by Stephen Thompson and Christine Lotter

CONSERVATION OF MATTER IN THE LIFE SCIENCES

Teaching the law of conservation of matter within a life-sciences context can be a challenge. Most common activities that demonstrate conservation of matter involve physical change (think sugar dissolved in water) or chemical-reaction labs presented in a physical-science context (think the baking soda and vinegar reaction). While such activities elucidate the physical and chemical nature of matter, they fail to help students understand the key roles that plants play in matter cycling (Helldén 2004; Lin and Hu 2003). The importance of such knowledge is stressed in the *Next Generation Science Standards* (*NGSS*), which emphasize the cycling of matter and flow of energy within ecosystems (MS-LS1-6, MS-LS1-7, MS-LS2-3) as well as the crosscutting concepts Energy and Matter, Stability and Change, and Cause and Effect (NGSS Lead States 2013). How well students understand matter cycling into and out of the atmosphere as a result of plant processes has also been identified as a precursor for making informed decisions about key societal issues such as global climate change (Hartley et al. 2011). In this article we describe an instructional sequence that we have successfully used with middle school students to teach interconnected plant functions, matter cycling, and conservation of matter.

Some students argue that the plant will grow over time, and because the plant gets bigger, the overall terrarium mass will increase. Other students argue the plant will lose leaves and therefore the terrarium will lose mass.

Introducing the driving questions

The instructional sequence is appropriate for middle school students being introduced to the disciplinary core idea Organization for Matter and Energy Flow in Organisms (NGSS Lead States 2013, p. 225) and to the plant processes transpiration, photosynthesis, and cellular respiration. Although not always taught in the same grade level or instructional unit, it is important to teach these three plant processes in conjunction so that students develop an understanding of their interrelated nature.

To initiate the unit, we have groups of four to five students each plant a healthy ivy plant in a sealed (taped) glass jar, or terrarium. We typically use the set of jars constructed by the first class of students with subsequent classes in order to reduce the overall number of jars in the classroom. The easiest setup involves placing a slow-growing plant in potting soil within a large, clear jar that has a removable clear lid (see Figure 1 for an example setup and the Activity Worksheet for a complete materials list).

Several retail stores sell large, glass cookie jars with a wide opening that work well. We use a small (so that it does not push against the sides or top of the jar) plant that can thrive under adverse conditions (e.g., ivy). Students place the soil and plant in the jar, making sure the soil is slightly moist but not overly wet. Soil that is too wet will promote the growth of mold in the jar, resulting in a shortened plant life span. To reduce mold growth, we have students add a small amount of activated charcoal to the potting soil (see Kalif 2014 for more information about how to reduce the development of mold in terraria). This setup is essentially a terrarium, although we intentionally omit that term during initial conversations with students.

After students construct and seal the terraria, we challenge them to consider what will happen to the plant over time using this scenario:

> Some moist soil is placed inside a clear glass jar. The soil has been properly fertilized. A small, healthy green plant is planted in the soil. The cover

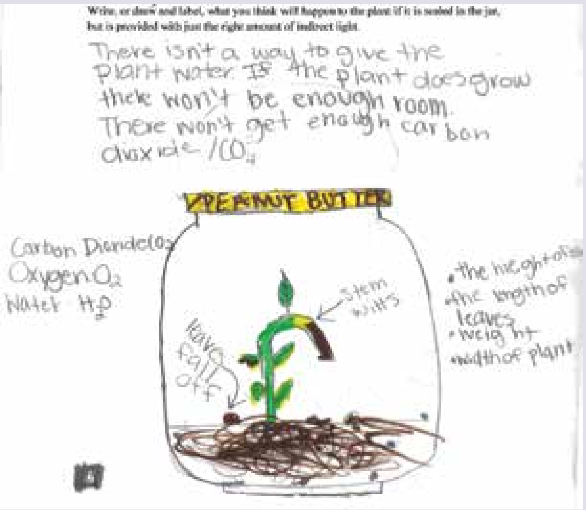
FIGURE 1 Example plant-in-a-jar setup

> of the jar is on tightly and taped shut to ensure no matter can enter or exit the sealed jar. The jar is located in a window where it receives indirect sunlight, and the temperature inside the jar is maintained between 60° and 80°F (as recommended for plant health). What do you predict will happen to the plant?

We ask students to individually create a drawing and narrative (explanatory model) that supports their predictions. We stress that the drawing and narrative should explain why students think the plant will or will not live a normal life span. After students have completed their drawings and narrative, we have them engage in a pair-share activity in which they share with a peer their thinking about the fate of the plant and possible factors that may affect the plant and then the entire class. During the group sharing, we record student ideas in a public location so we can refer to them during later instruction.

Most students believe the plant will die from a lack of resources. The representative drawing in Figure 2 captures a common student misconception that plants take in water and do not release it back into the environment. This drawing also highlights another common misconception held by many students who have knowledge of photosynthesis but are unaware that plants engage in cellular respiration: These students often believe the terrarium atmosphere will run out of carbon dioxide.

FIGURE 2 A representative student drawing



Write, or draw and label, what you think will happen to the plant if it is sealed in the jar, but is provided with just the right amount of indirect light.

There isn't a way to give the Plant water. If the plant does grow there won't be enough room. There won't get enough carbon dioxide /CO_2

In addition to asking students what they believe will happen to the plant, we also engage them in a think-pair-share activity centered on the questions "Will the mass of the sealed jar change over time?" and "If the plant mass changes, how will it change?" Students are required to respond to the prompt and connect their response to their terrarium drawing. During the discussion we allow students to share without making judgments about their initial ideas and again record all ideas in a public location. Students hold varying ideas about the mass of the sealed jar, as shown in these representative responses:

> "I think the mass might decrease a few tenths of a gram. Not a huge decrease. It might decrease because it might start to slowly die."
>
> "Will the mass change or stay the same? Yes, it will change because the plant will get bigger."

Some students argue that the plant will grow over time, and because the plant gets bigger, the overall terrarium mass will increase. Other students argue the plant will lose leaves and therefore the terrarium will lose mass. Another typical student argument is that the matter is trapped in the jar and has nowhere to go, so the terrarium mass will remain stable. Rather than answering the question directly, we tell students they will collect and analyze data to help answer the question.

As a class, students initiate data collection, determine a data-collection schedule (typically every day), and determine how to best measure the factors they are going to observe. Throughout the investigations, we start each class by collecting and recording information in the Plant in a Jar data table (see the Activity Worksheet for data we typically collect).

Constructing terraria and individual plant models and conducting the related class discussion and initial data collection take about one hour.

Water use in plants

Initial data collection reveals the mass of the jars has not changed. Students are also asked to make general observations of their plant's health and the environmental conditions inside the jar. Students' first observations and discussions generally center on the moisture accumulating inside of the jar, which typically appears within hours of planting. Students use terms such as *mist* and *fog* to describe their initial observations of the moisture. In some cases, students reference rain forests and swamps, which allows us to make connections to elevated humidity levels and environments with high plant densities. As a class, we discuss the origins of the moisture. Although we, as teachers, lead these conversations, we use student observations and ideas to co-construct a common understanding of the observations and related concepts, in this case the water on the side of the jar and the water cycle. If not offered by students, we use the observations to introduce related scientific vocabulary and concepts (precipitation, condensation, evaporation, and water cycle).

After this discussion of students' initial observations and the water cycle, we conduct an activity designed to confront a common misconception held by many students, who believe all the water entering the plants' roots becomes a part of the plant, which they think will eventually reduce the overall amount of water within the jar. The activity and related work can be completed in a little less than an hour (see Activity Worksheet).

To start this instructional phase, we focus students' attention by asking, "What happens to the water that goes into the plant roots?" After students share their ideas, we introduce the story of Stephen Hales, a British scientist who conducted several experiments examining this very question during the 1700s (Hershey 1991). We then suggest that by re-creating one of his experiments, we may be able to gain some additional insight into the plant-in-a-jar scenario.

At this point we takes students outside to see stations we have set up that re-create Hales' famous experiment. At each station, students find plants with sections or parts covered with a numbered plastic sandwich bag that we have already sealed as tightly as possible and left for several minutes prior to students observing them. (See the online version of this article at *www.nsta.org/middleschool* for an example transpiration demonstration setup.) Students observe moisture accumulating in most of the plastic bags, with more moisture accumulating in some plastic bags than others. We use this experience to introduce the concept of *transpiration*.

We tell students that *transpiration* is the name for the process of plants absorbing water through roots, into the stem, and then into the plant leaves. We also highlight that Stephen Hales was able to determine that about 98% to 99% of the water absorbed through plant roots eventually exits a plant through tiny holes on the underside of plant leaves called *stomata*. We

Nathaniel Ward attempted to protect the chrysalis (cocoon) of a moth from air pollution by covering it with a glass jar. In the process, an unintended fern grew in the jar.

underscore that transpiration moves about 95% of the water absorbed at a plant's roots directly through the plant to keep the plant cool, while the remaining 5% is used in other plant processes (see the online version of this article for a transpiration diagram). We make sure to tell students these other plant processes involve chemical reactions that break down water molecules, use the water-molecule components for plant functions, and then reconstruct the components back into water molecules that are later released back into the atmosphere via stomata. As a result of these other plant processes, a plant obtains energy and itself creates plant matter. We also point out that almost all of the water used in the other plant processes is returned to the atmosphere, while a very small amount becomes plant matter. In the event that a plant leaf or part dies and falls from the plant, the water within the plant leaf/part returns to the environment. Across these discussions we emphasize that none of the water that enters plant roots disappears but is continuously recycled through plant processes.

We also provide some relevant examples to help students understand the volume of water that plants transpire. For example, we tell them that a tomato plant can transpire up to 34 gal. of water in a growing season, while a 14.5 m silver maple tree in direct sunlight can transpire up to 59 gal. of water in a single hour (Bareja 2013).

At this point we ask students to individually respond on their Activity Worksheets to two questions: "Do these new data cause you to revise your thinking about the plant in a jar?" and "Do these new data raise any new questions?" Then we discuss students' responses as a class. During this discussion we reference students' original predictions and highlight discrepancies between students' original ideas about water use in plants and this new information. Finally, we tell students they will learn more about the other plant processes in future investigations.

Plants and sunlight

The next day, we continue data collection and observations of the plant-in-a-jar system. The observations typically reveal that the plants are relatively healthy and the data show no change in terraria mass. We continue daily observations throughout the remainder of the unit, which takes us a little less than two weeks to complete. However, we know teachers who have kept the sealed terraria in their classrooms for several months.

The next sequence of activities relates to plants making food and takes about three hours to complete. To initiate this sequence, we engage in whole-class discussion designed to solicit student understanding of other plant-related processes. Here we ask questions such as "What else do plants do that might disturb the sealed plant?" and "Do you know of any other things that plants do that might help us understand what is happening in the jar?"

During this discussion, we also have students complete a think-pair-share centered on the question "How do you think plants get food?" We again record all student ideas in a public place. Some students have limited knowledge of photosynthesis, but the most typical student idea we encounter is that plants take water and nutrients from the soil for food.

At this point we highlight that many scientists who lived in the time period after Stephen Hales' discovery believed plants interacted with the air in the atmosphere and that those interactions were somehow connected to plants making food. These scientists conducted numerous experiments that helped them better understand how plants get food. We then tell students we are going to conduct several key experiments that show what the scientists learned and discuss the sense they made of these discoveries.

These activities involve the use of gas-detection systems. Several gas-detection options are available, including systems that use computer gas-detection probes (see Resources). We use a non-computer-based system, Gastec gas-detector tubes (see Resources), primarily because these detector tubes provide a static reading and can be used in direct sunlight.

Ward secured a fern in a sealed jar and claimed it survived for years without care. Although scientists of his day initially questioned Ward's claim, his accidental discovery revolutionized worldwide plant transportation.

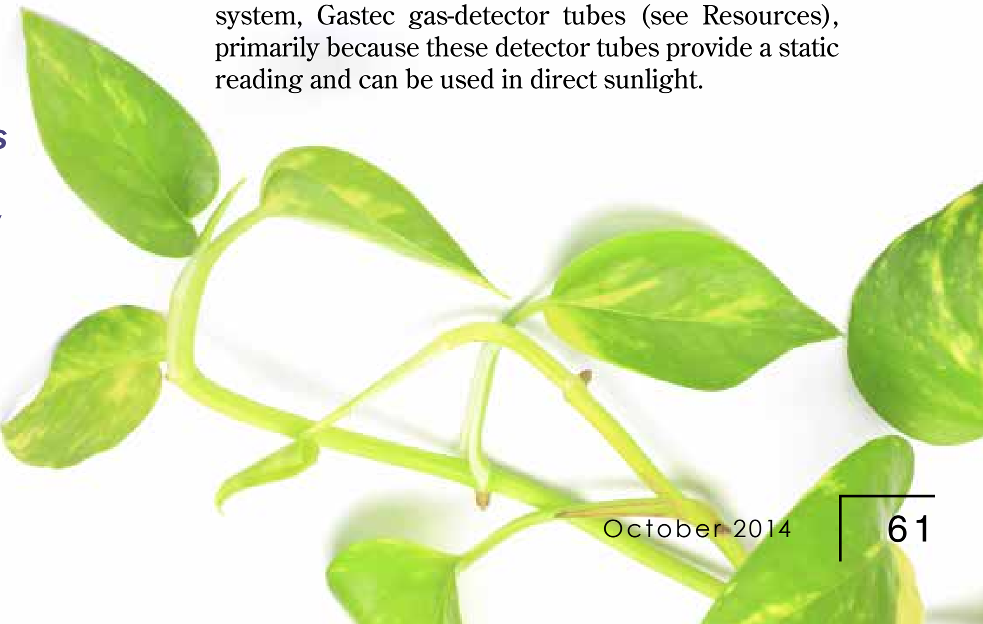


FIGURE 3 Potted plant sealed in gallon-sized plastic bag

To begin this activity, we show students several small potted plants that are individually sealed in gallon-sized plastic bags (see Figure 3; any broad-leaf plant will generate good experimental readings). We explain that scientists were particularly interested in how plants interacted with air in the sunlight and in the darkness, and how those interactions might be connected to plants making food. Work in this area led scientists to discover that plants have important interactions with two gases, carbon dioxide and oxygen. We also explain that in order to show students these interactions we are going to create environments that will allow us to demonstrate the plant processes.

At this point we provide student groups with the potted plants that are sealed in gallon-sized plastic bags. As a class, we examine the moisture level of the potted plants and add water to the soil if necessary. Next we establish what are normal concentrations of oxygen and carbon dioxide gases found in the atmosphere. To do this we take an oxygen and carbon dioxide reading of the air using gas-detection tubes, which reveal that the air contains about 21% oxygen and 0.03% carbon dioxide. We then explain that for this first investigation we want to create an environment high in carbon dioxide and low in oxygen. We ask for student ideas about how we might add carbon dioxide gas or reduce the amount of oxygen in the potted-plant environments. If students do not mention that human respiration reduces oxygen gas levels and increases carbon dioxide gas levels, we carry out a quick demonstration using the gas-detector tubes.

First we fill a plastic bag with room air and discuss how the concentrations of carbon dioxide and oxygen will be about the same as the classroom air (0.03% and 21%, respectively). Next we have a volunteer breathe into the bag, take a second round of oxygen and carbon dioxide gas readings, and highlight how the measured level of oxygen gas decreases and the measured level of carbon dioxide increases as a result of respiration. Then we discuss how we can breathe into the plastic bags to raise the carbon dioxide level and reduce the oxygen level within them. It is important that students breathe into the bags for one minute and leave them as sealed as possible when they are not breathing into them. To make this easier, we provide straws to each group that students can use to breathe into the setup (see Figure 4 for an example setup with a straw inserted in the plastic bag).

After students have added carbon dioxide to the plant environments, they take initial readings of the oxygen and carbon dioxide levels within each plastic bag and record the results in a class data table and on their Activity Worksheets. Next students place their plants sealed in plastic bags outside in direct sunlight. Changes in carbon dioxide and oxygen levels will occur in about 30 minutes, but leaving the setup under direct sunlight for longer periods of time produces more dramatic results. Photosynthesis takes about 10 minutes to start after a plant is placed in sunlight, so a reading at 30 minutes shows changes from about 20 minutes of photosynthetic reactions.

While students are waiting to collect data from this investigation, we ask them to answer two questions:

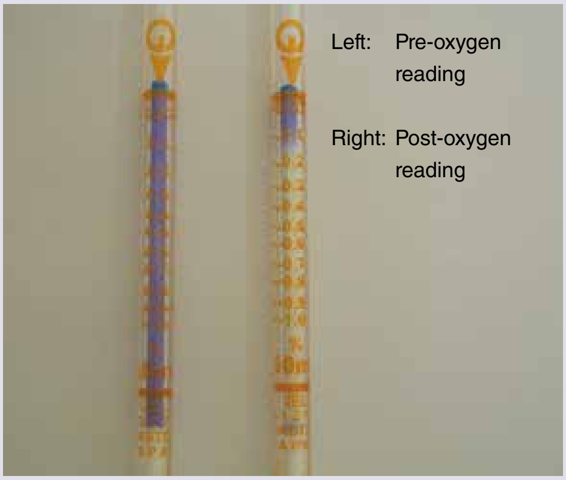
FIGURE 4 Potted-plant setup with a straw inserted in the plastic bag

"What do you expect to happen to the carbon dioxide and oxygen levels in the sealed bag?" and "Why do you think this will happen?" Then we solicit student thinking through class discussion. During this discussion we reference students' original predictions and highlight existing ideas related to interactions between plants and air.

After the setup has been in the sunlight long enough to show changes, students take oxygen and carbon dioxide readings again, record the data in a class data table and on their Activity Worksheets, complete post-investigation questions, and discuss results and their responses to the post-investigation questions. (See Figures 5 and 6 for typical oxygen and carbon dioxide readings.) Through student questioning and data analysis, we establish that the plants used up some carbon dioxide and created some oxygen in the presence of sunlight.

Next we complete a test for the presence of starch in the plant leaves as an accompaniment to this investigation (see Resources for instructions). If time permits, we complete this test as a class activity, but we find that conducting a class demonstration can provide students with the relevant background knowledge. At the end of the starch testing, we tell students that scientists used this test, and others, to determine that plants make glucose, a simple sugar that gives the plant energy needed to grow. We stress that plants use "extra" glucose to create starch, which stores energy so the plants can access it later as needed. We also highlight that because plants create more energy than they use when exposed to sunlight, starch is present in the plants' leaves.

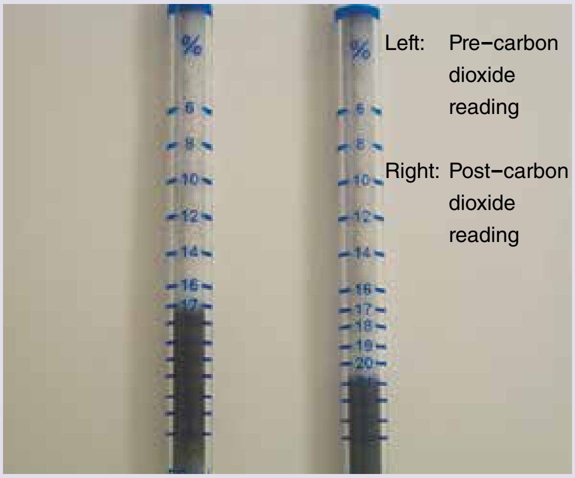
FIGURE 5 Typical pre- and post-oxygen readings



Left: Pre-oxygen reading

Right: Post-oxygen reading

FIGURE 6 Typical pre– and post–carbon dioxide readings



Left: Pre–carbon dioxide reading

Right: Post–carbon dioxide reading

After students answer post-investigation questions, we create a class description of what students know at this point from their water and gas investigations. We summarize that some water and carbon dioxide go into the plant, and plants use sunlight energy to makes glucose and oxygen. We tell students that these collective processes demonstrate how plants make food, which scientists call *photosynthesis*.

As a conclusion to this sequence, we return to the original questions about the fate of the plant sealed in a jar and the mass of the plant. We ask students to again consider if these new data raise any questions or confirm any of their existing ideas. Some students will use these data to support their incomplete conceptions about the fate of the plant in a jar. For example, some students believe the gas test results confirm their prediction that the plant will die from a lack of carbon dioxide or too much oxygen. Other students raise new questions related to the mass of the jar, centering their thinking on the "heavy" plant mass created by "lighter" gases during photosynthesis.

Plants in darkness

Students continue daily data collection and observations of the plants. If you meet with students every day, at this point the terraria have been sealed for about a week. If you meet less frequently, the additional time between activities should have little bearing on the health of the plant. We find that with more time, the plant appears healthy and the container gains no mass,

ACTIVITY WORKSHEET: Plants and conservation of matter

Plant in a jar

Materials (per group of four or five students)

- 1 small ivy (*Hedera*), fern, or other low-growing, dense plant
- Premixed potting soil
- 1 large (1 gal.) clear jar (glass) with an airtight lid (e.g., glass cookie jars that can be found in the kitchen section of most department stores or large plastic snack containers)
- 1 digital balance (minimum 9 kg capacity)
- Duct tape
- 1 small, non-mercury thermometer with large, easy-to-read numbers
- 1 ruler

Scenario

Some moist soil is placed inside a clear glass jar. The soil has been properly fertilized. A small, healthy green plant is planted in the soil. The cover of the jar is on tightly and taped shut to ensure no matter can enter or exit the sealed jar. The jar is located in a window where it receives indirect sunlight, and the temperature inside the jar is maintained between 60° and 80°F (as recommended for plant health).

Answer the following questions:

- What do you predict will happen to the plant?
- Create a drawing and narrative to explain your thinking.
- Do you think the total mass of the sealed jar will change over time?
- If you think the mass will change, do you think the mass will increase or decrease?
- Explain why you think the plant mass will, or will not, change over time.

Data collection

Directions: Collect the following plant data each day. Be sure to collect data from your assigned plant.

Plant number:

Plant in a Jar data table

	Day 1 date:	**Day 3 date:**	**Day 5 date:**	**Day 7 date:**	**Day 9 date:**
Plant height (cm)					
Plant width (cm)					
Plant mass (g)					
Temperature (°F)					
Plant description/ notable marks (e.g., “brown spot on leaf”)					
Other observations					

Water use in plants

Directions

Once you have completed your daily data collection, use data from the Plant in a Jar data table to answer the following questions:

- What qualitative observations did you make related to water in the jar?
- What quantitative observations did you make related to the mass of the jar?
- Did the mass of the jar change?

Answer these questions after the re-creation of Stephen Hales’s experiments:

- Do these new data cause you to revise your thinking about the plant in a jar?
- Do these new data raise any new questions? If so, list them here.

Plants and sunlight

Materials (per group of four or five students)

- 1 small potted plant sealed in a gallon-sized plastic baggie with a zip-seal system
- 1 straw
- 1 Gastec sampling pump (pump set GV-50PS)

- 2 Gastec 31E (measuring range 6%–24% O_2 concentration) oxygen-detector tubes (plus 1 for determining class oxygen concentration)
- 2 Gastec EL (measuring range 0.03%–1% CO_2 concentration) carbon dioxide–detector tubes (plus 1 for determining class carbon dioxide concentration)
- Indirectly vented chemical splash goggles (1 per student)

Procedure

1. Open the plastic bag containing the plant just slightly (only enough to insert the straw).
2. Use the straw to breathe into the bag for about one minute and then close it again. You want to fill the air inside the plastic bag with as much of the air you exhale as possible. Do not share straws with another student; dispose of your straw after use.
3. Prepare your carbon dioxide gas-detection tube as directed by your teacher.
4. Open the plastic bag containing the plant just slightly (only enough to insert the gas-detection tube).
5. Take an initial carbon dioxide reading (leave the gas-detection tube in the plastic bag for 30 seconds) and reseal the plastic bag.
6. Record your results in the Plants and Sunlight data table below.
7. Prepare your oxygen gas-detection tube as directed by your teacher.
8. Take an initial oxygen reading (leave the gas-detection tube in the plastic bag for 30 seconds) and reseal the plastic bag. Be careful: The oxygen tube will get warm during data collection.
9. Record your results in the data table.
10. Record your responses to the questions below. We are going to place the sealed bag and plant in sunlight for 30 minutes.
    - What do you expect to happen to the carbon dioxide and oxygen levels in the sealed bag?
    - Why do you think this will happen?
11. Place your sealed bag and plant in direct sunlight for 30 minutes.
12. Take a second carbon dioxide reading (leave the gas-detection tube in the plastic bag for 30 seconds) and reseal the plastic bag.
13. Take a second oxygen reading (leave the gas-detection tube in the plastic bag for 30 seconds) and reseal the plastic bag. Be careful: The oxygen tube will get warm during data collection.
14. Record your results in the data table.

Plants and Sunlight data table

	Pre	**Post**	**Pre/post difference**
Oxygen (%)			
Carbon dioxide (%)			

15. Create a statement using information from the data table summarizing what plants do in the presence of sunlight.
16. Refer to the Plant in a Jar data table. Did the mass of the jar change?
17. Answer one of the two questions below:
    - How do these new data support your original ideas about the mass of the plant in a jar?
    - If your ideas about the mass of the jar have changed, use data from our investigations to explain the changes to your thinking.
18. Answer one of the two questions below:
    - How do these new data support your original ideas about the fate of the plant in a jar?
    - If your ideas about the fate of the plant in a jar have changed, use data from our investigations to explain the changes to your thinking.
19. Do any of these new data raise any new questions? If so, list them here.

Plants in darkness

Materials (per group of four or five students)

- 1 small potted plant sealed in a gallon-sized plastic baggie with a zip-seal system
- 1 Gastec sampling pump (pump set GV-50PS)
- 2 Gastec 31E (measuring range 6%–24% O_2 concentration) oxygen-detector tubes (plus 1 for respiration demonstration)
- 2 Gastec EL (measuring range 0.03%–1% CO_2 concentration) carbon dioxide–detector tubes (plus 1 for respiration demonstration)
- Indirectly vented chemical splash goggles (1 per student)

Procedure

1. Open the plastic bag containing the plant just slightly (only enough to insert the gas-detection tube).

2. Prepare your carbon dioxide gas-detection tube as directed by your teacher.
3. Take an initial carbon dioxide reading (leave the gas-detection tube in the plastic bag for 30 seconds) and reseal the plastic bag.
4. Record your results in the Plants in Darkness data table, below.
5. Prepare your oxygen gas-detection tube as directed by your teacher.
6. Take an initial oxygen reading (leave the gas-detection tube in the plastic bag for 30 seconds) and reseal the plastic bag. Be careful: The oxygen tube will get warm during data collection.
7. Record your results in the Plants in Darkness data table.
8. Record your responses to the questions below. We are going to place the sealed bag and plant in a dark location for 24 hours.
    - What do you expect to happen to the carbon dioxide and oxygen levels in the sealed bag?
    - Why do you think this will happen?
9. Place your sealed bag and plant in darkness for 24 hours.
10. Take a second carbon dioxide reading (leave the gas-detection tube in the plastic bag for 30 seconds) and reseal the plastic bag.
11. Take a second oxygen reading (leave the gas-detection tube in the plastic bag for 30 seconds) and reseal the plastic bag. Be careful: The oxygen tube will get warm during data collection.
12. Record your results in the Plants in Darkness data table.

Plants in Darkness data table

	Pre	**Post**	**Pre/post difference**
Oxygen (%)			
Carbon dioxide (%)			

13. Create a statement using information from the Plants and Darkness data table summarizing what plants do in the presence of sunlight.
14. Refer to the Plant in a Jar data table. Did the mass of the jar change?
15. Answer one of the two questions below:
    - How do these new data support your original ideas about the mass of the plant in a jar?
    - If your ideas about the mass of the jar have changed, use data from your investigations to explain the changes to your thinking.
16. Answer one of the two questions below:
    - How do these new data support your original ideas about the fate of the plant in a jar?
    - If your ideas about the fate of the plant in a jar have changed, use data from your investigations to explain the changes to your thinking.
17. Do any of these new data raise any new questions? If so, list them here.

which intrigues students. For the next phase of instruction, we draw students' attention to other experiments scientists conducted on plants in the dark that helped them better understand a different plant process that we have not discussed yet. We point out that this last sequence of experiments will help resolve many of the remaining questions about the fate of the plants in jars and the unchanging mass of the plants in jars. These activities typically require about two hours, spread over two days, to complete.

Here we once again set up the plants sealed in plastic bags. Students take readings of the oxygen and carbon dioxide levels within each plastic bag and record the results in a class data table and on their Activity worksheets. Next students place the plants in plastic bags in a completely dark location until the next class meeting (usually about 24 hours). Then we again ask students to answer two questions: "What do you expect to happen to the carbon dioxide and oxygen levels in the sealed bag?" and "Why do you think this will happen?" Next we solicit student thinking about these questions through class discussion. During this discussion, we reference students' original predictions and highlight existing ideas related to interactions between plants and air.

After the setups have been in the dark, students take oxygen and carbon dioxide readings again, record the results in the data tables, complete post-investigation questions, and as a class discuss the results and their responses to the post-investigation questions. Students

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard: MS-LS2: Ecosystems: Interactions, Energy, and Dynamics		
Performance expectation: MS-LS2-3: Develop a model to describe the cycling of matter and flow of energy among living and non-living parts of an ecosystem		
Dimension	***NGSS* code or dimension name**	**Matching student task or question taken directly from the activity**
Disciplinary core idea	Cycle of matter and energy transfer in ecosystems (MS-LS2-B)	"What do you predict will happen to the plant?" "How will the mass of the plant in the jar system change over time?"
Science and engineering practices	Developing and using models	Drawing and revising a model to explain the cycling of matter within the jar.
	Analyzing and interpreting data	Using collected mass data to determine that the mass of the jar does not change over time. "How do these new data support your original ideas about the mass of the plant in a jar?"
Crosscutting concepts	Cause and effect	"Explain why you think the plant mass will or will not change over time."
	Energy and matter	"How do these new data support your original ideas about the mass of the plant in a jar?" "If your ideas about the mass of the jar have changed, use data from your investigations to explain the changes to your thinking."

will note that the carbon dioxide levels in the jars increased while the oxygen levels decreased. We then complete the test for the presence of starch in the plant leaves, as either a class activity or demonstration. The test reveals no starch is present in the leaves of the plants that have been in the dark. At the end of this starch testing, we tell students that scientists used this test, and others, to determine that plants use starch as energy when there is no sunlight available.

As a class students then create a description of what they know about plants in the dark. We summarize that some oxygen goes into plants, plants use stored energy (starch), and plants produce carbon dioxide. These observations and accompanying conversations allow us to address the misconception that plants do not respire. One way we do this is to ask students to brainstorm what it means to be alive. As part of the discussion we use guiding questions to introduce the idea that living organisms "respire" through cellular respiration, even if they have no gills or lungs. We stress that cellular respiration occurs in all living cells, including the cells of plants, and involves cells using oxygen and glucose to create carbon dioxide while also releasing stored energy for the cell to use for various functions.

At this point we ask students to exhale while holding their hands over their mouths. As students notice the moisture accumulating on their hands, we highlight that breathing is a form of cellular respiration and cellular respiration in all living things involves the return of moisture, water, back into the environment. Here we underscore that cellular respiration in plants and animals occurs all the time, not just in the dark. We also emphasize that this process in plants is "masked" or hidden during the day because the photosynthesis process typically involves higher carbon dioxide and oxygen exchange rates.

At the end of this sequence, we ask students to reexamine their original predictions about the fate of the plant in a jar and the mass of the plants and make any revisions they think are warranted. We also have students engage in a think-pair-share sequence where they state their current predictions and provide justifications for their current ideas. As students generate possible explanations for the constant terrarium mass and the still-healthy plants, we encourage them to return to key concepts we learned during our plant investigations.

Connecting the interrelated processes

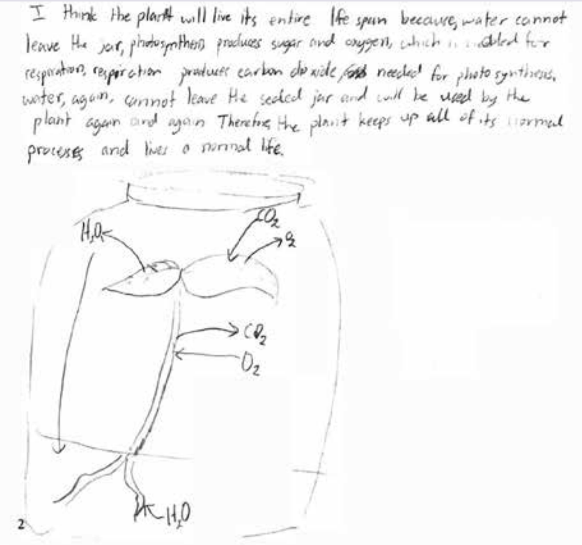
Next we return to our word descriptions of photosynthesis and cellular respiration and introduce the chemical equations for both by placing the words above the related formulaic representations (see the online version of this article).

Then we ask students to make observations about what happens to the water in the equations. If not offered by a student, we trace the path of water showing that water absorbed by plants during photosynthesis is released during cellular respiration. Then we discuss how these three processes (transpiration, photosynthesis, and cellular respiration) serve to move and rearrange atoms of hydrogen and oxygen (as evidenced by students' observations of moisture within the terrarium), but the overall amount of each remains stable within the jar (as evidenced by the terrarium mass data). If not offered by students, we remind them of the work of Stephen Hales (Hershey 1991), who proved that almost all the water absorbed by plant roots returns to the atmosphere as water vapor. We then emphasize that because the terrarium environment is closed, the water cannot escape the sealed jar.

As students come to understand that the amount of water within the jar remains stable, we return their attention to the plant process formulas (photosynthesis and cellular respiration; see the online version of this article). Here we ask students to make observations about the products and reactants of each process. Then we use either students' ideas or direct instruction to reinforce the idea that the products of one reaction are the reactants of the other and vice versa. We also explain that the plant uses these processes to cycle and reconfigure carbon, hydrogen, and oxygen, but the amount of each remains stable within the jar.

In some instances, students notice dead leaves and want to discuss the impact they have on the mass of the closed ecosystem. This provides us another opportunity to reinforce related conservation-of-mass concepts. To do this we discuss that nothing enters or leaves the jar and that as plant parts die and decay, some carbon dioxide gas is returned to the jar atmosphere while the remainder of plant mass evaporates as moisture or returns to the soil. Such instances also allow us to introduce students, as appropriate, to microorganisms that live in the soil of the sealed jar and discuss their role in matter cycling. We describe how the microorganisms, even though they cannot be seen, contribute to decomposition of matter and return matter to both the soil and atmosphere.

FIGURE 7 Student post-unit drawing and response (interrelated plant processes described)



I think the plant will live its entire life span because, water cannot leave the jar, photosynthesis produces sugar and oxygen, which is needed for respiration, respiration produces carbon dioxide, ~~gas~~ needed for photosynthesis, water, again, cannot leave the sealed jar and will be used by the plant again and again Therefore the plant keeps up all of its normal processes and lives a normal life.

Historical connections

As students begin to understand the various plant processes that cycle matter throughout a given ecosystem, we introduce them to the works of Antoine Lavoisier, who is widely cited as the scientist who discovered and named the law of conservation of matter (Holmes 1977). His major contributions included developing the notion that respiration and combustion are similar in nature—both are caused by reactions with a gas in the air (which he later named oxygen)—and his experiments that proved water is composed of oxygen and hydrogen.

The instructional unit also allows us to make other historical connections that help students better understand the nature of science. For example, we are able to introduce students to Nathaniel Ward, who was credited with accidentally discovering in 1829 that a plant can live in a sealed jar (Hershey 1996). Ward, who lived in London during the Industrial Revolution, attempted to protect the chrysalis (cocoon) of a moth from air pollution by covering it with a glass jar. In the process, an unintended fern grew in the jar. Ward then secured the fern in a sealed jar and claimed it survived for years without care. Although scientists of his day initially questioned Ward's claim, his accidental discovery revolutionized worldwide plant transportation.

Sharing stories of the work of scientists such as Nathaniel Ward and Stephen Hales can be particularly helpful in helping students understand the context of scientific work and the nature of science itself. See Thompson 2014 for more examples of historical science research that can be used to support plant-related instruction.

Assessment

To assess student understanding, we return to the original questions, "What do you predict will happen to the plant?" and "Do you think the total mass of the sealed jar will change over time?" We require students to respond to the prompts and connect their responses to a post-unit drawing (final explanatory model). Within their drawings and responses, we encourage students to include details related to plant processes they learned during the unit. Figure 7 shows an example of a post-unit student drawing and responses to the prompt that capture the range of answers we typically receive (see online version of this article for additional images). A variation of this sequence is to present small groups of students with the question and allow them to work together to create a model and narrative response that explains their thinking about the sealed plant's fate and what happens to the mass of the jar over time.

This unit provides many formative-assessment opportunities, challenges students to consider their own conceptions, and highlights the importance of arguing from evidence in science. In addition to revealing student reasoning, the act of predicting the fate of the plant seems to have a particularly motivating effect. Students generally want to understand how the plant is still living after they have stated with some certainty that it will not survive for long.

Conclusion

This unit may seem ambitious, but it can help you organize your matter and energy science content around the three dimensions emphasized in the *NGSS*: science practices, disciplinary core ideas, and crosscutting concepts (NGSS Lead States 2013). Students also engage in multiple scientific practices throughout the unit. They build and revise models, collect and analyze data to support their claims, and construct scientific explanations in order to understand how matter and energy cycle within their plant in a jar. Students also begin to understand the interrelatedness of plant processes and how cause-and-effect relationships influence parts of a system. All of this from a plant in a jar! ■

References

Bareja, B.G. 2013. Transpiration in plants causes huge losses of water. Crop Agriculture Review. *http://www.cropsreview.com/transpiration-in-plants.html.*

Hartley, L.M., B.J. Wilke, J.W. Schramm, C. D'Avanzo, and C.W. Anderson. 2011. College students' understanding of the carbon cycle: Contrasting principle-based and informal reasoning. *BioScience* 61 (1): 65–75.

Helldén, G. 2004. A study of recurring core developmental features in students' conceptions of some key ecological processes. *Canadian Journal of Science, Mathematics and Technology Education* (4) 1: 59–76.

Hershey, D.R. 1991. Education: Linking history and hands-on biology. *BioScience* 41 (9): 628–30.

Hershey. D.R. 1996. Doctor Ward's accidental terrarium. *American Biology Teacher* 58 (5): 276–81.

Holmes, F.L. 1977. *Lavoisier and the chemistry of life: An exploration of scientific creativity.* Madison, WI: University of Wisconsin Press

Kalif, W. 2014. *The secret art of terrarium making revealed. www.stormthecastle.com/terrarium/terrarium-ebook.htm.*

Lin, C.-Y., and R. Hu. 2003. Students' understanding of energy flow and matter cycling in the context of the food chain, photosynthesis, and respiration. *International Journal of Science Education* 25 (12): 1529–44.

NGSS Lead States 2013. *Next Generation Science Standards: For states, by states,* Washington, DC: National Academies Press.

Thompson, S. 2014. Historical plant studies: Tools for enhancing students' understanding of photosynthesis. *Science Scope* 37 (6): 43–53.

Resources

Testing leaves for starch—*www.nuffieldfoundation.org/practical-biology/testing-leaves-starch-technique*

Gas-detection tubes

Gastec—*www.gastec.co.jp/english/kids/index.htm*

Pasco—*www.pasco.com*

Vernier sensors—*www.vernier.com/products/sensors*

Stephen Thompson (*sthompson@sc.edu*) is an associate professor of science education at the University of South Carolina in Columbia, South Carolina. **Christine Lotter** (*LOTTER@mailbox.sc.edu*) is an associate professor of science education at the University of South Carolina in Columbia, South Carolina.