the order they are presented in the curriculum, beginning with Cellular Respiration, then Photosynthesis, and finally Biosynthesis.

Another way to teach the three processes is according to what has worked well for you and your students in the past. If you feel more confident teaching Photosynthesis first, and your students have always done well learning Photosynthesis first, then this order may work best for you.

Another way to teach the three processes is according to the types of questions your students are asking over the course of their Plants investigations, and particularly during the EBA activity. We designed the following table in an attempt to help you think through this option.

Consider your students' questions on the EBA Tool: *What are they wondering?* Use their unanswered questions to guide instructional sequencing of the three carbon-transforming processes.
You and your students can choose whether to start with cellular respiration (Activities 4.1 and 4.2) or photosynthesis (Activities 4.3 and 4.4). You may choose the order presented in the curriculum, an order more familiar to you, or according to the types of questions students are asking. • If your students are asking *"Why do plants give off CO_2 in the dark?"* or *"How do plants move and function?"* then teach cellular respiration (Activities 4.1 and 4.2) first. • If your students are asking *"Why do plants absorb CO_2 in the light?"* or *"Where does the mass of the growing plants come from?"* then teach photosynthesis (Activities 4.3 and 4.4) first.

4 (1 hr 20 min)	4.1: Molecular Models For Potatoes Moving and Functioning: Cellular Respiration (40 min)		The molecular modeling part of Activity 4.1 is the same as the molecular modeling for cellular respiration in the *Plants* and *Decomposers Units*. **Do not repeat unless for review.**
	4.2: Explaining How Plants Move and Function: Cellular Respiration (40 min)		There are multiple scaffolds you can choose from to use with Activity 4.2 including the cellular respiration PPT, the Three Questions Checklist, example explanations, and a reading. Choose options that fit for your class at this time.
	4.3: Molecular Models for Potatoes Making Food: Photosynthesis (60 min)		
	4.4: Explaining How Plants Make Food: Photosynthesis (40 min)		In Activity 4.4, you can choose from among similar scaffolding tools as those listed for Activity 4.2
5 (2 hr)	5.1: Tracing the Process of Plants Growing: Biosynthesis (40 min)		
	5.2: Molecular Models For Plants Growing: Biosynthesis (40 min)	 	Activity 5.2 is exactly the same as molecular modeling for biosynthesis in the *Plants* and *Decomposers Units*. It's also a 2-turtle activity. **Consider skipping 5.2 if you've already taught it in another unit or if it's too advanced for your class.**
	5.3: Explaining How Plants Grow: Biosynthesis (40 min)		In Activity 5.3, you can choose from among similar scaffolding tools as those listed for Activity 4.2

Keeping the Main Goals in Mind

As you decide which choices are right for your class, keep in mind that *all* the choices are designed to help students master the core ideas. You can decide how much detail you want to include in your teaching based on the academic level of your students and the time you have available.