# The Power of Sunlight:
# Investigations in Photosynthesis and Cellular Respiration

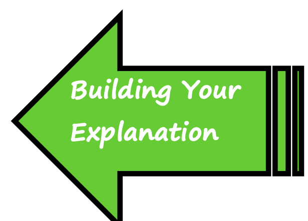
## *Teacher's Guide*

## Overview

**Premise:** Many students are familiar with the terms "photosynthesis" and "respiration." Beyond reciting the biochemical reactions, what do students really understand about them? Research has shown that even graduates from elite universities in the country are not connecting these processes to plant growth, even though they know the basic facts. It is important that students understand that photosynthesis is the key biochemical process responsible for capturing energy from the Sun and using it to generate biomass, and that cellular respiration uses photosynthetic products to fuel the chemical reactions needed for growth. From this understanding, one can appreciate the vital roles played by photosynthetic organisms in ecosystems thereby supporting all life on Earth.

**How the *Power of Sunlight* Module Works:** This module consists of a series of activities for students. These include two guided laboratory investigations that prepare them for designing and conducting an independent investigation based on their own research question. The investigations build upon one another and move from guided to open-ended inquiry. Unlike many classroom investigations, these investigations are not designed to confirm what was taught in lecture. Rather, they are designed to produce results that students do not expect. By "rocking students' boats," the investigations aim to illustrate the importance of unexpected results and to demonstrate they can lead to new models, hypotheses, and experiments. Beyond the lab investigations, three other types of activities are essential to fully benefit from this module:

- **Classroom discussion:** Students engage in authentic classroom dialogue before, during, or following lab activities.
- **Online mentoring:** students have the opportunity to discuss and get feedback about their investigation with professional scientists and to learn more about what it is like to be a scientist.
- **Development of synthesis board:** Throughout the module, students work together to construct a synthesis board which enables them to construct a fuller explanation of the phenomenon at the center of the module.




We have found that a teacher's commitment to dialogue and a focus on student ideas and reasoning emphasizing the process of science is an important aspect of building an open culture for science learning. Explanations using everyday vocabulary are valued over the use of scientific vocabulary in the absence of explanations. A more detailed description of teaching and learning strategies used in the module can be found on the PlantingScience *Teacher Resources page*.

**Grade levels:** This module is designed for high school students. Appropriate courses may include introductory biology, AP biology, honors biology, environmental science, AP environmental science, horticulture, botany, and other life science electives in which the topics of photosynthesis and cellular respiration are taught.

**Class time:** Students should be able to complete activities in the module over a two- to three-week period. During that time period, there will likely be time that can be used for other aspects of your curriculum. For example, when students are waiting to hear back from their mentors, you can fill that class time with other lessons from your standard curriculum.

**Computer access:** Optimally, students will be able to access computers at least every other class session during the module. Ideally, students would access computers daily while designing, conducting, and communicating about their open inquiry investigation.

At minimum, students would access the computer at least three times over the course of the full investigation period. Team project pages require logins. In the procedures, a step for communicating with mentors is included at the end of the lessons. This can be a reminder for this important step. However, there may be additional opportunities for contacting mentors and helping students build their relationship as well as get feedback and advice on their investigations.

# The Power of Sunlight:
# Investigations in Photosynthesis and Cellular Respiration

## *Teacher's Guide*

## Planner

**Suggested Schedule of Activities:** The core of the *Power of Sunlight* module consists of two guided inquiries related to photosynthesis and cellular respiration, and an open inquiry in which student teams ask their own research questions and carry out an experiment to answer them. This module may, if time allows, spur interest in additional investigations based on results and new questions that arise from their investigations. For example, the investigations into photosynthesis and cellular respiration in aquatic plants in this module may generate interest in doing another investigation to learn about photosynthesis and cellular respiration in seeds before and during germination.

You can expect to complete the *Power of Sunlight* module over the course of 2–3 weeks of class time. During this time, you will intersperse the *Power of Sunlight* activities with your normal classroom curriculum. For example, you may want to allow 2–3 days between when students contact their mentors and when you would begin the next activity in the *Power of Sunlight*. This would enable students to get the benefit of working with their mentor before beginning the next step in the module. If time permits, consider extending the module so that students can either repeat their independent investigations or extend their experience by conducting additional investigations.

Please post a message to the group forum to let your scientist mentor(s) know

- which lessons you will be implementing;
- your expected start and end dates for interacting with students online;
- how frequently your students meet;
- the tentative dates for when students will be communicating with mentors;
- a brief summary of what students should know about photosynthesis, cellular respiration, and scientific inquiry;
- any special experiences or challenges that the students may have with respect to completing these activities;
- a brief description of the laboratory equipment and supplies available to your students; and
- how often students will have computer access.

Students should work in teams of 3 to 4, and individual team members are encouraged to post online. In the *Student's Guide*, the image at right indicates opportunities for posting messages or information for their mentors. Teams may post from school or from home.

**Suggested Assessment Schema:** This module is designed so that students can be assessed continuously for changes in understanding. Classroom discussions, teacher interactions with teams during lab investigations, science notebook entries, and online mentoring discussions can all serve as embedded formative assessment tools. The class-developed synthesis board, a final individual reflection, and the post-experience survey serve as summative assessment tools. If desired, summative assessment in an exam format could involve written responses to questions such as the following:

- What are the relationships between photosynthesis, cellular respiration, and changes in mass in a plant?
- Compare and contrast the biological roles of photosynthesis and cellular respiration in a plant.
- What are the inputs and outputs of photosynthesis and cellular respiration? How are they similar or different?
- What are the main pathways of cellular respiration, and in what sequence do they occur?

**Additional Resources:** The *Photosynthesis and Respiration Resources* contains a bibliography of online videos, websites, articles, and books. References are organized by biological process and media type. They may relate directly to the biological process itself, to classroom tools and techniques for teaching about the process, or to educational research relating to effective teaching and student misconceptions about the process.

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# Tips for Using the Question Boards and the Synthesis Board in the Classroom

As you work through the lessons in this module, you, along with your students, use a question board and a synthesis board to help monitor learning and understanding. The use of the question board and synthesis board can be an effective way of making student thinking visible---and changing as students progress. It can also help them construct a better framework for their knowledge to help them organize their thoughts and ideas.

Some teachers may have used these strategies before while it is new for other teachers.

**Question Boards**

The purpose of the questions board is to have a place where students can both express their ideas at the beginning of the module, and also keep track of how they are answering their questions as they proceed through the lessons in the module.

Some tips for using the question board.

- Keep these posted throughout your time using the module so students can revisit their ideas and check their progress.
- This should be a dynamic document. Students can add new questions if they have new wonderings at times during the module. They could also revise questions if they feel it would make the question clearer. They could also remove questions that they do not feel apply well after they get more understanding of the module. (Instead of totally getting rid of the questions, you could just move them off to the side as less applicable to their goals.)
- Keep revisiting the question board at different times, especially after doing the synthesis board. You can work with students to identify questions that have been answered or think about which questions might be answered next.
- If possible, identify one or more questions that relate to what students will be doing next. Remind students of these questions as you introduce the next activity.
- There may be some opportunities for scaffolding through the use of the question board.
    - If students are more accustomed to asking questions or expressing ideas, they may do this more quickly.
    - If students are less comfortable sharing ideas aloud in class, you may want to go more slowly and recognize their additions as important and helpful. Reassure them that there are lots of good questions when we do science—even if you may not get to those questions in the limited time you have for this topic.
- The questions are most helpful if they are closely related to the driving question being asked (the phenomenon that is the focus).
    - It can often happen that students will post questions that are interesting but not directly relevant to the driving question. For example, if our question is, "How does 1 single seed grow into 1 very large tree?" there may be many questions posted about trees that are unrelated to how a seed grows into a tree.
    - You can respond to these questions in different ways.

        - If students are accustomed to sharing ideas or questions (and "putting themselves out there," you can ask them to share how their suggested question relates to the larger driving question.
        - If students are not experienced with sharing in this way, you may want to accept a broader range of questions at the beginning and reassure them that they posed an interesting question about the phenomenon.
        - As students become more comfortable with this experience, you can encourage them to focus their questions more closely to the driving question and phenomenon.
- It is unlikely that all questions will be answered during the module.
    - For the Power of Sunlight module, there may be questions that students could use as the basis of their independent investigations at the end of the module.
    - There may also be times when you will teach related ideas in your class. You can come back to this if those situations arise to remind students of a question they had that wasn't answered before.
    - Encourage students to seek answers on their own to share with the class.
- If possible, you may want to finish one class period with the development of the question boards. This would give you time to consider how you will tie the questions to the next activity (since each class would be somewhat different).

**Synthesis Board**

The synthesis board can be a valuable tool for helping students (working as a class) to summarize and synthesis what they have learned over the course of the module.

**Some tips for use of the synthesis board**

- Start the synthesis board with the class after their first investigation (data collection).
- This may be a new experience for students so starting with a discussion of an investigation that has just a few main points can help them learn to use this tool.
- Ask students to provide evidence to back up the statement they made about a scientific conclusion. (For example, if students respond that "Plants need carbon dioxide for photosynthesis." Make sure you ask them for their evidence to back up their statement.
- Students may also provide information from a text resource to back up their claims. That is appropriate as well if they state that they learned it from a provided reading. (Hopefully, they can also tie this to something from their investigation as well.)
- Students may cite something as a conclusion, but their statement is not backed up fully by evidence. Ask them to explain what their evidence is. If they cannot, you can mark their statement as something they have some information about, but maybe not to the point of having solid evidence to back up at this point.
- If appropriate, add questions to the question board for things that still need to be more completely investigated.
- You may want to use a different color marker for each time you add to the synthesis board. This can help learners visualize and remember what they did in each investigation or each time they added to the board.
- After adding to the synthesis board, students can use the information to add to their models.

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## Lesson 1

# GET ACQUAINTED WITH PLANTS

## From a Tiny Seed to a Large Tree

**Overview**
The goal of this activity is to have students begin to consider what they know about how plants grow and increase in mass. They start by looking at photographs of a seed and a very large tree to consider what they observe and what questions they have about how this phenomenon occurs. They contribute their questions to a class discussion and will refer back to these questions as they move through the module. To monitor their understanding of this growth, students begin developing a model that they will add to and revise over the course of the module.

**Time Required:** Approximately 2 class periods (about 45 minutes each)

**Learning Goals**
- Elicit students' prior knowledge about photosynthesis and cellular respiration
- Reveal misconceptions about plant growth, photosynthesis, and cellar respiration
- Begin constructing a model to explain how plants grow

**Common Preconceptions and Student Biases**
Students may bring up some of the following preconceptions during this lesson. You will not be addressing or correcting these ideas at this point in the module, but the following may prepare you for some of the preconceptions that may come up during discussion.
- Plants and trees get their mass from the soil.
- Plants get their food from the soil.
- Photosynthesis takes place during daylight while cellular respiration takes place during the night.
- Scientists are often older males who wear lab coats and glasses.

## Getting Ready

**Note to Teachers:** The design of this module advocates having students follow the materials and procedures presented in the *Student's Guide*. This allows students the greatest autonomy of the materials. However, if you do not feel this approach works well with your students, the *Teacher Guide* can be used to lead the class sessions without the *Student Guide*. The instructional steps listed in the *Teacher's Guide* correlate with the same step number in the *Student Guide*. You may want to refer to the student guide when you prepare, but the teacher materials should provide most of the details you will need.

This module calls for students to keep their own science notebook in which they record their ideas, questions, observations, and results. Research has shown the benefits of keeping science notebooks, but this may be new to some students. As an alternative, we have included some optional handouts or slides that could provide more structure.

Students would still use journals to record thoughts, ideas, and observations. Students could tape or staple the handouts into their science notebooks in the appropriate place.

***Student's Guide* Section and Resources Used in Lesson**

| | |
|---|---|
| From a Tiny Seed to a Large Tree from the *Power of Sunlight Student's Guide* | 1 copy per student |

***Teacher's Guide* Resources**

| | |
|---|---|
| Handout 1: *How Does a Tree Grow from a Small Seed into a Large Tree?* | 1 per student (optional) |
| Handout 2: *Constructing My Model* | 1 per student (optional) |
| Slide 1: *The Growth of a Giant Sequoia Tree* | 1 to project |
| Slide 2: *Getting Started on the PlantingScience Website* | 1 to project (optional) |
| Slide 3: *Updating the Project Page* | 1 to project (optional) |

**Materials and Supplies**

| | |
|---|---|
| Document camera or computer with projector | 1 setup per class |
| Science notebook | 1 per student |
| chart paper or butcher paper | several sheets to post in classroom (See *Preparations*) |
| sticky notes | several per student |
| markers | 1 per student or team |

**Preparations**

***Prior to Beginning the module***

- Set up student teams in the PlantingScience platform if you have not already done so:
    - Create one project for each team by clicking on 'Projects' in the side menu of your group page. Then click "Add Projects" in the upper right-hand corner.
    - Create student accounts by clicking on Projects in the side menu of your group page, and then on the "Students" tab. (Students will be prompted to change their passwords when they log in, so it is fine to give everyone the same password now.)
- Create student tickets: click "Export" on the Student page to download a PDF of student account tickets that can be cut apart and distributed to easily give students their usernames. (The password field will be blank so that students can write in their chosen password once they change it.)

***Preparations for this lesson***

- Review the student and teacher procedures for the lesson.
- Prepare photocopies as indicated in the table above.

- Gather needed materials.
- Review *Tips for Using the Observation/Question Boards and the Synthesis Board in the Classroom*.
- Students will need to use computers during Parts 2 and 3 of this lesson. You may want to bookmark the PlantingScience site to make this easier for students to navigate to the correct pages.
- The materials call for chart papers that can be posted in the classroom. Some teachers may prefer to use an electronic system for this, which can be an effective tool. The goals for this are to allow students to review the questions chart throughout the module and add to it as appropriate as they progress through the lessons. Therefore, regardless of how you create the charts in class, they should remain posted and visible to students.

## Procedure

### Part 1: Exploring a Phenomenon in Plants

The procedural steps in the *Teacher's Guide* align with the corresponding steps in the *Student's Guide*.

1. **In this step, students are introduced to the question that will guide their learning throughout the module: "How does a tree grow from a small seed into a large tree?" Write that question on a piece of chart paper and display it in the classroom. At the same time, students should write the question on new page in their science notebooks.**

   It will be helpful to have that question posted in the room throughout the lessons in this module so you can draw students back to it as they work through lessons, activities, and discussions. This will help keep them focused as they work to develop explanations to answer this question.

2. **In this step, students create a table in their science notebooks to record their ideas and questions during Step 3.**

| Observations | Questions |
|---|---|
| | |

If you are not using the Student's Guide or if you plan to use the optional handout (see Step 3), you can skip this step.

3. **In this step, students are introduced to the phenomenon of a giant sequoia tree growing from a very small seed and asked to think about how that happens. The Student's Guide includes the same text box with information as the one below.**

The Student's Guide includes the photographs and the text information about sequoias, but you may also want to project Slide 1: *The Growth of a Giant Sequoia Tree*. Students may read the information to themselves, or you may ask a volunteer to read it aloud to the class.

You may need to help students with the pronunciation of the word "sequoia" since it is probably unfamiliar to many students. The word is pronounced "suh·**kwoy**·uh."

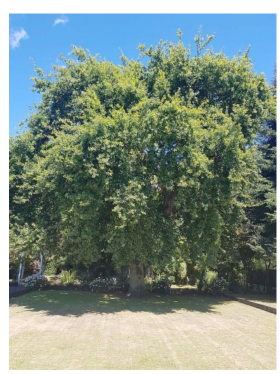
**The General Sherman tree in the Sequoia and Kings Canyon National Park in California**

- The General Sherman tree is a sequoia tree that is 84 meters (275 feet) tall—and still growing. It is 31 meters (103 feet) around. Each year it adds enough wood to make another 18-meter (60 foot)-tall tree.
- The seed of the giant sequoia tree is very small—about the size of a grain of oatmeal.

Students may have never seen a sequoia tree. This example was selected merely because its growth is so dramatic. You could ask students to think of a tree (or other plant) in their area that they have seen grow from a very small size to a large tree or plant. For example, the seed within an acorn grows into an oak tree. Maple trees produce samaras, dry fruits that contain the seeds. Students may have seen these "helicopter seeds" that are spread by the wind. You could point out that the examples they are more familiar with are similar to what happens with the sequoia in terms of growing from a very small seed to a tree or plant that is much, much larger.

**A.**

**B.**



C.

D.

**Figure 1:** Tree Growth. **A.** Oak trees grow from the seeds contained within acorns, which are the fruits of the oak. Each acorn contains one seed encased within the tough outer shell. **B.** A mature oak tree. **C.** Maple trees produce samaras, a type of dry fruit. Usually, the samara comes in pairs with each one containing one seed. When the wind blows, the samara carries the seeds farther away than most other fruit seeds. **D.** A mature maple tree.

**4. Students will first work independently to write some observations and questions about the seed and the tree related to the main question about how a tree grows into a large tree. Allow a few minutes for students to record their observations and questions. Students should work individually at this point.**

At this point, students should write things that they can see. Examples include ideas such as

Seeds are really small;
Trees are very large; or
Trees have a big round trunk, bark, branches, and leaves.

Questions that may come to mind might include

What does a seed need to start growing?
How does a seed become a tree with bark, leaves, and branches?
Does a tree get its mass from the soil?

Students should write their current ideas about what is happening to enable a seed to grow into a large tree. If helpful, you could ask for a volunteer to give share one of his or her questions before they start working independently.

Allow time for students to think about this individually and write some observations and questions. At this point, it is expected that their ideas will be more directly related to the central question than others. This is a time during which students will consider what they know and what they think would be helpful to learn.

**Optional Handout**

**Note:** If preferred, instead of having students write in their science notebooks, you can give each student a copy of Handout 1: *How Does a Tree Grow from a Small Seed into a Large Tree?* In this step, students would use the left column. In the next step, they would use the right-hand column. At the end of this part of the activity, they can tape or staple it into their science notebooks.

5. **Have students work in teams of 3-4 for this step. In this step, students should**
- compare their observations and questions with those of their teammates.
- choose questions to share with the class.
- work as a team to write the questions that they want to share on sticky notes that they will add to the class charts.
- use a marker (and write larger) so that it is easier for class members to read.
- write one question per sticky note.

**While students are working, post a chart paper in the classroom labeled "Questions."**

| **Questions** |
| --- |
| |

6. **Lead a class discussion about the questions. Have teams take turns sharing their questions and adding their sticky notes to the chart papers that you posted in the room. If their sticky note is similar to one that another team has posted, they can group them together. If appropriate, ask students to give more information about what their questions are based on.**

As students add their questions to the question board, you might ask them if their question relates to an observation they made. This might give you additional insight into student thinking.

As the discussion continues, you can ask students if there are questions that are similar to those of another team. The goal is not to correct student ideas or even to give any feedback about accuracy of the ideas, but rather to draw out what students currently think and what questions they have.

It may be helpful to do some sorting of ideas on the posters. If teams have sticky notes that are similar to ones that are already posted, you could ask them to put theirs next to the other one with a similar or related idea. You could also use a marker to circle questions that are related and even add a general heading to the cluster of questions.

**NOTE:** There are many questions that students may suggest related to trees and seeds. However, not all questions will relate to the central question of this module about how 1 small seed grows into 1 very large tree. If appropriate for your students, you could draw students back to the central question about how one tiny seed grows into one very large tree. Do they think some of the questions that they posed are more likely to help them answer this question? For example, a student may look at the seed and propose the question, "How many seeds does a tree produce?" or "How many seeds germinate?" Although these are interesting questions, knowing the answers may not help answer the question about how 1 seed grows into 1 large tree. These other questions are still good and interesting questions, but they may not lead to answering the question that is at the core of this module. When students are finished adding their questions, you can tell them that you may not be able to answer all of the questions by the end of the module, but there may be other times to think about these questions in the future.

For more strategies and tips for using the question and synthesis boards during this module, see the section, *Tips for Using the Observation/Question Boards and the Synthesis Board in the Classroom.*

7. **Allow a few minutes for students to start constructing their model. Ask for a volunteer to read aloud the introduction to what a model is and how to create a model that is in the Student's Guide.**

   If you are not using the Student's Guide, give each student a copy of Handout 2: *Constructing My Model* and ask for a volunteer to read the information at the top of the page aloud.

   Optional Handout

8. **Conclude the discussion by informing students that they will be revisiting these questions in the activities over the next couple of weeks and that they will have the opportunity to add questions or identify questions that they can now answer as they go along.**

   Keep the chart paper with the questions posted in the classroom throughout the activities in this module. You and your students will revisit them periodically to assess what questions they have answered and to ask new questions that may arise.

## Part 2: What Is a Scientist Like?

9. **Inform students that they will be communicating with a scientist during this module. Students will start this part of the lesson by considering what they currently think about scientists. Students should write 3 words or phrases that describe**
   a. **What a scientist is like?**

**b. What does a scientist do?**

Allow just a few minutes for students to record their ideas. The goal is to get student's current ideas—not ones that they ponder over and wonder if it is a "correct" answer. Reassure students that there are no "right" or "wrong" answers.

**10a. Give students a link to a survey called "What Is a Scientist Like?" PlantingScience will provide you with the link before you start teaching the module. Have students complete the short survey to record their initial thoughts about scientists.**

An integral part of this program is the online mentorship that students take part in with professional scientists. Many students will not have met a scientist before and their initial ideas may come from experiences with stories, television shows, movies, and other media sources. Studies have shown that students often have limiting, stereotypical views of scientists, both positive (*e.g.,* scientists are brilliant problem-solvers) and negative (e.g., scientists have trouble interacting socially with other people). Students also have limiting ideas about what scientists do (wear lab coats, work with glassware in a laboratory, work alone). Our experiences with PlantingScience show that students are often shocked to learn that their scientist mentors have pets or children, or that they enjoy current music or sports. The goal of this step is to allow students to reflect on their preconceptions about scientists, which will help them notice the ways in which the scientists they work with are the same or different from what they expected. At the end of the module students will revisit these ideas, reflect on how their experience may have reinforced or changed their ideas, and also discuss how the scientists working with different teams were similar and different from each other. Research suggests that guided reflection (individual and group) can be an effective way to expand limiting stereotypical views and increase the impact of experiences like this one.

**10b. Click on the link to see the results of the survey. You will see how your students responded. This information can be used as the basis for a short class discussion. The goal is not to determine what is "accurate" or "not accurate" at this time.**

The link will enable you to choose either to focus on the results of your class or to see the results from all classes that are using this module. You don't need to have a lengthy discussion about the results. You can just ask students to make some initial comments about any trends or patterns they see in the results. Students will spend more time analyzing ideas and patterns later in the module.

## Part 3: Getting Started with the Website

**11-12. During these steps, students get set up to use the PlantingScience website and start getting acquainted with its features.**

Have students complete the steps outlined in the Student's Guide. Alternatively, you can display Slide 2: *Getting Started on the PlantingScience Website* and walk through the steps with students.

Optional Slide

Slide 3 gives additional information for students about using the PlantingScience website. This information will be needed in Lesson 2 as students start posting and updating their projects on the website. This material is also included in the Student's Guide in the section, Getting Ready to Do an Investigation.

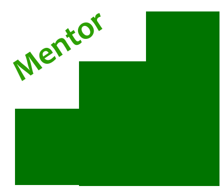
**Optional Slide**

## Part 4: Communicating with Your Mentor

13. **Students should log on to the PlantingScience website.** Distribute tickets to students and direct them to log in [www.plantingscience.org](http://www.plantingscience.org) using the password you set for them. Students will be prompted to:
    - a. **Accept the Terms of Use for the website.**
    - b. **Change their password.** Encourage them to write their new password on the ticket you gave them and to keep the ticket in their science notebook or in another safe, easily referenced place.

    **Note:** Instruct students to tape their ticket with their username and new password in their science notebooks. They will need this information each time they log onto the website.

14. **Direct students to find their Project in the Updates section, they should see a text box that they can use to introduce themselves to their mentor.**




Allow time for students to explore their project pages. Students should:

a. Look at the Members page to see who their mentor and liaison are.

b. Click on the names of their mentor and/or liaison to read their profiles. You might specifically direct students to find out what kind of research their mentor does, and pick one of the mentors' responses to the profile questions to read aloud to their group or to the class.

c. Post on the Updates feed and

- Introduce themselves. They might want to share things like
    - their interests
    - their experience with plants (Does their family garden? Do they have a favorite plant?)
    - their favorite subjects in school
    - their career goals
- Ask your mentor a question.
    - Did you have a question based on what you read about your mentor?

**NOTE: To ensure privacy and security, students should never post**

- **their last names.**
- **Post Google Docs or Google Drive links**

The next time that students log on, they should be able to see a response from their mentors, and possibly some questions the mentors have for them.

**15. As students work through the lessons in this module, they will continue to post messages for their mentors and to receive responses from their mentors.**

Things that are important for effective communication and for building a good working relationship with their mentors include:

- Carefully reading any messages posted by their mentors.
- Responding to questions asked by their mentors (even if their answer is "I don't know" or to ask a follow-up question if they do not understand the mentor's comment.)
- Updating and describing your team's progress and class activities.
- Asking one or two questions for the mentor to answer when they post again.

Handout 1

# How Does a Tree grow from a Small Seed into a Large Tree?

Write your observations and questions in the chart below.

| Observations | Questions |
| --- | --- |
| | |

Handout 2

## Constructing My Model

In science, a model is a representation of an idea, an object, or a process. It can be used to describe and explain phenomena. A model can include words or drawings. You may want to use arrows or other symbols to show connections or interactions between things.

During this module, you will be developing a model to explain how 1 small seed grows into 1 very large tree. When you start the model, you probably will not be able to explain everything. You may not even be sure your ideas are correct. Do not worry about that. You can add or change things as you learn more in the lessons that follow. The most important thing about creating your model is that it helps you form an explanation that is based on evidence you learn.

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Slide 1

**The Growth of a Giant Sequoia Tree**

**The General Sherman tree in the Sequoia and Kings Canyon National Park in California**

- The General Sherman tree is a sequoia tree that is 84 meters (275 feet) tall—and still growing. It is 31 meters (103 feet) around. Each year it adds enough wood to make another 18-meter (60 foot)-tall tree.
- The seed of the giant sequoia tree is very small—about the size of a grain of oatmeal.

**Seeds of a sequoia tree**


**A giant sequoia tree**

Slide 2

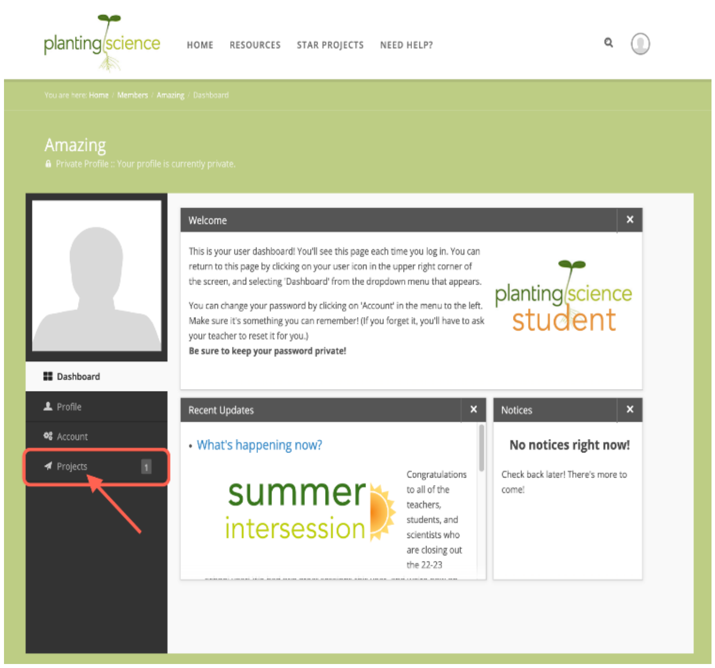
## Getting Started on the PlantingScience Website

Before you can start communicating with your mentor, you need to set up and learn about your account on the PlantingScience website.

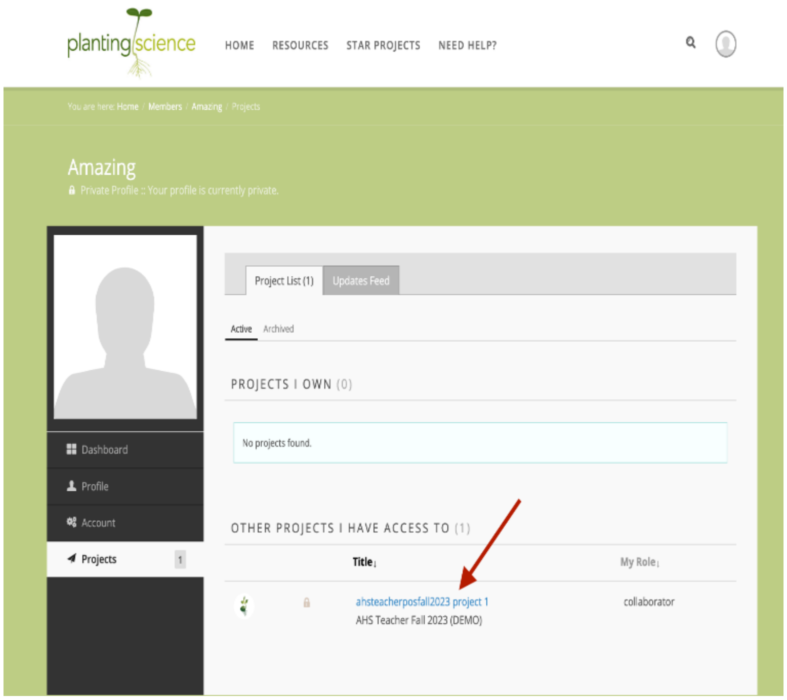
a. The first thing you will do is to log onto the site. Your teacher will provide you with a unique username and password. Remember to use this username (not your email address) to log in.

   **Remember, your password is case sensitive.*

b. Change your password after you log in.
c. Click on "Account" in the side menu to do this. Choose a password that you can remember easily and make sure to keep it private. Do not share it with other members of your team or class. (If you forget it later, you'll need to ask your teacher to reset it.)
   d. Take a couple of minutes to look through your user dashboard.
   e. Locate the "Projects" link on the side menu and click it to find your project page.



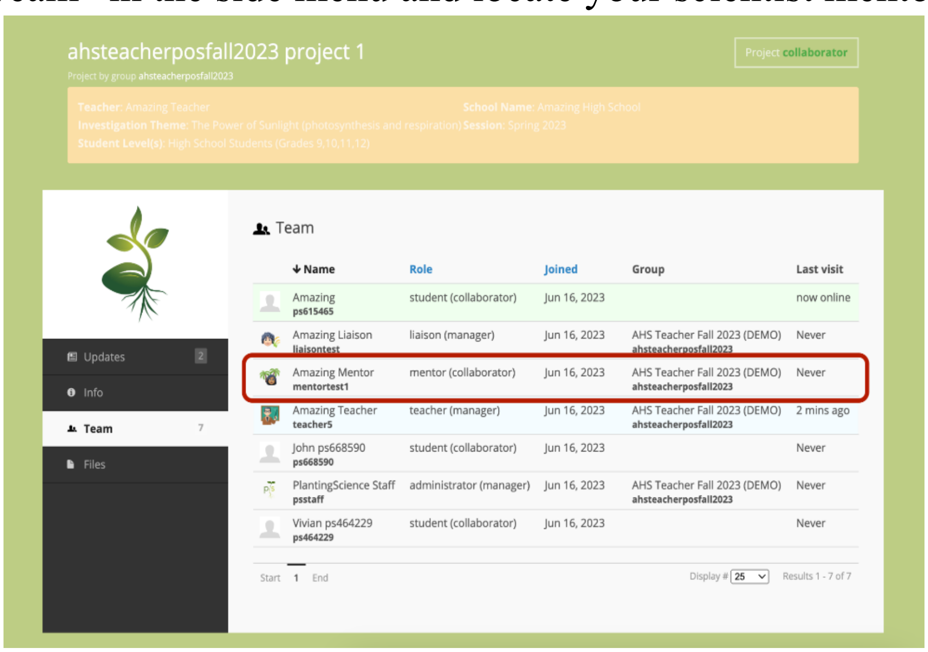

   f. Your project will appear at the bottom of this screen.




g. Click the name of the project to open your Project page.

10. Familiarize yourself with the layout of your Project page.

a. You'll be filling in the Info Fields during your project. Click on "Team" in the side menu and locate your scientist mentor:



b. Click on their picture to visit their profile page. Read the information to learn about your mentor's work and interests. (Note: if your team does not list a mentor, click on the 'Liaison' instead.)

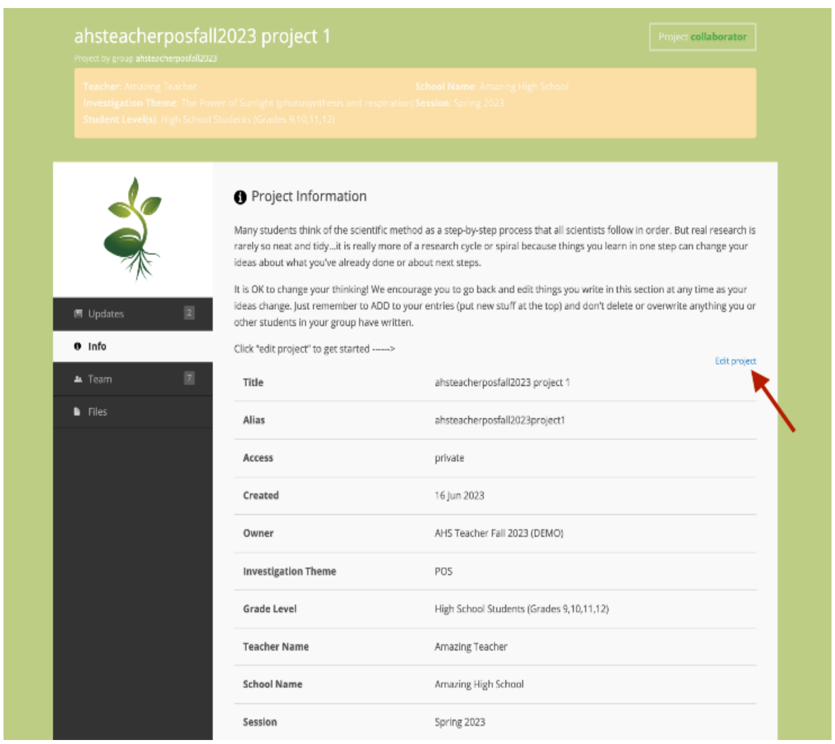
Slide 3

## Updating the Project Page

As you complete each of these stages, you will be updating your team's project page by editing the Info fields at the top.

Start by clicking on "Info" on the side menu to open the Project Information page.

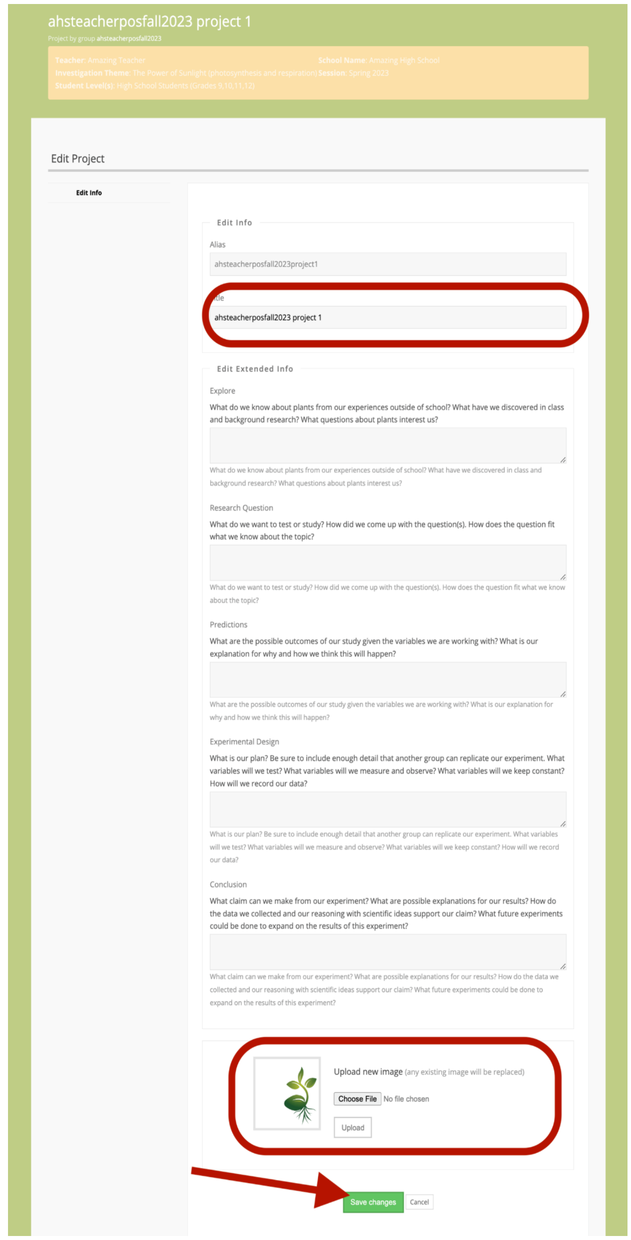
Look for the "Edit Project" link to the right of the Info fields.




You will update this screen frequently during your investigations based on what you have completed during class. You can also change the information that you added earlier if you decide that your project has changed.

## Personalizing Your Team

You can edit the name of your team or change the image on this screen. Make sure the name and image that you choose are appropriate for school.




## Complete Project Info Fields

The info field described here approximately match the steps of an investigation described in a previous section. Prompts will help remind you about what information should be included in each field.

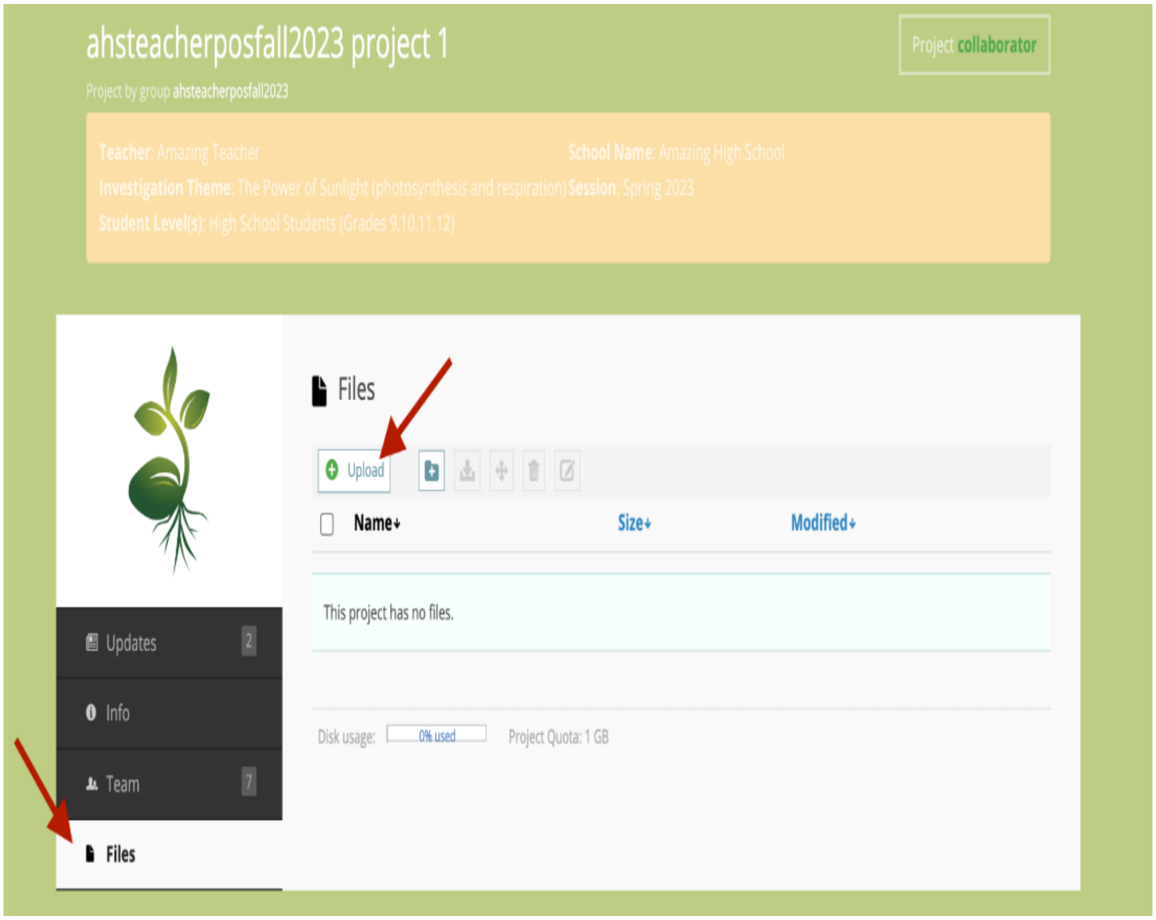
> **Remember to click SAVE!** If you leave this page without saving, your changes will not appear.

## Where do you describe your observations and data?

You can update observations and data for your mentor either as messages or by uploading photos or files.

> Click the "Files" link in the side menu of your project page. Then click "Upload" to attach your files.
>
> Do NOT include the last names of any team members in the files or photographs.

**IMPORTANT:** Do not post any Google Drive or Google Docs links in your updates. These will be removed to maintain privacy and security.



planting science

**Lesson 2**

# Guided Inquiry: Investigating Photosynthesis Using a Leaf Disk Floatation Method

**Overview**
In this lesson, students explore photosynthesis using a spinach leaf disk floatation method. Students investigate the research question, "How does carbon dioxide affect photosynthesis?" By comparing leaf disks submerged in water, bicarbonate solution, and water with carbon dioxide blown into it, students learn that carbon dioxide is an input necessary for photosynthesis. The teacher's role is to help students use evidence and sound reasoning to construct explanations, while also laying groundwork for recognizing the importance of experimental design.

**Time Required:** Approximately 3 class periods (45 minutes)

- **Day 1:** Opening discussion, demonstration, and beginning of the guided inquiry to gain experience with the method [Students can complete Steps 1–4, 9, and 10 (practicing infiltration). See the Note to Teachers following Step 4.]
- **Day 2:** Complete the guided inquiry to collect and analyze data (Steps 5–19).
- **Day 3:** Class discussion and introduction of the Synthesis Board (Steps 20–22).

**Learning Goals**

- Understand the use of leaf disks as a model for leaves
- Use the leaf disk flotation method as an indirect measure of photosynthesis
- Link the leaf disk method to a conceptual model for photosynthesis
- Discuss how an experimental design relates to a research question
- Identify and explain unexpected data

**Common Preconceptions and Student Biases**

- Plants produce oxygen for use by animals.
- Only green plants carry out photosynthesis.

Students may try to "adjust" data to meet expectations (i.e., their conceptual models for growth). If assessments stress explanations over "right answers," students may be more honest.

## Getting Ready

***Student's Guide* Section and Resources Used in Lesson**

| | |
|---|---|
| Investigating Photosynthesis Using a Leaf Disk Floatation Method from the *Power of Sunlight Student's Guide* | 1 copy per student |
| Observations and Questions charts | from previous activity |
| Reference 1: *Plant Structure and Photosynthesis* | 1 copy per student (if not using Student's Guide) |

| | |
|---|---|
| Reference 2: *Photosynthesis* | 1 copy per student (if not using Student's Guide) |
| Handout 3: *Practicing Preparing Leaf Disks* | 1 per student (optional) |
| Handout 4: *The Leaf Disk Investigation* | 1 per student (optional) |
| Handout 5: *Leaf Disk Investigation Data Table* | 1 per student (optional) |
| Handout 6: *Why Does Carbon Dioxide Dissolve in Water While Oxygen Does Not?* | 1 per student (optional) |
| Handout 7: *Making Sense of the Leaf Disk Investigation* | 1 per student (optional) |
| Teacher Page 1: *Answer Key for Student Questions* | Teacher use |

**Materials and Supplies**

| | |
|---|---|
| Chart paper | 1-2 sheets (may need to add more later) |
| Cardboard (approximately 20 inches square; size can vary) | 2 pieces for class demo |
| Balloons (see *Preparations*) | Approximately 15 green and 7 white |
| Transparent tape or masking tape | 1 roll for class demo |
| Science notebook | 1 per student (started in previous activity |
| Safety goggles | 1 per student |
| Clear, wide-mouth plastic cups | 3 per team* |
| Plastic straw | 1 per team |
| Baby spinach leaves | 2–4 leaves per team |
| Baking soda | Small box (will be more than enough for all activities in the module) |
| ¼ tsp. measuring spoon | 1–2 per class |
| Liquid dish or hand soap (diluted) | 50 mL per class (see Preparations) |
| Dropper bottles (for dilute soap solution) | 1 per class or 1 per team |
| Distilled water (room temperature) | Approximately 1 gallon per class |
| Single-hole paper punch (or plastic straw, No. 3 cork borer, or scissors) | 1 per team |
| Small pieces of paper (approximately 2" square or index cards (3 × 5 inch) | 3 per team |
| Small paint brush | 1 per team |
| 10-mL or larger disposable syringes, without needles | 3 per team |
| Permanent marker | 1 per team |
| Light source (40 W or more) | 1 per team (this could be a light bank with adjustable shelves or height used by the whole class) |
| Ruler | 1 per team |

| | |
|---|---|
| Hand lens | 1 per team |
| Stopwatch (cell phone), watch, or clock with a second hand | 1 per team |
| chart or butcher paper (large sheets for creating synthesis board) | several sheets (You will add to this over the remainder of the module.) |

*Students should work in teams of 3–4 for this investigation.

**Preparations**

Review the student and teacher procedures for the lesson.

Prepare leaf structure demonstration.

- Blow up balloons.
- Tape balloons to one piece of cardboard. Intersperse the white balloons among the green ones. Place the second piece of carboard on top so that balloons are in between the cardboard. The top piece of cardboard is not attached to the balloons.
- If you have any concerns about any allergies to balloons, you could do this same demonstration using circles cut from green and white construction paper.

Prepare dilute soap solution.

- Add approximately 1 mL of dishwashing liquid soap in 50 mL of water. Do this ahead of time so the soap fully dissolves into the water without making suds.
- Place the solution into a dropper bottle. If multiple dropper bottles are available, you can divide the solution equally into different bottles so that each team has a bottle.

Prepare spinach leaves.

- Spinach is the recommended plant material for the leaf disk floatation assay. Buy spinach from the grocery store (or a farmer's market) just before your classes begin the activity so they are fresh. Some teachers report getting better results if they place the spinach leaves under a bright light for a few hours before students begin the activity. You may also want to dampen the spinach leaves so they do not dry out.

Punch holes in straws.

- In this lesson and in Lesson 3, students will use straws to blow into solutions. In this lesson, they will blow into distilled water. As a safety precaution, put a hole into the side of the straw above the expected level of solution. This prevents students from sucking up any liquid. You can use a single hole paper punch (similar to what students use to cut leaf disks) to punch a hole in the side of a straw. You could also use a pin to create the hole.

Different protocols for the spinach leaf-disk investigation call for different ways to use the baking soda. Some protocols use a 0.2% solution (prepared in distilled water). The procedure in this module asks for students to add baking soda directly to the cup in their investigation. Tests that we have done show that 1/8 to ¼ tsp. in approximately 150 mL (volume used in 1 cup) of distilled water works well.

Prepare the Synthesis Board.

- On a piece of chart paper, write the heading "Synthesis Board." Under that, divide the sheet into two columns. On one side, write "Science Idea We Learned." On the other side, write, "Supporting Evidence." An example is provided below.

| **Synthesis Board** | |
|---|---|
| **Evidence** | **Science Idea We Learned** |

- Review *Tips for Using the Observation/Question Boards and the Synthesis Board in the Classroom* for more information about using the Synthesis Board more effectively in the classroom.
- Add additional chart papers as needed.
- Students will continue to add to this as they complete activities throughout the module.
- You may want to develop the Synthesis Board electronically. The important part is that the Synthesis Board remains visible to students throughout the module and that they refer to it and add to it as they progress through the lessons.

Students will use many of these same materials in Lesson 3.

## Procedure

**Note to Teachers:** The step numbers listed in these procedural steps match those in the *Student's Guide*.

### Part 1: Investigating Photosynthesis Using Leaf Disks

1. **Open the lesson by conducting a class discussion. Ask students to recall the question at the center of this module, "How does a tree grow from a small seed into a large tree?" Explain that they will be conducting an investigation to learn more about photosynthesis.**

   It is likely that, in the previous activity, students posted sticky notes on the Observations and Questions posters that relate to photosynthesis. If so, point those out to students and let them know they will be doing an investigation to find out more about photosynthesis. If the word "photosynthesis" is not mentioned, it is likely that some questions would relate to where the mass of a tree comes from or what does a tree need to grow. You could use those questions to link to exploring photosynthesis by saying something along the lines of "Does photosynthesis provide anything that trees need to grow?" Most students have probably heard something about photosynthesis from their work in earlier grades, but their understanding of it may be limited.

2. **A goal for this activity is to learn about the inputs and outputs of photosynthesis. Allow a couple of minutes for students to write in their science notebooks a few statements that summarize what they currently know about photosynthesis.**

   Encourage students to write their ideas down even if they are not sure about the accuracy of the statement. They can revise statements later that are incorrect.

3. **Students will be using small disks cut from spinach leaves for the investigation. Instruct students to pay attention as you conduct a brief demonstration.**

**Conduct the demonstration as follows:**

- Display to the class the cardboard "sandwich" that has the balloons attached to one of the pieces of cardboard.
- Explain that this is a model for a piece of a leaf.
- The cardboard represents the outside portion of the leaf—the part you see when you look at a leaf. Take off the top piece of cardboard and tell students that this represents a model of what they might see if they could look inside of the "leaf."
- State that the green balloons represent cells that are inside of the leaf and that the white balloons represent spaces between the cells in the leaf filled with air.
- Ask students what would happen if you put the leaf under a vacuum. (*Students should respond that the vacuum would pull air out.*)
- Ask a volunteer to come up and demonstrate what would happen in the model if the air was pulled out of the "leaf." (*Students should pull the white balloons off of the board.*)
- Ask, "If the leaf is in water, what would happen after you released the vacuum?" (*If the leaf is in water, when the vacuum is released, water would flow into the leaf spaces where the air used to be.*)

This demonstration will help students visualize the spaces between cells inside the leaf and appreciate the importance of the infiltration process, whereby air is drawn out of leaf disks using a syringe and replaced with carbon dioxide in liquid form (baking soda dissolved in water) or with plain water.

The reading, Reference 1: *Plant Structure and Photosynthesis*, provides additional information about the structure of leaves to give students more background information.

4. **Have students write the research question, "How does carbon dioxide affect photosynthesis?" in their science notebooks. The investigation they are about to carry out will help answer this question.**

If there are similar questions on the question board started in the previous activity, ask students to write those questions in their science notebook.

**Note to Teachers:** If time permits, it would be helpful if students have the opportunity to practice preparing and infiltrating leaf disks before conducting their actual investigation. To do this, have students follow the steps on Handout 3: *Practicing Preparing Leaf Disks*. For the practice, students can use plain water for the infiltration. They will use other solutions for the actual investigation. This can be helpful so that when time comes for the experiment, some team members can prepare the leaf disks while others set up the cups and other parts of the experiment.

Optional Handout

5–6. **Students should work in teams of 3–4 for this investigation. During these steps, students should read through the complete procedure so they are familiar with the steps before starting. They will also gather their materials.**

These steps should be fairly straightforward for students. However, if your students do not have much experience following a procedure, you may want to go over the steps one by one to make sure they understand what they are supposed to do.

If there is not an opportunity for students to practice the preparation of leaf disks and the infiltration, you could do a demonstration for the class.

**Note to Teachers:** The complete instructions for performing the leaf disk investigation are in the Student's Guide. If you are not using the student guide, the instructions are included on the optional Handout 4: *The Leaf Disk Investigation*.

**Optional Handout**

**7-8. Students prepare the solutions they will need for their investigation. They can also read information about carbon dioxide in an aqueous form. This may help them understand the investigation better.**

Students will use different solutions for their investigation. One is plain water. The other two solutions involve adding carbon dioxide to the water (either in the form of baking soda which breaks down into carbon dioxide and water or by blowing into the water to add carbon dioxide from their breath.

The following text box presents some information about what happens to carbon dioxide in water. This can be helpful information for students who question why they don't see carbon dioxide bubbles in water. The main thing they need to understand is that they don't see bubbles of carbon dioxide in water because carbon dioxide is soluble in water.

**What Happens to Carbon Dioxide in Water?**

Let's think about carbon dioxide. You probably know that carbon dioxide is a gas in the air around us. But did you know that carbon dioxide can exist in other forms? Have you ever seen dry ice? Dry ice is carbon dioxide in a solid form. Did you know that carbon dioxide can also be in an aqueous form in water? Carbon dioxide actually dissolves in water. Most oxygen molecules do not dissolve in water, but instead they cluster together to form bubbles. In fact, at the growing temperatures for most plants, about 40 times more carbon dioxide than oxygen dissolves in water.

How can we add carbon dioxide to water? What happened when you blew air into the water? When you blew through the straw, you were exhaling carbon dioxide into the water. Most of this carbon dioxide dissolves in the water—so you won't see bubbles or anything to know it is there. Even so, the carbon dioxide is changing from a gas to an aqueous form.

$$CO_2\text{ (gas)} \longrightarrow CO_2\text{ (aqueous)}$$

You also added baking soda to a different cup of water. Baking soda, whose chemical name is sodium bicarbonate, has the chemical formula of $NaHCO_3$. In water, the atoms in sodium bicarbonate come apart as seen below:

$$NaHCO_3 \xrightarrow{\text{in water}} CO_2 + H_2O + Na^+$$

**9. Students cut out their leaf disks.**

Advise students to prepare extra leaf disks. (The procedure says to make 36–40 leaf disks. Students should use 10–12 disks for each of the 3 treatments conditions.) Having extra leaf disks will ensure that they have enough in case some disks get damaged or do not infiltrate as expected.

**10. In this step, students infiltrate 1 set of 10-12 leaf disks with an experimental solution consisting of water that a student has exhaled into for 60 seconds.**

The syringes pull air out of the intercellular spaces within the leaf disks. When the vacuum is released, the air that occupied those spaces is replaced with either water or bicarbonate solution. Because the air is replaced with liquid, the disks will lose buoyancy and sink to the bottom of a cup rather than float.

**TIP:** You may ask students to mark their syringes with the solution they will be using. For example, label one syringe "water," one "baking soda," and the third one "breath." Students will use these syringes again (when they do the actual experiment if practicing infiltration and in Lesson 3).

**11–13. In these steps, students complete the infiltration process for the other 2 experimental conditions and prepare for their experiment.**

**14. Students should record their predictions for what will happen to the leaf disks in their science notebooks.**

**15. Recording the results of experiments is an important step. Students should create a data table similar to the example in the *Student's Guide* in their science notebooks.**

Everyone's data will be slightly different. Students should leave room in their data table to collect data at additional time points.

The *Student's Guide* directs students to create a data table in their notebooks for recording their data from this investigation. Handout 5: *Leaf Disk Investigation Data Table*, provides an alternative if desired.

**Optional Handout**

**16–19. Allow approximately 45 minutes for students to conduct their investigation (including up to 25 minutes for data collection).**

During these steps, students will:

16. Place their 3 cups in the appropriate spots for testing.
    - The cups should be placed close to a light source. They should NOT turn the light on until they are ready to start timing their experiment.
    - The 3 cups should be an equal distance from the light (2–5 cm between the light and the liquid).

- Students should measure the distance between the light and the top of the liquid in their cups (or the side of their cups, depending on whether the light is over the cups or to the side of the cups).
- Students should record the distance between the light and the liquids in the cups in their notebooks.

17. Record the number of leaf disks that are floating or not floating in each cup in the data table. This is time zero.
18. Start a timer or stopwatch when they begin the treatment to keep accurate data. The treatment begins when they turn the light on.
19. Count the number of leaf disks that are floating in each cup at one-minute intervals after they begin treatment and record these numbers in the data sheet they prepared beforehand.
    - They can also use a hand lens to look at the leaf disks during the investigation.
    - After about 25 minutes, they can stop collecting data.

As the experiment proceeds, students should see leaf disks in the breath cup and the baking soda cup begin to float. On average, the leaf disks will start to float within 10 minutes of beginning the investigation, and all the disks will probably float within about 20–25 minutes. However, different student teams are likely to get somewhat different results depending on their leaf disks, the amount of baking soda used, distance between the light source and the liquid in the cups, and so forth. The amount of time is less important than the observed result of leaf disks floating or not floating depending on the liquid in the cup.

**Troubleshooting**

**If leaf disks do not sink**, air bubbles may be trapped on the surface of the leaf disks or infiltration may be incomplete. Small amounts of liquid soap may help reduce surface tension and enhance the infiltration process.

**If leaf disks do not float**, the problem is likely due either to a concentration of carbon dioxide (baking soda or breath) that is too low or to damaged or otherwise unhealthy leaf tissue. In general, it should be adequate to use 1/8 to ¼ teaspoon of baking soda in their cup. The spinach leaves should be as fresh as possible. However, it is likely that you may see differences across different packages of spinach. If leaf disks adhere to the bottom of a cup, they can be released by gentle tapping.

In this leaf disk floatation assay, the leaves that are in a solution containing carbon dioxide (the **breath** cup and the **baking soda** cup) will float because photosynthesis takes place and produces oxygen bubbles. The leaf disks in plain water do not have a source of carbon dioxide and cannot carry out photosynthesis, so the leaf disks remain submerged.

Students may observe bubbles forming around the edges of the leaf disks in the **breath** cup and the **baking soda** cup. Some students may surmise these bubbles to be oxygen, whereas other students may be confused as to their identity. Although students cannot be sure what gas the bubbles contain, they may use the photosynthesis reaction to guess that these are oxygen because according to the reaction, oxygen is an output of photosynthesis.

The issue of the bubbles' composition can be confusing. It is important to remember that carbon dioxide readily dissolves in water—so you do not see bubbles containing carbon dioxide. In fact, carbon dioxide is about 40 times more soluble in water than is oxygen. You see bubbles of oxygen because the oxygen is not very soluble in water. Because oxygen gas is less dense than water, the oxygen bubbles produced by photosynthesis cause the leaf disks to float.

Optional Handout

If you feel that your students can benefit from Handout 6: *Why Does Carbon Dioxide Dissolve in Water While Oxygen Does Not?*, give each student a copy of this reading. It will give students additional background on the chemistry of carbon dioxide and what happens when it dissolves in water. This reading may be most advantageous if students have previously had chemistry. If you feel that this reading is too advanced for your students, you can simply explain that carbon dioxide molecules are surrounded by water molecules, and the carbon dioxide molecules dissolve into the water. Oxygen molecules, on the other hand, cluster together away from the water molecules, forming bubbles. Carbon dioxide forms hydrogen bonds with water molecules whereas oxygen molecules do not.

**20. Have teams work together to discuss and answer the questions in this step. Students should write their own answers in their science notebooks.**

Sample answers to these questions are provided on Teacher Page 1: *Answer Key for Student Questions*.

Reference 2, *Photosynthesis*, may provide additional information that will help students make sense of their experimental data. Encourage students to create diagrams to help them develop and supplement their explanations. Diagramming can be a good shorthand for students to get their working ideas on paper—scientists often use this approach, too! If students are not used to sketching out their thoughts in pictures, you can model this by drawing pictures as the class develops a working model.

Optional Handout

The student guide includes several questions to help students make sense of their experimental results. If you choose, you could give students a copy of Handout 7: *Making Sense of the Leaf Disk Investigation*, instead of using their science notebooks directly. When complete, students could tape or staple the handout into their science notebooks.

**21. Hold a class discussion about the results of the investigation and what they learned about photosynthesis. This is the time to introduce the Synthesis Board, on which students will add information from their investigation to answer the big question**

Building Your Explanation Opportunity

**for the module, "How does a tree grow from a small seed into a large tree?" When students suggest additions to the synthesis board,**

- **ask them to also to discuss the evidence that leads them to their statement/addition to the synthesis board; and**
- **identify things that they think may be true but are not sure of or for which they need more evidence.**

The goal for the Synthesis Board is for students to collectively summarize what they have learned in this activity and use that information to help answer the module's main question. You may also want to point out questions from their initial observations and questions (from the first activity) and ask if they can now answer those questions.

*See *Tips for Using the Observation/Question Boards and the Synthesis Board in the Classroom* for more information about using the Synthesis Board more effectively in the classroom.

Examples of things that could be added to the synthesis board might include:

| Synthesis Board | |
|---|---|
| **Evidence** | **Science Idea We Learned** |
| The leaf disks in the baking soda cup and the breath cup floated. The ones in the water cup did not. | Photosynthesis requires carbon dioxide as an input |
| We observed bubbles on the edges of the leaf disk right before they floated and after they rose to the top. | A gas is an output of photosynthesis, but we can't tell from the experiment what that gas is. |
| You cannot determine from the experiment what the gas is, but the reading informs us that oxygen is an output of photosynthesis. | The gas produced during photosynthesis is oxygen. |

Students will add to this synthesis board as the lessons progress. The goal now is for students to get more comfortable sharing their ideas and research findings.

**22. Allow a few minutes for students to add to their model that they started in Lesson 1.**

## Part 2: Catching Up with Your Mentor

**23. Students can continue their conversation with their scientist mentors online.**

Mentor

Have students log into the PlantingScience platform and go to their Project pages to check the updates feed to see if they have a response from their mentor. If they do students should:

- **Respond to any questions.** This is an important step, and one that students often skip. Encourage them to read the mentors' response carefully and click 'reply' to answer any questions the mentor asked.
- **Compose and post an update.** Students can do this individually or have one member post an update for the group. Encourage them to summarize what they did during the day's activity and what they learned.
- **Ask one or two new questions for the mentor to answer.** These questions may arise from the day's activity or from the mentor's post.

**Additional Resources**
Additional videos, webpages, books, and articles to support teaching and learning about photosynthesis can be found in the PlantingScience *Photosynthesis and Respiration Resources* page.

**Additional Investigation Ideas**
Students may want to investigate other plants (including those with different colored leaves) to see if they respond in a similar way to spinach leaves. Alternatively, they might want to investigate whether photosynthesis occurs in other parts of a plant. Some plants will have a waxy coating or hairs that will make it difficult to use the leaf disk floatation method, and it can be helpful for students to get experience with a wide range of leaves early on to inform their later experimental choices.

If time permits, students could conduct these experiments, or you might encourage students to write their ideas in their notebook so they can refer back to them when they do their independent investigations later.

Handout 3

# Practicing Preparing Leaf Disks

1. Make your leaf disks.
   1a. Choose the darker green leaves. This works best with healthy plant material.
   - For practice, you will make about 10-15 leaf disks. (You will need more when you do the actual experiment.)

   1b. Use a paper hole punch to punch out your leaf disks.
   - Avoid the heavy leaf veins.
   - Put the disks onto a piece of paper or index card. This will make it easier to pour all the disks into the syringe in Step 2b.
   - Use a small brush to help move the leaf disks around without damaging them.

2. Remove the gases inside the leaf disks and infiltrate them with water. (You will use different solutions when you do the experiment.)
   2a. First, remove the plunger from the syringe.
   2b. Pour the leaf disks into the barrel of the syringe.
   2c. Tap the syringe on the table or in your hand so that the leaf disks move toward the narrow end where a needle would normally go. A small brush may help you move the disks down farther into the syringe barrel.
   2d. CAREFULLY push the plunger back into the syringe.
   - Avoid damaging the leaf disks.
   - Push the plunger nearly all the way into the barrel—about 1/10th of the way from the tip. You want to leave enough space so you don't damage the disks.

   2e. Place the syringe tip into a small cup of water and pull up some of the solution until the syringe is about 1/3 full.
   2f. Holding the tip of the syringe upwards, tap the side of the syringe to get the leaf disks down into the liquid as much as possible.
   2g. Hold the tip of the syringe upwards. Push out any air from the syringe that you can but be careful of the leaf disks.
   2h. Continue holding the syringe with the tip upward. Cover the tip of the syringe with your finger. Slowly pull back on the plunger a bit (to about the 2 or 3 cc mark on the syringe) with your finger still blocking the open tip. You will feel a vacuum pulling on your fingertip.
   - You may notice your leaf disks darkening in color and/or sinking as they become infiltrated with the solution.

2i. Hold the vacuum for about 10 seconds. Then, gently release the plunger while continuing to hold your finger over the tip of the syringe. You should see at least some of the leaf disks sink.

**Careful!** Keep the syringe pointing upward throughout Steps 10f–i.

2j. Take your finger off the tip of the syringe. If there is air space at the top of your syringe, push the syringe plunger to get rid of the air.

2k. Pull a vacuum 3 more times or until all of the leaf disks sink in the solution.
- If you have done this 5 times and some leaf disks are still floating, add more soap to the solution and try again.

2l. Once all leaf disks have sunk, they are ready for testing.

2m. Pour the infiltrated leaf disks into the cup of water. To transfer the leaf disks from the syringe to the cup, hold the syringe sideways over the cup. Gently pull the plunger out of the syringe. When the plunger comes out, the disks should flow with the liquid in the syringe into the cup.
- If some of the leaf disks get stuck. Pour a small amount of the liquid back into the syringe and then pour out the liquid and leaf disks again.

You have now successfully practiced preparing the leaf disks. When you do the experiment, you will use different solutions, but the procedure with the syringes will be the same.

Handout 4

# The Leaf Disk Experiment

1. Prepare solution for three different treatment conditions:
   1a. Label the three cups as follows:
   **Baking soda**
   **breath**
   **water**
   1b. Add distilled water to each cup to a level about 3 cm deep.
   1c. To the cup labeled **"baking soda,"** add 1/8 to ¼ teaspoon of baking soda. Stir to dissolve.
   1d. Next, work with the cup labeled **"breath."** Using a straw inserted *into* the water (not just above the water), blow for 60–90 seconds. Don't blow too hard! You want to keep the water in the cup!
   1e. To the cup labeled **"water,"** do not add anything.
   1f. Add 1–2 drops of diluted liquid soap to all 3 cups and stir until thoroughly mixed. Do not stir vigorously and make suds!
   1g. Set the cups to the side while you continue with the setup.

2. The information in the shaded box below helps you understand the different treatment conditions. Use this information to answer the following questions in your science notebook.

   2a. What are you adding to the water when you blow into it?
   2b. What are you doing when you add baking soda to the water?
   2c. How is blowing into the water similar to adding baking soda to the water?

**What Happens to Carbon Dioxide in Water?**

Let's think about carbon dioxide. You probably know that carbon dioxide is a gas in the air around us. But did you know that carbon dioxide can exist in other forms? Have you ever seen dry ice? Dry ice is carbon dioxide in a solid form. Did you know that carbon dioxide can also be in an aqueous form in water? Carbon dioxide actually dissolves in water. Most oxygen molecules do not dissolve in water, but instead they cluster together to form bubbles. In fact, at the growing temperatures for most plants, about 40 times more carbon dioxide than oxygen dissolves in water.

How can we add carbon dioxide to water? What happened when you blew air into the water? When you blew through the straw, you were exhaling carbon dioxide into the water. Most of this carbon dioxide dissolves in the water—so you won't see bubbles or anything to know it is there. Even so, the carbon dioxide is changing from a gas to an aqueous form.

$$CO_2 \text{ (gas)} \longrightarrow CO_2 \text{ (aqueous)}$$

You also added baking soda to a different cup of water. Baking soda, whose chemical name is sodium bicarbonate, has the chemical formula of $NaHCO_3$. In water, the atoms in sodium bicarbonate come apart as seen below:

$$NaHCO_3 \xrightarrow{\text{in water}} CO_2 + H_2O + Na^+$$

3. Make your leaf disks.
   - 3a. Select enough leaves to make about 36–40 leaf disks.
     - This method works best with healthy plant material. Choose the darker green leaves.
     - Make enough leaf disks so that you have at least 10 disks per treatment condition. (Starting with a few extra disks is helpful in case a few get damaged.)
   - 3b. Use a paper hole punch to punch out your leaf disks.
     - Avoid the heavy leaf veins.
     - Put the disks onto the card. This will make it easier to pour all the disks into the syringe in Step 4b.
     - Use a small brush to help move the leaf disks around without damaging them.

4. Remove the gases inside the leaf disks and infiltrate them with the 3 solutions prepared in Step 1.
   - 4a. First, remove the plunger from the syringe.
   - 4b. Pour about 12 leaf disks into the barrel of the syringe.
   - 4c. Tap the syringe on the table or in your hand so that the leaf disks move toward the narrow end where a needle would normally go. A small brush may help you move the disks down farther into the syringe barrel.
   - 4d. CAREFULLY push the plunger back into the syringe.
     - Avoid damaging the leaf disks.
     - Push the plunger nearly all the way into the barrel—about 1/10th of the way from the tip. You want to leave enough space so you don't damage the disks.
   - 4e. Place the syringe tip into the breath + soap solution (from the **breath** cup) and pull up some of the solution until the syringe is about 1/3 full.
   - 4f. Holding the tip of the syringe upwards, tap the side of the syringe to get the leaf disks down into the liquid as much as possible.
   - 4g. Hold the tip of the syringe upwards. Push out any air from the syringe that you can but be careful of the leaf disks.
   - 4h. Continue holding the syringe with the tip upward. Cover the tip of the syringe with your finger. Slowly pull back on the plunger a bit (to about the 2 or 3 cc mark on the syringe) with your finger still blocking the open tip. You will feel a vacuum pulling on your fingertip.
     - You may notice your leaf disks darkening in color and/or sinking as they become infiltrated with the solution.

4i. Hold the vacuum for about 10 seconds. Then, gently release the plunger while continuing to hold your finger over the tip of the syringe. You should see at least some of the leaf disks sink.

**Careful!** Keep the syringe pointing upward throughout Steps 10f–i.

4j. Take your finger off the tip of the syringe. If there is air space at the top of your syringe, push the syringe plunger to get rid of the air.

4k. Pull a vacuum 3 more times or until all of the leaf disks sink in the solution.
- If you have done this 5 times and some leaf disks are still floating, add more soap to the solution and try again.

4l. Once all leaf disks have sunk, they are ready for testing.

4m. Pour the infiltrated leaf disks into the cup with breath + soap solution **(breath** cup). To transfer the leaf disks from the syringe to the cup, hold the syringe sideways over the cup. Gently pull the plunger out of the syringe. When the plunger comes out, the disks should flow with the liquid in the syringe into the cup.
- If some of the leaf disks get stuck. Pour a small amount of the liquid back into the syringe and then pour out the liquid and leaf disks again.

5. Repeat the infiltration process (Steps 10a–m) using the other 2 solutions [the water + soap solution **(water** cup) and the baking soda + soap solution **(baking soda** cup)].

   **Hint:** One team member can infiltrate disks for the **breath** cup at the same time other team members infiltrate disks for the **baking soda** or the **water** cup.

6. Adjust the volume of solution in each cup by eye so that they have the same amount of liquid in them. About 2 cm deep is sufficient.

7. Count the number of leaf disks in each cup. Try to use the same number of leaf disks in each cup. All leaf disks should be at the bottom of the cups after infiltration. You can remove any floating disks if you have at least 10 disks that are at the bottom of the cup.

planting science

Handout 5

# Leaf Disk Investigation Data Table

| Time (minutes) | Breath cup | | Baking soda cup | | Water cup | |
|---|---|---|---|---|---|---|
| | Number floating | Number NOT floating | Number floating | Number NOT floating | Number floating | Number NOT floating |
| 0 | | | | | | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
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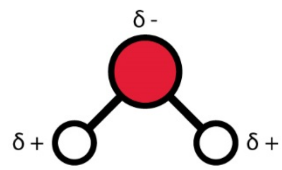
Handout 6

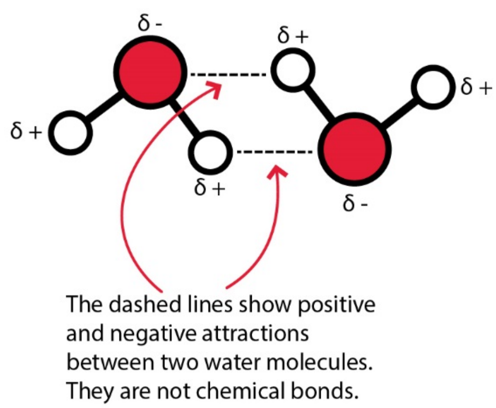
# Why Does Carbon Dioxide Dissolve in Water While Oxygen Does Not?

**Water**

You may know that a water molecule has one atom of oxygen and two atoms of hydrogen. Oxygen and hydrogen share electrons, forming chemical bonds between the atoms. These electrons are not shared equally, however. The oxygen atom attracts the electrons more strongly than the hydrogen atoms do. The electrons spend more time near the oxygen atom than they do near the hydrogen atoms. As a result, the oxygen atom in each water molecule has a slight negative charge, while each hydrogen atom has a slight positive charge. When electrons in a chemical bond share electrons but don't share them equally, we describe the bond as a polar covalent bond. We draw the chemical structure like this:



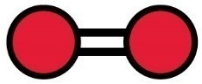

The red circle indicates the oxygen atom, the smaller white circles indicate hydrogen atoms, and δ stands for "partial." Each line represents two electrons that are shared between the atoms. The slight charges on the atoms within the water molecule are attracted to the slight charges on atoms within other water molecules:




The dashed lines are not chemical bonds and do not show shared electrons. The dashed lines simply show the positive side of one water molecule being attracted to the negative side of another water molecule.

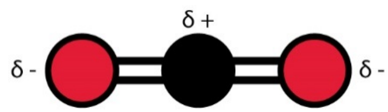
**Oxygen**

The two atoms in an oxygen molecule also form chemical bonds by sharing electrons. Because the two atoms in this gas are identical, these electrons are shared equally and so the molecule does not have slightly charged areas—the molecule is not polar. When electrons in a covalent bond are shared equally, we describe the bond as a nonpolar covalent bond. The chemical structure is shown as:



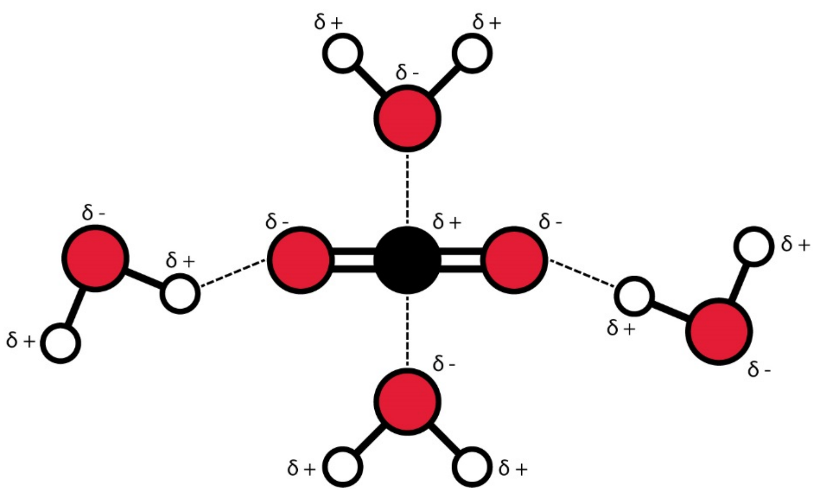
**Carbon dioxide**

In a carbon dioxide molecule, two pairs of electrons are shared between each oxygen atom and the carbon atom. The atoms are linked in chemical bonds. (The black circle below indicates the carbon atom.) As in water, the oxygen atoms attract the electrons the most. The electrons spend more time near the oxygen atoms than they do near the carbon atom. Thus, the oxygen atoms each have a slightly negative charge while the carbon atom has a slightly positive charge:



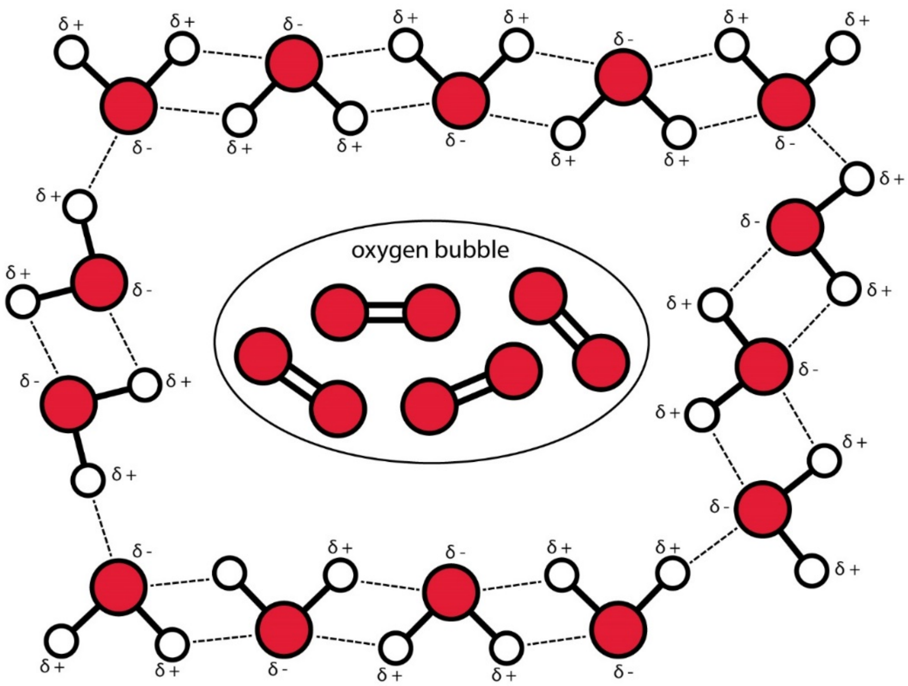

**Carbon dioxide and oxygen in water**

Because of the slight partial charges on atoms in a carbon dioxide molecule, a carbon dioxide molecule can be attracted to a water molecule:




When carbon dioxide is added to water, each carbon dioxide molecule is completely surrounded by water molecules. Carbon dioxide is still a gas, but the gas has dissolved in the liquid water. Carbon dioxide won't form bubbles in water unless there is a very high concentration of carbon dioxide (as is the case with soda drinks).

Unlike carbon dioxide, oxygen does not have partial charges on its atoms. Therefore, it won't be attracted to water molecules. But water molecules are attracted to other water molecules. The water molecules will tend to stick to each other. Because the water molecules tend to stick to each other, the oxygen molecules won't be surrounded by water molecules as much as carbon dioxide molecules are. Instead, the oxygen molecules will tend to cluster together away from the water molecules. In other words, oxygen doesn't dissolve as well as carbon dioxide does. Of course, oxygen does dissolve in water a little bit—if it didn't, all the fish would die. We won't go into the details of how a completely nonpolar covalent molecule can dissolve in water; the important point is that polar covalent molecules like carbon dioxide dissolve more easily than nonpolar covalent molecules like oxygen.



Handout 7

# Making Sense of the Leaf Disk Investigation

**Research Question:** How does carbon dioxide affect photosynthesis?

| **What evidence from your leaf disk experiment helps you answer your research question?** (You can continue on another piece of paper if you want more space.) | **Related science ideas** (You may have information from the reference readings or even prior activities that relate to evidence from your experiment.) |
|---|---|
| *Example:* Bubbles formed around the edges of the leaf disks in the water with baking soda and in the water that was breathed into. | *Example:* The leaf disks floated because the gas inside them is less dense than water. |
| | |
| | |
| | |

Write a one sentence answer to your research question.

| |
|---|
| |

How did your results compare with your predictions?

What did you learn from the demonstration that helped you understand the leaf disk activity?

Were the results of your experiment similar to those of other teams? If not, can you think of reasons to account for the differences?

Did you notice anything during your experiment that seemed unusual or problematic? Please describe and explain why it was a problem.

How might you respond if someone asked, “How do you know that your experiment worked from a technical point of view?”

**Hint:** *Think about your procedure. How are controls important for answering this question?*

Refer back to the ideas about photosynthesis that you wrote for Step 2 in your science notebook. Do your experimental data provide information that either supports or contradicts some of your initial ideas about photosynthesis? Please explain.

# Answer Key for Student Questions

21a. Use the following chart to describe in your science notebook what you learned from your data.

| **What evidence from your leaf disk experiment helps you answer your research question?** (You can continue on another piece of paper if you want more space.) | **Related science ideas** (You may have information from the reference readings or even prior activities that relate to evidence from your experiment.) |
|---|---|
| *Example:* Bubbles formed around the edges of the leaf disks in the water with baking soda and in the water that was breathed into. | *Example:* The bubbles caused the leaf disks to float because gas is less dense than water. |
| Bubbles were not seen in the leaf disks in distilled water. | Oxygen is an output of photosynthesis. |
| Leaf disks floated in the cups with carbon dioxide (either from baking soda or from breath). | Oxygen is an output of photosynthesis and the gas formed causes the leaf disks to float. |
| Bubbles do not form when baking soda is added to water but form as the experiment progresses. | Carbon dioxide is much more soluble in water as compared to oxygen. |

21b. Write a one sentence answer to your research question.

| |
|---|
| How does carbon dioxide affect photosynthesis?<br>Carbon dioxide is necessary for photosynthesis to occur. |

21c. How did your results compare with your predictions?

Answers will vary depending on the students' predictions.

21d. What did you learn from the demonstration that helped you understand the leaf disk activity?

The hope is that the demonstration helped students realize that inside leaves are air spaces between the leaf cells. When these air spaces are removed under vacuum, surrounding liquid can rush in to fill those spaces. This concept is critical to understanding why the leaf disk method can be used to study photosynthesis.

21e. Were the results of your experiment similar to those of other teams? If not, can you think of reasons to account for the differences?

Answers will vary. If the leaf disk method is working, then most teams will see similar results, though variation in how fast the leaf disks sink will be expected. This variation may be due to the condition of the leaf tissue and/or how effectively the infiltration process was carried out.

21f. Did you notice anything during your experiment that seemed unusual or problematic? Please describe and explain why it was a problem.

Answers will vary. Even when the leaf disk method is carried out properly some students may report that air bubbles were trapped on the surface of leaf disks. Other problems commonly reported include "sticky" leaf disks that adhere to the syringe or cup or leaf disks that refuse to float or sink.

21g. How might you respond if someone asked, "How do you know that your experiment worked from a technical point of view?"

**Hint:** *Think about your procedure. How are controls important for answering this question?*

Assuming that the leaf disks in the sodium bicarbonate solution did float in response to the light, then the logical reason for this observation is that photosynthesis used carbon dioxide dissolved in the water to produce oxygen bubbles that caused the leaf disks to float. The other two experimental treatments serve as controls that support this claim. The **breath** cup contained water that someone breathed into for 60 seconds. Since we breathe out carbon dioxide, the fact that the leaf disks in this cup floated suggests that carbon dioxide from breath was used to support photosynthesis. The water cup lacked carbon dioxide and therefore would not support photosynthesis. Without the oxygen produced from photosynthesis, the leaf disks in water could not become more buoyant and rise to the surface.

21h. Refer back to the ideas about photosynthesis that you wrote in your science notebook for Step 2. Do your experimental data provide information that either supports or contradicts some of your initial ideas about photosynthesis? Please explain.

Answers will vary depending on the initial ideas expressed by the students.

Lesson 3

# Guided Inquiry: Investigating Light and Dark

**Overview**
In this lesson, students conduct two investigations to learn about the effects of light and dark on plants. Students also will be challenged to make decisions about the experimental design that they use for the investigation.

**Time Required:** Approximately 2 or 3 45-minute class periods

- **Day 1:** Opening discussion, experiment planning, review experimental design (Students can complete Steps 1–4.)
- **Day 2:** Complete guided inquiries to collect and analyze data (Part 1, Steps 5–8 and Part 2, Steps 9–13, and Part 2, Steps 16-–25).
- **Day 3:** Class discussion of experimental and continue development of synthesis board

**Learning Goals**
During this guided investigation, students will

- use an indicator solution to learn about the effects of light and dark conditions on plants,
- extend their use of the leaf disk floatation method to learn how light and dark conditions affect photosynthesis,
- use the leaf disk floatation method to learn about the process of cellular respiration in leaves,
- link the leaf disk floatation method to a conceptual model for photosynthesis and cellular respiration,
- modify the experimental design for the method to answer a new research question, and
- identify and explain unexpected data.

**Common Preconceptions and Student Biases**

- Plants photosynthesize and animals use cellular respiration. (Photosynthesis occurs in plants and cellular respiration occurs in animals.)
- Students may try to "adjust" data to meet expectations (i.e., their conceptual models for growth). If assessments weight explanations over "right answers," students may be more honest.

## Getting Ready

***Student's Guide* Section and Resources Used in Lesson**

| | |
|---|---|
| Using the Leaf Disk Floatation Method to Answer New Questions from the *Power of Sunlight Student's Guide* | 1 copy per student |
| Reference 3: *Cellular Respiration* (see Student Guide) | 1 copy per student (if not using Student's Guide) |
| Reference 4: *More about Photosynthesis* (see Student Guide) | 1 copy per student (if not using Student's Guide) |

| | |
|---|---|
| Handout 8: *Planning Your Experiment* | 1 copy per student (optional) |
| Handout 9: *Data Table* | 1 copy per student (optional) |
| Handout 10: *Making Sense of Your Investigation* | 2 copies per student (optional) |
| Handout 11: *The Elodea Experiment* | 1 copy per student (optional) |
| Slide 4: Phenol Red Is an Indicator | 1 to project (optional) |
| Teacher Page 2: *Answer Key for Student Questions* | Teacher use |

**Materials and Supplies**

| | |
|---|---|
| Science notebook | 1 per student |
| **Part 1: Another Investigation with Leaf Disks** | |
| Clear, wide-mouth plastic cups | 2 per team* |
| Baby spinach leaves | 2–4 leaves per team |
| Baking soda | Small box |
| Liquid dish or hand soap (diluted) | 1 small container per team (see *Preparation* in Lesson 2) |
| Distilled water (room temperature) | Approximately 2 L |
| Single-hole paper punch (or plastic straw, No. 3 cork borer, or scissors) | 1 per team |
| Small pieces of paper (approximately 2” square or 3 × 5” index cards) | 2 per team |
| Small paint brush | 1 per team |
| 10-mL or larger disposable syringes, without needles | 2 per team |
| Permanent marker | 1 per team |
| Light source (40 W or more) | 1 per team (this could be a light bank with adjustable shelves or height used by the whole class) |
| Ruler | 1 per team |
| Hand lens | 1 per team (optional) |
| Stopwatch (cell phone), timer, watch, or clock with a second hand | 1 per team |
| Cardboard boxes or foil to cover cups | 1 per team |
| Index cards (green, red, yellow, and blue) or other system for polling student ideas | 1 set per student |
| Sticky notes | 2–5 per team (optional) |
| **Part 2: The Elodea Investigation** | |
| Clear plastic cup | 1 per team (see *Preparation*) |

| | |
|---|---|
| Drinking straw | 1 per team (see *Preparations*) |
| Stoppers or plastic wrap to cover test tubes | 4 stoppers or 4 small pieces of plastic wrap |
| Safety goggles | 1 pair per student |
| Large test tubes (or clear plastic cups) | 4 per team (see *Preparation*) |
| Dilute phenol red solution | (see *Preparations*) |
| Elodea | Each team will need 2 pieces approximately 6-8 cm in length depending on the size of the test tubes |
| Test tube racks (or beakers to hold the test tubes) | 2 per team |
| Lamps | 1 per team |
| Aluminum foil or cardboard boxes to cover tubes in the "dark" condition | 1 per team |

*Students should work in teams of 3–4 for this investigation.

**Preparations**
Students will utilize the spinach leaf disk protocol similar to what they did in the previous activity. Their familiarity with the procedure should be advantageous for completing this investigation.

Review the student and teacher procedures for the lesson.

**Part 1: Another Investigation with Leaf Disks**

- Prepare spinach leaves.
    - Buy spinach from the grocery store (or a farmer's market) just before your classes begin the activity so they are fresh. Some teachers have recommended placing the spinach leaves under a bright light overnight or for a few hours before students begin the activity. You may also want to slightly dampen the spinach leaves so they do not dry out.

**Part 2: The Elodea Investigation**

- Elodea (*Egeria densa*) can be an invasive plant and is not available in some states. Alternatives for this include *Elodea canadensis* or Chara. You can also test this activity with plants you are able to obtain at a local aquarium shop or pet store. Regardless of which plant you use, you should be careful about disposal so you do not allow the release of a potentially invasive species.
- If appropriate for your students, you can do Step 2 as a demonstration instead of having them do it within their teams.

- The Elodea experiment can be done using clear plastic cups if appropriate test tubes are not available. If using cups, students should place the Elodea in the appropriate cups and then add phenol red solution until the plant is covered (not to the top of the cup).
- Students will use drinking straws to blow into a phenol red solution so they can see the effect of adding carbon dioxide to the solution, thereby decreasing the pH and causing a color change. It is important to put a hole in the side of the straw so that students are unable to suck up and ingest any liquid. You can use a hole punch to cut a hole in the side of the straw (above the fluid level) or you can use a pin to create the hole.
- Prepare phenol red solution.
    - Add 2 mL of 0.04% phenol red stock solution into 400 mL water.
    - Phenol red often turns yellow when diluted with distilled water. Use tap water for dilution if you have this problem. It should be a light pink color.
    - This should give you a light pink solution. If you blow carbon dioxide into a sample of this dilute solution, it should turn yellow in 15-30 seconds. (Bromthymol blue should also work for this investigation if you are more familiar with that indicator.)

**CAUTION:** Students must be careful not to suck up and ingest the phenol red solution.

Students should wear safety goggles or glasses when working with the phenol red solution.

***Adjusting Procedure When Time Is Limited***
If you have a block schedule, it is likely that students will be able to complete the Part 1 investigation during one class period. If you have shorter class periods (e.g., 45-minute periods), it may be difficult for students to complete this investigation during a class period. An alternate strategy is to have students complete the first part of the investigation (investigating effects of light and dark on leaf disk floatation) during one class period. To complete the next part of the investigation (moving cups from light to dark and dark to light), you could prepare leaf disks in advance [both in light (floating) and in dark (not floating)] that students could use as the starting point for their investigation (starting with Step 8).

> **NOTE**: In this lesson and others in this module, we include a step at the end of the lesson for students to communicate with their mentors. If time permits, it can be beneficial for students to check for messages from their mentors and post additional messages or updates on their investigations more frequently.

## Procedure

**Note to Teachers:** The procedural steps listed in this section align with the procedural steps in the *Student's Guide* for this investigation.

### Part 1: Another Investigation with Leaf Disks

1. **Begin the activity by holding a class discussion. Use questions such as the following to guide the discussion:**
    - **What did you learn about photosynthesis during the previous leaf disk investigation?**
      Students should mention that carbon dioxide is a required input. They also may talk about oxygen being an output of photosynthesis (with the caveat that they could not prove that the bubbles were oxygen, but their experiment and information about photosynthesis from the *Reference 2: Photosynthesis* reading leads them to think that the bubbles are oxygen). They may also suggest that light is required since they did their investigation using a lamp, but they did not fully investigate this. This is a good time to look back at the synthesis board to remind students of what they have learned so far.

    - **What was your evidence that photosynthesis was occurring?**
      The leaves in the **breath** cup and the **baking soda** cup floated during the assay.

    - **Do you think that there are other things besides carbon dioxide that are needed for photosynthesis?**
      If students do not mention it, you might foreshadow the rest of the investigation by discussing whether they could tell from their last investigation if light is necessary for photosynthesis.

2. **Students should write a new research question in their science notebooks. This question will serve as a focus for the investigations in this activity.**

    ***What effect(s) do light and dark have on plants?***

3. **In this part of the lesson, students will use the same leaf disk floatation method that they used previously. In this step, students should read through the procedure for Part 1 in preparation for making design decisions about the investigation protocol.**

    At this point, it may be beneficial for students to concentrate on Steps 5–6 of the procedure. Reading the rest of the procedure will let them know what to expect in the full investigation, but for now it may help them focus if they concentrate on these two steps.

4. **Ask volunteers to share ideas about how they could use the leaf disk floatation method to investigate the research question.**

    A straightforward way to use the leaf disk method to investigate the effects of light and dark conditions on leaf disks is to repeat the previous experiment but put 1 cup in the light and 1 cup in the dark. Both cups should contain baking soda solution—since students now know that carbon dioxide is required for photosynthesis.

5. **Briefly explain that team members should work together to plan and conduct their investigations.**

The student procedure includes some questions that students should think about as they design their experiment. They may also think of other issues that should be included in their design. Make sure that students record these answers and observations in their science notebooks.

If students are not using the student guide, you can give each team a copy of Handout 8: *Planning Your Experiment* or you could project that handout to help guide students' thinking.

**Optional Handout**

If helpful for your students, you could provide Handout 9: *Data Table*, for students to use for data collection. They would still need to add detail to the headings as appropriate for their experiment. Students would then add this to their science notebooks when complete.

**Optional Handout**

6. **Review each team's procedure before they begin their investigation. After you feel the plans are well made, teams can proceed with their experiments.**

   Ask questions if you feel they are missing important details in their procedure or data collection plans.

   Depending on your students' experience designing experiments, you may want to discuss some of these design considerations as a class before students continue with conducting the investigation.

**Important!** At the end of the first part of the investigation, make sure students leave their leaf disks set up in their cups (in both light and dark) for use in the next part of the investigation (assuming that students will have time to complete the "dark phase" of the investigation during the class period). If they cannot finish the full investigation during the class period, they will discard their leaf disks. See *Adjusting Procedure When Time Is Limited* for some ideas about how to complete the investigation in shorter class periods.

7. **After completing their experiment, allow time for students to analyze their results and summarize their findings.**

   The Student's Guide includes a framework for helping students make sense of their investigation. As an alternative, give each student a copy of Handout 10: *Making Sense of Your Investigation*, to assist them.

   **Optional Handout**

8. **Remind students that the reading, Reference 4: *More about Photosynthesis* (and other readings) may be helpful for answering some of the questions.**

9. **The part of the investigation conducted in Step 6 can set up thinking about two new questions that students should write in their notebooks:**

   "What happens if you put leaf disks that have been in the light in the dark?"

"What happens if you put leaf disks that have been in the dark in the light?"

**10-12. Students should work with their teams to decide how to approach this next part of the investigation. They will then have another team look at their design and give feedback. Teams can modify their design based on feedback.**

The basic idea for the investigation is that teams will take the cup that has been in the light (with leaf disks now floating) and place it in darkness (wrapped in foil or covered with a box). The cup that was in the dark (leaf disks still at bottom of the cup) will then be placed in the light.

**13-15, Students prepare for, conduct, and analyze their experiments in these steps.**

Students may not anticipate that this part of the experiment could take longer than the initial "floating in the light" part of the experiment. In general, when the leaf disks are moved from light to dark, it may take longer for leaf disks to sink, and it is likely that only some of the disks will sink. If students terminate the investigation early, they may never see any of the leaf disks sink when placed in the dark. Use questions to probe their ideas about what to expect and why the time may be different.

When the leaf disks that had been in the dark are moved to the light, they will start to float over time. This shows that the leaf disks are still viable—they start photosynthesizing when placed in the light. When the leaf disks that had been in the light previously (and are floating) are placed into the dark, they will sink over time. These leaf disks (now in the dark) can no longer carry out photosynthesis. Instead, they will be using the oxygen (that caused the leaves to float) for cellular respiration. As the oxygen is depleted, they will sink again to the bottom of the cup. This process will be slower than the time needed to start floating, and it is likely that students will need to continue this experiment longer than before. Students may decide, upon seeing slower changes, that they do not need to collect data as frequently as before.

If not using the Student's Guide, give each student another copy of Handout 10: *Making Sense of Your Investigation* to analyze this new investigation.

Optional Handout

## Part 2: The Elodea Investigation

**Note to Teachers:** Some members of a student team can set up the Elodea investigation (Part 2) at the same time other team members begin the leaf disk investigation (Part 1, Steps 9 and 10). Alternatively, you can set this up as a demonstration for the class. In that case students should still be involved in recording information about the setup and results of the experiment in their science notebooks.

**16. Students read information about an indicator that they will use in this part of the activity. If you choose, you could ask volunteers to read this aloud to the class.**

You can project Slide 4: *Phenol Red Is an Indicator*, if you want the information read aloud in class.

**Optional Slide**

**17. In this step, students use a straw to blow into a cup containing phenol red solution. This will serve as a way for students to see that blowing carbon dioxide into the solution will cause a color change from pink to yellow, which will be important for the experiment using Elodea that they will do next. It should only take about 30 seconds of blowing to turn the solution yellow.**

**CAUTION:** Students should take appropriate safety precautions, including wearing safety goggles. It is important that the straw has a hole in it so that students cannot suck up any phenol red solution. If preferred, you can do this as a demonstration.

**18. Students should answer the following questions in their science notebooks.**

18a. What are you adding to the phenol red solution when you blow into it? *(Answer: carbon dioxide)*

18b. Complete the following sentence: When _*carbon dioxide*___ is added to a pink phenol red solution, the color of the solution turns _*yellow*____. Adding __ *carbon dioxide* _ to the solution makes the pH ___*decrease*__.

Choose from: increase decrease yellow red/dark pink carbon dioxide oxygen

Steps 18-26 are captured in Handout 11: *The Elodea Experiment*. If you wish to have students use this instead of following these steps in the student guide, you can give each student a copy of this handout.

**Optional Handout**

**19-23. Students set up their experiment using four test tubes.**

**19. Label 2 test tubes "light" and 2 test tubes "dark."**

**20. Add 1 piece of Elodea to one of the "light" tubes and 1 piece to one of the "dark" tubes.**

**21. Add phenol red solution to all four tubes. Make sure the Elodea is completely covered and the fluid level is about the same in each tube. Cover each tube with a stopper or piece of plastic wrap.**

**22. Cover the "dark" tubes (one with and one without Elodea) under a box or wrap in foil to keep completely dark.**

**23. Place the "light" tubes under a lamp.**

**Note:** You may want to add a pinch of baking soda to each tube. Adding baking soda will lead to the phenol red in the "light" tube with Elodea turning a slightly darker pink at the end of the experiment. It should not affect the "dark" tube. This isn't required, in part, because the main outcome will be seeing a change in the "dark" tube (turning yellow) and carbon dioxide is not required for cellular respiration. Adding baking soda may reinforce that photosynthesis is happening in the light.

**24. Students should draw a picture in their notebook of the experimental setup. They should include details about what the phenol red looks like at the beginning of the experiment.**

**25. Students should use what they have learned about phenol red and photosynthesis to make predictions about what will happen in each tube. They should record this in their science notebooks.**

It is likely that students will need to leave their investigation overnight to see the results.

**26. After the investigation is complete, students should record their results and draw a new picture representing their new observations of their experiment.**

26a. Add to the drawing in your notebook to illustrate how the experiment looks at the end.

26b. How do your results compare with your predictions?

26c. Do you think photosynthesis is occurring in any of the tubes? Which one(s)? Explain your reasoning.

26d. Based on your results, do you have evidence of something other than photosynthesis happening in any of the tubes? Please explain your thinking.

Teacher Page 2: *Answer Key for Student Questions*, is provided for your reference related to questions about the Elodea experiment.

**27. Ask students to read Reference 3, *Cellular Respiration*, and Reference 4, *More about Photosynthesis*, to help better understand these processes.**

Students should think about how the information in these resources relates to your experiments. This could help them make decisions about what to add to the synthesis board.

## Part 3: Checking Your Understanding

**28. Hold a class discussion to update the synthesis board based on the results of what students have learned through their investigations (supported by their readings). They can then also add to the model they started in Lesson 1.**

As before, encourage students to consider evidence to support their statements. They may also provide ideas learned from their readings. You may want to give students a few minutes either individually or in teams to think about what they should add to the synthesis board before holding the discussion.

## Part 4: Communicating with Your Mentor

**29. This would be a good point for students to check in with their mentors.**


As in the previous lesson, have students log in to the PlantingScience platform and check their Project pages for updates from their mentors. Once again, students should:

- **Read any messages left by their mentor since their last class period.** If possible, have student teams read the message aloud.
- **Answer any questions the mentor asked.** Again, the best way to do this is to reply directly to the mentor's message.
- **Compose an update summarizing today's activities and what the students learned.** As before, one student may post an update on behalf of the team, or each student may post separately per your preference.
- **Ask new questions of the mentor.** Suggested topics include the day's activity, the mentor's previous posts, or about aspects of the scientist's job.

**Additional Resources**
Additional videos, web pages, books, and articles to support teaching and learning about photosynthesis can be found in the *Photosynthesis and Respiration Resources* document.

**Additional Investigation Ideas**
These investigations may suggest other ideas for investigation. Encourage students to write their ideas in their notebooks. When they do their independent investigations, they may want to consider one of the ideas sparked by this investigation.

Handout 8

# Planning Your Experiment

**Research Question**: "What effect(s) do light and dark have on plants?"

For this investigation, you will modify the leaf disk floatation method to answer this new research question. You will investigate what happens when some leaf disks are placed in the light while others are placed in the dark.

Working with your teammates, start developing your experimental design. Keep in mind the following questions as you plan your experiment.

- How many leaf disks will you use?
- In what type of solution will you place the leaf disks?
- How will you keep some leaf disks in the dark?
- What data will you collect?
- How frequently will you collect data?
- What will your data table look like?

When describing your experimental design, you do not need to write out all the details of each experimental step if they are written somewhere else. For example, you do not need to describe all the steps for preparing your leaf disks. You can simply state that you will use the same basic procedure for preparing leaf disks that you used in the previous investigation. You only need to write things that are new or different in your procedure. Be sure you include your predictions about your investigation's outcomes.

**Hint!** The time it takes for a leaf disk to respond to the dark condition may not be the same as the time it takes to respond to light.

Ask your teacher to check over your procedure before you start your investigation.

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Handout 9

# Data Table

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Handout 10

# Making Sense of Your Investigation

Use complete sentences to describe what the data tell you in terms of answering the research questions. Indicate whether the data support or refute your predictions.

What was your research question?

What conditions or variables did you manipulate in your experiment? What were your controls?

Describe evidence from your experiment that helps answer your research questions.

| **What evidence from your experiment helps you answer your research question?** | **Relevant Science Ideas** (You may have information from the reference readings or even prior activities that relate to your experimental findings) |
| --- | --- |
| | |
| | |
| | |

Write a sentence or two answering your research questions.

Were the results of your experiment similar to those of other teams? If not, can you think of reasons to account for the differences?

Did you notice anything during your experiment that seemed unusual or unexpected? Please describe and explain why it might be a problem.

If you did this experiment again, would you change anything in the procedure? Why or why not?

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Handout 11

# The Elodea Experiment

**Answer the following questions about phenol red.**

1. What are you adding to the phenol red solution when you blow into it?

2. Complete the following sentence:

   When _______________ is added to a pink phenol red solution, the color of the solution turns __________. Adding__________________ to the solution makes the pH ________.

   Choose from: increase decrease yellow red/dark pink carbon dioxide oxygen

**Set up the experiment.**

You will need 4 test tubes (or other container provided by your teacher).

a. Label 2 test tubes "light" and 2 test tubes "dark."

b. Add 1 piece of Elodea to one of the "light" tubes and 1 piece to one of the "dark" tubes.

c. Add phenol red solution to all four tubes.
   - Make sure the Elodea is completely covered and the fluid level is about the same in each tube.
   - Cover each tube with a stopper or piece of plastic wrap.

d. Cover the "dark" tubes (one with and one without Elodea) under a box or wrap in foil to keep completely dark.

e. Place the "light" tubes under a lamp.

f. Draw a picture in their notebook of the experimental setup. Include information about what the phenol red looks like at the beginning of the experiment.

g. Use what you have learned about phenol red and photosynthesis to make predictions about what will happen in each tube.

h. After about 1 day, record your results and draw a new picture to show your observations.

i. How do your results compare with your predictions?

j. Do you think photosynthesis is occurring in any of the tubes? Which one(s)? Explain your reasoning.

k. Based on your results, do you have evidence of something other than photosynthesis happening in any of the tubes? Please explain your thinking.

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Slide 4

## Phenol Red Is an Indicator

An indicator is a substance that shows a visible change when conditions in a solution change. Many indicators change color when a solution changes. Phenol red is an indicator dye that changes color when the pH of the solution changes. In other words, phenol red changes color depending on whether the solution becomes more acidic or more basic.

| | |
|---|---|
| pH 7 (neutral) | phenol red is orange or light pink |
| pH 6.4 or below (acidic) | phenol red turns yellow |
| pH 8.2 or above (basic) | phenol red turns dark pink or red |

These color changes give you a quick way to see how the pH of a solution changes just by looking.

Teacher Page 2

# Answer Key for Student Questions

**Part 2: The Elodea Investigation**

1. What are you adding to the phenol red solution when you blow into it?

   They are adding carbon dioxide to the cup of phenol red solution.

2. Complete the following sentence: When _carbon dioxide_ is added to a pink phenol red solution, the color of the solution turns __yellow__. Adding_carbon dioxide_ to the solution makes the pH __decrease__.

   | Choose from: | increase | decrease | yellow | red/dark pink |
   |---|---|---|---|---|
   | | carbon dioxide | oxygen | | |

3.. Add to the drawing in your notebook to illustrate how the experiment looks at this time.

The controls (tubes without Elodea) should remain unchanged (pink). The tube with Elodea that has been placed in the dark should be yellow or much lighter pink/orange. The tube with Elodea that was in the light should be very similar to the control. In some cases, the tube with Elodea in the light may look slightly darker pink than the control. Sometimes, it can be difficult to tell if it is actually a color change (getting darker) because of the Elodea in the tube. There may be photosynthesis occurring in the tube. As students learned earlier, photosynthesis requires both carbon dioxide and light. Even if they did not add a carbon dioxide source to these tubes, carbon dioxide may have diffused into the solution.

25b. How do your results compare with your predictions?

Answers will vary depending on student predictions.

25c. Do you think photosynthesis is occurring in any of the tubes? Which one(s)? Explain your reasoning.

This is likely to be a somewhat challenging question for students. Students are likely to think that photosynthesis is occurring in the Elodea that has been in the light because they associate photosynthesis and light. However, students may question whether photosynthesis is occurring if they did not add any baking soda as a carbon dioxide source necessary for photosynthesis. Depending on which way students respond, probe their thinking to get a better idea of their thought processes. For example, if they think photosynthesis is occurring, they should discuss both light and carbon dioxide in their responses. If they do not think that photosynthesis is occurring in any of the tubes, they should again consider both light and carbon dioxide in their responses. This is an opportunity, also, to probe their understanding by asking them what happened in the cup containing distilled water (only) in their leaf disk experiment.

25d. Based on your results, do you have evidence of something other than photosynthesis happening in any of the tubes? Please explain your thinking.

Students should realize that the color change (pink to yellow) in the Elodea tube that was in the dark reflects something happening in the plant. Photosynthesis would not be happening because the necessary inputs (carbon dioxide and light) for photosynthesis are not available. The control tube placed in the dark informs them that the color change is not due to a breakdown or change in the indicator solution that occurs in the dark. Therefore, something else must be happening involving the plant to explain the color change. From the reading they should be able to consider that cellular respiration could be that other process happening in the plant to explain the color change. Cellular respiration produces carbon dioxide as an output which would cause the indicator to turn yellow.

**Results of the Elodea Investigation:** The tubes on the left remained in the light for 24 hours. The tubes on the right were placed in the dark for 24 hours.

If students think that the color changed because there is something wrong with the plant after being in the dark, you could ask them to think about how they might show that the plant is OK. Students could put the Elodea tube (with yellow phenol red solution) in the light. In the light, the Elodea would use the carbon dioxide in the solution for photosynthesis and, as photosynthesis consumes the carbon dioxide, the phenol red would turn pink again.

This could also be a good time to raise the question to students about whether the “some other process” (cellular respiration) could also be taking place in the “light” tube with Elodea. From the Elodea experiment, they would not be able to confirm that or disprove that idea. You might raise the idea that the oxygen produced during photosynthesis has a greater effect to keep the indicator solution pink than the carbon dioxide produced during cellular respiration to turn the indicator solution yellow. This could be discussed as a limitation to the technique and what can be determined using the indicator solution.

## Lesson 4

# Building On Knowledge from Others

**Purpose:** The purposes of lesson include
1. learning more about photosynthesis and cellular respiration in plants, and
2. relating what students have learned through investigations to work done by other scientists.

**Time Required:** 1 class session (approximately 45 minutes)

**Learning Goals**
- Plants grow by changing the sugars/carbohydrates formed during photosynthesis into other substances that are required for structure, growth, or function.
- Review and interpret experiments done by other scientists.

**Common Preconceptions and Student Biases**
Students may bring up some of the following preconceptions during this lesson.
- Plants gain their mass from materials from the soil.
- Plants get food from the soil.
- Plants get their mass from water.
- The sugars plants make through photosynthesis are solely or mostly used to fuel cellular respiration.

## Getting Ready

**NOTE**: If you wish, you could teach this lesson after starting Lesson 5. You could have students start Lesson 5 through Step xxx in which they develop their research question. While students are waiting for feedback from their mentors on their research question, you could complete this lesson.

***Student's Guide* Section and Resources Used in Lesson**

| | |
|---|---|
| From a Tiny Seed to a Large Tree from the *Power of Sunlight Student's Guide* | 1 copy per student |

***Teacher's Guide* Resources**

| | |
|---|---|
| Handout 12: *The van Helmont Experiment* | 1 per student (optional) |
| Handout 13: *The Radish Seed Experiment* | 1 per student (optional) |
| Handout 14: *Interpreting the Radish Seed Experiment* | See *Preparations* |
| Slide 5: *Results of the van Helmont Experiment* | 1 to project |
| Slide 6: *Common Molecules in Trees and Plants* | 1 to project |
| Slide 7: *Recording Predictions for the Radish Experiment* | 1 to project |
| Slide 8: *Results of the Radish Seed Experiment* | 1 to project |
| Slide 9: *Explaining the Radish See Experiment* | 1 to project |
| Teacher Page 3: *Answer Key to Questions about the van Helmont and Radish Seed Experiments* | Teacher use |

| | |
|---|---|
| Teacher Page 4: *Optional Supplemental Investigation: The Pea Growth Experiment* | Teacher use (optional); see Preparation |
| Teacher Page 5: *Results of the Pea Growth Experiment* | 1 to project (optional); see Preparation |

**Materials and Supplies**

| | |
|---|---|
| Document camera or computer with projector | 1 setup per class |
| Science notebook | 1 per student |
| Colored paper or index cards [approximately 2 x 4 inches; 4 colors (red, blue, green, yellow)] | 1 piece of each color per student |

**Preparations**

- Review the student and teacher procedures for the lesson.
- Prepare photocopies as indicated in the table above.
- Handout 14: *Interpreting the Radish Seed Experiment*, includes 9 statements. You will need to cut them apart so that each statement is on a separate slip of paper. You may want enough copies so that each statement is reviewed by at least two teams of students. You may also want to organize it so that a team of students has a statement related to a different phenomenon (i.e., results in which the mass increased, mass decreased, or mass stayed about the same).

**Note to Teachers:** This lesson is designed so that students will review and analyze experiments that have been done previously. This aligns with how scientists work—they learn from what others have done before. Some teachers may question why have students just review the radish experiment when it could be done relatively easily in the classroom. The rationale for this approach is that students have been doing hands-on inquiries in the previous lessons and will focus on that in the following lesson. Also, you may not have easy access for drying the seeds or a sensitive-enough balance to detect small changes in mass, which would be needed for these experiments. At this point, the goal is for students to focus on analyzing and interpreting the data.

However, if you want another in-class investigation, we have included a procedure for a plant growth investigation using pea seeds. You could set this up as a demonstration if you so wish using the instructions on Teacher Page 4: *Optional Supplemental Investigation: The Pea Growth Experiment.* You would need to set this up approximately a week before you want students to see the demonstration and analyze the data (Teacher Page 5: *Results of the Pea Growth Experiment*).

## Procedure

### Part 1: The van Helmont Experiment

1. **Remind students of the overarching question for this module: How does a tiny seed grow into a very large tree? Revisit the question board started in Lesson 1 and point out any questions related to the increasing mass or size of the tree.**

   If there are no questions on the question board about where the mass of the tree comes from, you can remind students of the sequoia tree example from Lesson 1 and the mass of the tree and how much mass it is adding each year.

2. **Students should answer the following questions in their science notebooks based on their current understanding.**

   **2a. Where do you think the mass of a tree comes from?**

   **2b. Why do you think this? Have you seen or experienced something that makes you think this?**

   Encourage students to write answers even if they are unsure about their responses. Students will revisit these questions later in the lesson. After a few minutes, ask for a few volunteers to share their thoughts with the class.

3. **Students will be reviewing and analyzing experiments done by other scientists to see if they can learn anything that might help them learn more about where the mass of the tree comes from. The first experiment they will learn about was done by a scientist named van Helmont. He wanted to find out if the mass of a tree comes from the soil, which was a common idea at the time.**

   Students can work in teams of 3-4 to learn about this experiment. Students should write answers to the questions in their science notebooks. When students get to Step 5, project a copy of Slide 5: *Results of the van Helmont Experiment* so students have the data from the experiment.

   If students are not using the Student Guide, give each student a handout of Handout 12: *The van Helmont Experiment*. This includes the information in steps 3-7.

   **Optional Handout**

4. **Students should answer the following questions in their science notebooks to express their current thinking.**

   **4a. If trees *do* get their mass from the soil, would the soil weigh more, less, or the same at the end of the five-year experiment? Record your prediction and explain your thinking.**

   **4b. If trees *do not* get their mass from the soil, would the soil weigh more, less, or the same at the end of the five-year experiment? Record your prediction and explain your answer.**

5. **Display Slide 5: *Results of the van Helmont Experiment*, containing the results of the experiment.**

Students should record this information in their science notebooks.

6. **Students should write their answers to the following question in their science notebooks.**

**"Based on the results of van Helmont's experiment, does the mass of plants come from the soil around them? Why or why not?"**

This question asks students to interpret data from the experiment and to explain their thinking. Students should recognize from the data that the mass of the tree would not come from the soil. If the mass came from the soil, you would expect a dramatic decrease in the mass of the dried soil, which did not happen according to the experimental results.

7. **Allow students a few minutes to go back and review or revise their answers to the questions in Step 2.**

Sample answers to the questions about the van Helmont experiment are included on Teacher Page 3: *Answer Key to Questions about the van Helmont and Radish Seed Experiments*

8. **From the van Helmont experiment, students should conclude that the mass of the tree does not come from the soil. Another common idea is that the mass comes from water. Inform the class that you will be showing them some additional information to think more about that possibility. Display Slide 6, *Common Molecules in Trees and Plants*. Ask students to look at the chemical structures of common molecules that make up the mass of trees and plants. Ask students to write their observations in their science notebooks. Follow this with a class discussion about their observations and ideas about where these molecules come from.**

The goal for this step is for students to simply notice that the most common molecules in trees and plants are made up, in high proportions, of carbon, hydrogen, and oxygen. They do not need to go into greater detail about the elements or chemical bonds.

You can guide the discussion by asking students to think about

- What is the relationship between cellulose and glucose?
- Where do the carbon, hydrogen, and oxygen in these common molecules come from?

The following information may be useful during the discussion.

- Glucose is a product of photosynthesis (as students should know from their previous experiments and readings). It is made up of carbon, hydrogen, and oxygen.

- Cellulose is the main constituent of plant cell walls.
  - Wood contains approximately 40-45 percent cellulose.
  - Cellulose is a chain of thousands of glucose molecules.
  - Cellulose is important for giving trees their structure and strength.
- Proteins also contain carbon, hydrogen, and oxygen.
  - Proteins also contain nitrogen, which is not an output of photosynthesis.
- Lignin is another highly abundant molecule in trees.
  - The lignin content in wood ranges from about 20-40 percent.
  - The molecular formula for lignin is $C_{81}H_{92}O_{28}$.
  - You could share the molecular formula of lignin with students or ask them to look up the structure.

The main point for students to be aware of is that plants cannot get their mass from water since water does not have carbon in it. Trees and other plants get their mass by using the sugars (glucose) made during photosynthesis by breaking down glucose and using those atoms to make new molecules such as cellulose and lignin. For proteins, they also need a source of nitrogen, from a different source.

## Part 2: The Radish Experiment

**9. Students read about an experiment using radish seeds investigating the relationship between photosynthesis and plant growth.**

Students can work in teams of 3-4 to learn about and analyze the experiment.

If students are not using the Student Guide, give each student a copy of Handout 13: *The Radish Seed Experiment*. This handout includes the information in steps 9-13. Where appropriate, students can write answers to questions in their science notebooks.

Optional Handout

**10. Students should try to answer the question, "Why did the scientist dry the seeds and seedlings before measuring their mass?" in their notebooks.**

This question asks students to think about the experimental design and why it made sense to dry the seeds and seedlings before measuring their mass. This was necessary because the scientist was interested in learning about the mass of the plant, not including the amount of water that was in or on the seeds or seedlings.

**11. In this step, students should draw a data table in their science notebooks and write predictions of the changes in mass that they would see in each of the three dishes after the 2-week experimental period. After students think about their predictions, you can use Slide 7: *Recording Predictions for the Radish Experiment* to take a poll to see how students responded.**

Students should indicate whether the mass will increase, decrease, or stay the same in each dish. The goal for taking the poll is to get an idea of students' current thinking, not to correct their thinking. You can use the colored cards or paper listed in the materials section. For example, blue could represent an increase in mass, red a decrease in mass, and yellow for no change in mass. Alternatively, you could do a simple show of hands to get student responses, or you could use another process where students do not see who responded in which way.

12. **Project Slide 8: *Results of the Radish Seed Experiment*. Students can add that data to their tables. They can then calculate the change in mass in each treatment.**

13. **In their science notebooks, students should record their ideas to explain the changes that occurred in each dish. Students should spend a few minutes thinking independently before discussing their ideas with a partner or participating in a class discussion.**

14. **Give teams 2-3 of the statements on Handout 13, *Interpreting the Radish Seed Experiment* (see Preparations). Students or teams should read the statement on each slip and make a decision about it. They then should write a sentence or two to explain their reasoning.**

    After students have some time to evaluate their statements and write responses, hold a class discussion. Each team can present their statement and their evaluation of it. If more than one team has the same statement, you can ask the other team if they agree with the analysis and reasoning or if they have a different idea.

    Sample answers to the questions about the radish seed investigation are included on Teacher Page 3, *Answer Key to Questions about the van Helmont and Radish Seed Experiments*

15. **To conclude, hold a class discussion that revisits the radish seed experiment. Ask students if they can use what they have learned about photosynthesis and cellular respiration to explain what happened in each of the 3 dishes. Display a copy of Slide 9: Explaining the Radish Seed Experiment. To give you an overall impression of what the students are thinking, conduct a quick poll. For each of the 3 dishes, ask students to use a colored index card to indicate which process or processes best explain the changes in mass.**
    - **Green card = photosynthesis**
    - **Red card = cellular respiration**
    - **Yellow card = both photosynthesis and cellular respiration**
    - **Blue card = neither photosynthesis nor cellular respiration**

    **Ask for volunteers to share their reasoning for their responses. Their explanation should justify their response.**

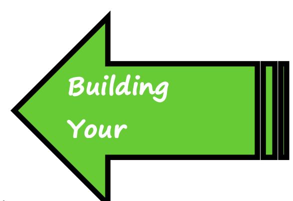
    **Dish 1:** Photosynthesis occurred because seeds had water, carbon dioxide (from the air), and light. The plants increased in mass as carbon dioxide was used to produce carbohydrates during photosynthesis. You can also remind students of the molecules that they looked at earlier (Slide 4: *Common Molecules in Trees and Plants*). The carbohydrates (glucose) produced during photosynthesis are used to make important carbon-based molecules. These molecules, including lignin, form the mass of the tree (or other plant). The seedlings in this dish would also be undergoing cellular respiration, but the mass lost through cellular respiration would be less than the mass gained through photosynthesis.

**Dish 2:** Photosynthesis could not occur in this dish because the seedlings were not exposed to light—a necessary input for photosynthesis. When plants need energy, they have to metabolize their stored sugars through cellular respiration, just as animals do. Plants need energy to maintain homeostasis, to perform normal functions, and to grow. The seedlings in this dish were able to carry out cellular respiration. They used the stored “food” contained in the seed for germination and initial growth. As cellular respiration continued, the plants lost mass by releasing carbon dioxide.

**Dish 3:** These seeds were placed in the light but were not given any water. The mass of these seeds did not change appreciably during the experiment. Without water, the seeds remained dormant. Cellular respiration is occurring at a very low level in these dormant seeds. (Some dormant seeds remain viable for several years.) The small decrease in mass in this dish can be attributed to use of a small amount of stored energy for cellular respiration, the loss of a small amount of water, or possibly to measurement error (balances commonly used in classrooms often are not accurate when measuring differences this small). Students could not completely rule out any of these explanations for why the seeds lost mass in these conditions. This could lead to an interesting class discussion because many students assume that experimental error almost always explains small differences without considering other options.

## Part 3: Building Your Explanation

16. **Ask students what they should add to the synthesis board that continues to build their understanding of photosynthesis and cellular respiration.**




This is also a good time to have them add to or revise the model they have been developing.

## Part 4: Communicating with Your Mentor

17. Allow a few minutes for students to check for messages from their mentors or to post ideas they have learned during this lesson.

Handout 12

# The van Helmont Experiment

Read the following paragraph that summarizes an experiment done a long time ago by a scientist who wondered about how trees grow.

> Jan Baptist van Helmont was a Belgian scientist who lived from 1580 to 1644. He wanted to find out where the mass of a tree comes from. At that time, many people thought that the mass of a tree might come from the soil.
>
> Van Helmont designed an experiment to test that idea. He planted a young willow tree in a pot containing 90 kilograms (kg; about 200 pounds) of dried soil. The willow tree weighed 2.2 kg (about 5 pounds) when it was first planted. For the next five years, he watered the tree with either rainwater or distilled water as needed.

Before you learn more about van Helmont's experiment and his results, write your initial thoughts to the following questions in your science notebook.

a. If trees *do* get their mass from the soil, would the soil weigh more, less, or the same at the end of the five-year experiment? Record your prediction and explain your thinking.

b. If trees *do not* get their mass from the soil, would the soil weigh more, less, or the same at the end of the five-year experiment? Record your prediction and explain your answer.

Your teacher will show you a chart with van Helmont's results. Add the data to the following chart.

| Mass | At the start of the experiment | 5 years later |
|---|---|---|
| **Mass of tree** | 2.2 kg (about 5 pounds) | 77 kg (about 169 pounds)* |
| **Mass of dried soil** | | |

*He did not weigh the leaves that fell off the tree each year.

Answer the following question in your science notebook.

c. "Based on the results of van Helmont's experiment, does the mass of plants come from the soil around them? Why or why not?"

Look back to your answer to the question a. Do the results from van Helmont's experiment support your answer or suggest that you should revise your answer? If you revise your answer, use a different colored pen or pencil to make revisions so you can see how your thinking has changed.

Handout 13

# The Radish Seed Investigation

The following is a description of an experiment done using radish seeds.

The scientist put exactly 1.0 gram (g) of radish seeds in each dish. Each dish received a different treatment:

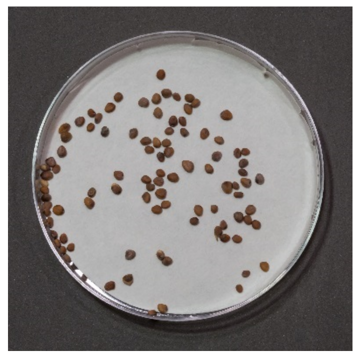
- Dish 1 was placed in the LIGHT and was watered.
- Dish 2 was placed in the DARK and was watered.
- Dish 3 was placed in the LIGHT but was NOT watered.

The dishes were kept in these conditions for two weeks. After that time, this is what the scientists saw:

**Dish 1**

**Dish 2**

**Dish 3**



**Dish 1:** Almost all seeds germinated (sprouted); short seedlings; green leaves

**Dish 2:** Almost all seeds germinated; longer seedlings; pale green leaves

**Dish 3:** None of the seeds germinated.

Next, the scientist put each dish into a drying oven to remove all the water from the dishes and the seeds or seedlings.

Write your answer to the following question in your science notebook.

"Why did the scientist dry the seeds and seedlings before measuring their mass?"

Making predictions and recording the reasoning you used to make those predictions is an important part of developing an understanding of science. In your science notebook, write a prediction about how you expect the mass to change (increase, decrease, or stay the same) for each of the 3 experimental treatments following the 2-week growth period. Be sure to include your reasoning for each prediction.

Your teacher will display data about the mass of the seeds or seedlings after they were dried. Record these data in your table. Calculate the change in mass of the seeds or seedlings for each treatment.

**Results of the Radish Experiment**

| **Treatments** | **Dish 1** | **Dish 2** | **Dish 3** |
|---|---|---|---|
| | **Radish seeds: 1.0 g (at beginning of experiment)**<br><br>**Light: Yes**<br>**Water: Yes** | **Radish seeds: 1.0 g (at beginning of experiment)**<br><br>**Light: No**<br>**Water: Yes** | **Radish seeds: 1.0 g (at beginning of experiment)**<br><br>**Light: Yes**<br>**Water: No** |
| **Initial mass of seeds** ($M_{initial}$) | 1.00 g | 1.00 g | 1.00 g |
| **Predicted change in mass (** | | | |
| **Mass of seeds or seedlings after being dried** ($M_{final}$) | | | |
| **Change in mass** ($M = M_{final} – M_{initial}$) | | | |

For your predictions you can use

↑ if you predict an increase in mass

↓ if you predict a decrease in mass

↔ if you predict no change in mass

Think about how you might explain the changes in mass for each of the different treatments. If you like, discuss your ideas with a partner. Record explanations for each dish in your science notebook. Don't worry if you are not sure that an explanation is correct.

Handout 14

# Interpreting the Radish Seed Experiment

Consider the dish with seedlings that INCREASED in mass. Decide if the statement is reasonable or not reasonable. Write 1 or 2 sentences describing why you made your decision.

a. The increase in mass was mostly due to the water the seedlings were given.

  i. reasonable
  ii. not reasonable
  iii. not sure

Decision and reasons.

Consider the dish with seedlings that INCREASED in mass. Decide if the statement is reasonable or not reasonable. Write 1 or 2 sentences describing why you made your decision.

b. The increase in mass was mostly due to molecules in the air that the seedlings took in.

  i. reasonable
  ii. not reasonable
  iii. not sure

Decision and reasons.

Consider the dish with seedlings that INCREASED in mass. Decide if the statement is reasonable or not reasonable. Write 1 or 2 sentences describing why you made your decision.

c. The increase in mass occurred because light itself has mass. The seedlings used the mass in light to become heavier.
   i. reasonable
   ii. not reasonable
   iii. not sure

Decision and reasons.

Consider the dish with seedlings that DECREASED in mass. Decide if the statement is reasonable or not reasonable. Write 1 or 2 sentences describing why you made your decision.

d. The decrease in mass was mostly due to losing water when the seedlings were dried.
   i. reasonable
   ii. not reasonable
   iii. not sure

Decision and reasons.

Consider the dish with seedlings that DECREASED in mass. Decide if the statement is reasonable or not reasonable. Write 1 or 2 sentences describing why you made your decision.

e. The decrease in mass was mostly due to the seedlings breaking down molecules stored in the seed into gas and releasing it into the air.
   i. reasonable
   ii. not reasonable
   iii. not sure

Decision and reasons.

---

Consider the dish with seedlings that DECREASED in mass. Decide if the statement is reasonable or not reasonable. Write 1 or 2 sentences describing why you made your decision.

f. The decrease in mass was mostly due to the lack of mass from light. Seedlings use the mass in light to become heavier.
   i. reasonable
   ii. not reasonable
   iii. not sure

Decision and reasons.

---

Consider the dish with seeds that STAYED ABOUT THE SAME in mass. Decide if the statement is reasonable or not reasonable. Write 1 or 2 sentences describing why you made your decision.

g. The lack of change in mass was due to the absence of water because water is needed for the seeds to germinate and begin growing.
   i. reasonable
   ii. not reasonable
   iii. not sure

Decision and reasons.

Consider the dish with seeds that STAYED ABOUT THE SAME in mass. Decide if the statement is reasonable or not reasonable. Write 1 or 2 sentences describing why you made your decision.

h. The lack of change in mass was due to an equal balance of the seeds taking in molecules from the air and losing molecules to the air.
   i. reasonable
   ii. not reasonable
   iii. not sure

Decision and reasons.

Consider the dish with seeds that STAYED ABOUT THE SAME in mass. Decide if the statement is reasonable or not reasonable. Write 1 or 2 sentences describing why you made your decision.

i. The lack of change in mass was due to the light damaging the seeds so they could not germinate.
    i. reasonable
    ii. not reasonable
    iii. not sure

Decision and reasons.

Slide 5

## Results of the van Helmont Experiment

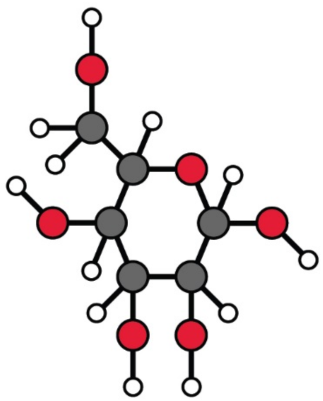
| Mass | At the start of the experiment | 5 years later |
|---|---|---|
| **Mass of tree** | 2.2 kg<br>(about 5 pounds) | 77 kg<br>(about 169 pounds)* |
| **Mass of dried soil** | 90 kg<br>(about 200 pounds) | 89.4 kg<br>(about 200 pounds less 2 ounces) |

*He did not weigh the leaves that fell off the tree each year.

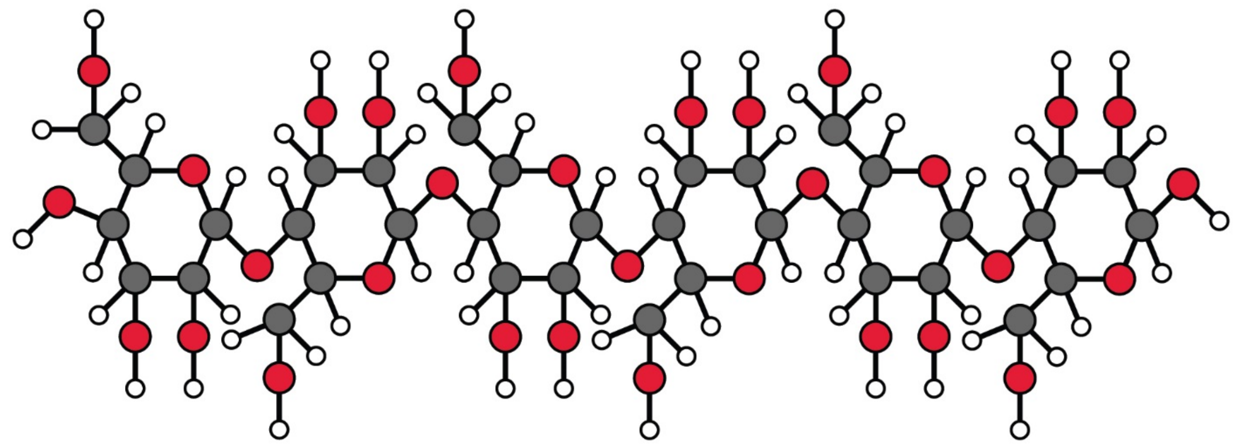
Slide 6

## Common Molecules in Trees and Plants

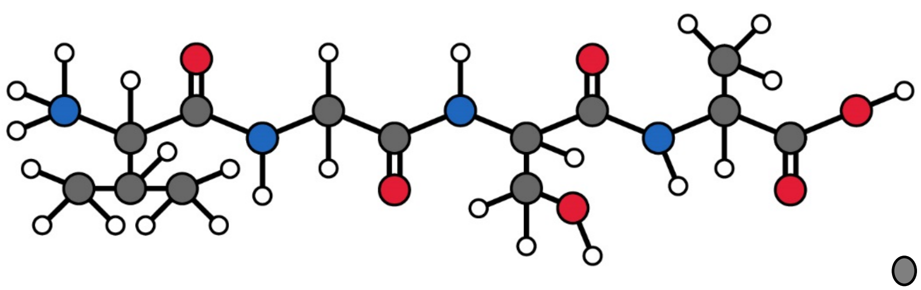
### Glucose



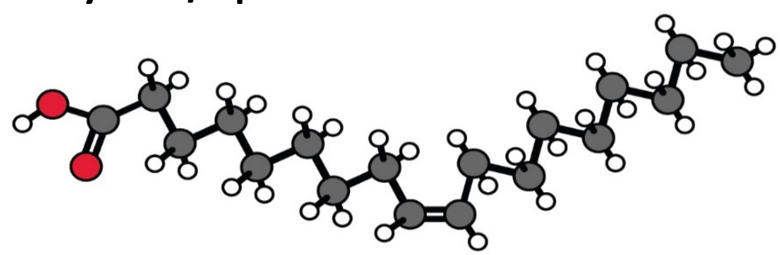
### Cellulose



### Protein



### Fatty Acid/Lipid



**Key:** Carbon Oxygen Hydrogen Nitrogen



Last updated August 2023

Slide 7

## Recording Predictions for the Radish Experiment

| Treatments | Dish 1 | Dish 2 | Dish 3 |
|---|---|---|---|
| | **Radish seeds: 1.0 g**<br><br>**Light: Yes**<br>**Water: Yes** | **Radish seeds: 1.0 g**<br><br>**Light: No**<br>**Water: Yes** | **Radish seeds: 1.0 g**<br><br>**Light: Yes**<br>**Water: No** |
| **Predictions about how the mass will change**<br>(change in mass = mass of seeds/seedlings after being dried – initial mass) | **Increase** | **Increase** | **Increase** |
| | **Decrease** | **Decrease** | **Decrease** |
| | **Stay the same** | **Stay the same** | **Stay the same** |

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Slide 8

## Results of the Radish Experiment

| **Treatments** | **Dish 1** | **Dish 2** | **Dish 3** |
|---|---|---|---|
| | **Radish seeds: 1.0 g (at beginning of experiment)**<br><br>**Light: Yes**<br>**Water: Yes** | **Radish seeds: 1.0 g (at beginning of experiment)**<br><br>**Light: No**<br>**Water: Yes** | **Radish seeds: 1.0 g (at beginning of experiment)**<br><br>**Light: Yes**<br>**Water: No** |
| **Initial mass of seeds** ($M_{initial}$) | 1.00 g | 1.00 g | 1.00 g |
| **Predicted change in mass** | | | |
| **Mass of seeds or seedlings after being dried** ($M_{final}$) | 1.20 g | 0.77 g | 0.98 g |
| **Change in mass** ($M = M_{final} – M_{initial}$) | | | |

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Slide 9

## Explaining the Radish Seed Experiment

Which process best explains the change in mass observed in each dish?

| Treatments | Dish 1 | Dish 2 | Dish 3 |
|---|---|---|---|
| | **Light: Yes**<br>**Water: Yes** | **Light: No**<br>**Water: Yes** | **Light: Yes**<br>**Water: No** |
| **Photosynthesis** | | | |
| **Cellular Respiration** | | | |
| **Both** | | | |
| **Neither** | | | |

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# *Answer Key to Questions about the van Helmont and Radish Seed Experiments*

**Part 1: The van Helmont Experiment**

2a. Where do you think the mass of a tree comes from?

Student answers will vary, but a common idea is that trees (and other plants) grow in mass because they take it from nutrients in the soil. As students learn more about photosynthesis, they will learn that almost all of the mass comes from carbon dioxide taken in from the air and used to make glucose during the dark reactions of photosynthesis.

2b. Why do you think this? Have you seen or experienced something that makes you think this?

Students may struggle with the idea that the mass of a tree comes mostly from a gas in the air. Some students may forget that gases have mass. The idea that trees get their mass from soil also may stem from seeing boxes of plant "food" or fertilizer. Although plant food or fertilizer may provide nutrients that plants need, they do not provide a source of energy. The use of the word "food" can be problematic when discussing plants and photosynthesis.

Since plants are largely made of carbon-containing molecules, $H_2O$ cannot be the source of this mass. Some students may argue that plants also contain other elements besides C, H, and O. For example, phosphorus and nitrogen are used to make DNA, and sulfur and nitrogen are used to make proteins. These elements are taken in by the plant from the soil.

4a. If trees *do* get their mass from the soil, would the soil weigh more, less, or the same at the end of the five-year experiment? Record your prediction and explain your answer.

If the trees do get their mass from the soil, you would expect the soil to weigh less at the end of the experiment because the mass moved from the soil into the tree. (And you might expect to see a big hole where the soil used to be.)

4b. If trees *do not* get their mass from the soil, would the soil weigh more, less, or the same at the end of the five-year experiment? Record your prediction and explain your answer.

If the trees do not get their mass from the soil, you would expect the soil to weigh the same amount at the end of the experiment.

6. Based on the results of van Helmont's experiment, does the mass of plants come from the soil around them? Why or why not?

   Based on van Helmont's experiment, the mass of plants does not come from the soil. The mass of the soil changed very little during the course of the experiment. This suggests that almost all of the dry mass of the tree or plant comes from something other than soil.

7. Look back to your answer to the question in Step 2a. Do the results from van Helmont's experiment support your answer or suggest that you should revise your answer?

   Answers will vary depending on how students answered the question in Step 2a.

**Part 2: The Radish Experiment**

10. Why did the scientist dry the seeds and seedlings before measuring their mass?

    The seeds and seedlings in the 3 dishes will contain different amounts of water. To compare the amount of plant matter among the 3 dishes, it is important to remove the water from the plants.

12. Draw a table similar to the one below in your science notebook. Your teacher will display data about the mass of the seeds or seedlings after they were dried. Record these data in your table. Calculate the change in mass of the seeds or seedlings for each treatment.

**Results of the Radish Experiment**

| | **Dish 1** | **Dish 2** | **Dish 3** |
|---|---|---|---|
| **Treatments** | **Radish seeds: 1.0 g (at beginning of experiment)**<br><br>**Light: Yes**<br>**Water: Yes** | **Radish seeds: 1.0 g (at beginning of experiment)**<br><br>**Light: No**<br>**Water: Yes** | **Radish seeds: 1.0 g (at beginning of experiment)**<br><br>**Light: Yes**<br>**Water: No** |
| **Initial mass of seeds** (Minitial) | **1.00 g** | **1.00 g** | **1.00 g** |
| **Predicted change in mass** | | | |

| | | | |
|---|---|---|---|
| **Mass of seeds or seedlings after being dried** (Mfinal) | **1.20 g** | **0.77 g** | **0.98 g** |
| **Change in mass** (M = Mfinal – Minitial) | 0.20 g | -0.23 g | -0.02 g |

13. Think about how you might explain the changes in mass for each of the different treatments. If you like, discuss your ideas with a partner. Record explanations for each dish in your science notebook. Don't worry if you are not sure that an explanation is correct. You will have a chance to revisit your explanations later.

| **Treatments** | **Dish 1**<br>**Radish seeds**<br>**Light: Yes**<br>**Water: Yes** | **Dish 2**<br>**Radish seeds**<br>**Light: No**<br>**Water: Yes** | **Dish 3**<br>**Radish seeds**<br>**Light: Yes**<br>**Water: No** |
|---|---|---|---|
| **How might you explain the results from the experiment?** | The seedlings increased in mass compared to the seeds. The ultimate explanation for this observation is that the plants took in $CO_2$ from the air which was used to make new organic molecules (biomass). | These seedlings lost mass compared to the seeds. In the absence of light, the plants only performed cellular respiration, not photosynthesis. In respiration, $CO_2$ is released, which causes the decrease in mass. | Most seeds need water to germinate. Because there was no water in this treatment, the plants did not perform photosynthesis or respiration at an appreciable rate. The very small mass decrease observed may represent very low levels of cellular respiration taking place in dormant seeds. Students will likely want to attribute this to measurement error because the mass change is small but encourage students to consider the idea that cellular respiration could explain a loss of mass. Students may want to attribute mass loss to measurement error because they do not |

| | | | |
|---|---|---|---|
| | | | view seeds as being alive (although dormant). |

14. Consider the dish with seedlings that INCREASED in mass. Decide if each statement is reasonable or not reasonable. For each statement, write down 1 or 2 sentences describing why you made your decision.

14a. The increase in mass was mostly due to the water the seedlings were given.
   i. reasonable
   ii. not reasonable
   iii. not sure

ii. The plants in this experiment were dried before their mass was taken, so the increase was not simply due to water taken in. Additionally, the seeds placed in water without light did not gain in mass. It is true that some of the mass from the plants in the light with access to water comes from atoms that were originally a part of water molecules, but most of the mass gain comes from incorporating $CO_2$ from the air.

14b. The increase in mass was mostly due to molecules in the air that the seedlings took in.
   i. reasonable
   ii. not reasonable
   iii. not sure

i. $CO_2$ in the air is incorporated into organic molecules during the dark reactions of photosynthesis.

14c. The increase in mass occurred because light itself has mass. The seedlings used the mass in light to become heavier.
   i. reasonable
   ii. not reasonable
   iii. not sure

ii. This is a confusion between matter and energy. Plants use $CO_2$ to gain mass. Light provides the energy to drive the process.

15. Consider the dish with seedlings that DECREASED in mass. Decide if each statement is reasonable or not reasonable. For each statement, write down 1 or 2 sentences describing why you made your decision.

15a. The decrease in mass was mostly due to losing water when the seedlings were dried.
   i. reasonable
   ii. not reasonable
   iii. not sure

ii. Water was removed from all of the seeds/seedlings and does not account for the mass change observed. The seedlings that decreased in mass were undergoing cellular respiration but not photosynthesis. The decrease in mass is largely attributed to $CO_2$ being released into the air.

15b. The decrease in mass was mostly due to the seedlings breaking down molecules stored in the seed into gas and releasing it into the air.
   i. reasonable
   ii. not reasonable
   iii. not sure

i. The seedlings that decreased in mass were undergoing cellular respiration but not photosynthesis. During cellular respiration, carbohydrates such as glucose are broken down and $CO_2$ is released into the air as a byproduct.

15c. The decrease in mass was mostly due to the lack of mass from light. Seedlings use the mass in light to become heavier.
   i. reasonable
   ii. not reasonable
   iii. not sure

ii. This is a confusion between matter and energy. Plants use $CO_2$ to gain mass. Light provides the energy to drive the process.

16. Consider the dish with seeds that STAYED ABOUT THE SAME in mass. Decide if each statement is reasonable or not reasonable. For each statement, write down 1 or 2 sentences describing why you made your decision.

16a. The lack of change in mass was due to the absence of water because water is needed for the seeds to germinate and begin growing.
   i. reasonable
   ii. not reasonable
   iii. not sure

i. Radish seeds do require water to germinate. Since water was lacking, germination did not occur. While dormant seeds do cellular respiration at a very low rate, it may be difficult to measure any changes in mass.

16b. The lack of change in mass was due to an equal balance of the seeds taking in molecules from the air and losing molecules to the air.
   i. reasonable
   ii. not reasonable
   iii. not sure

ii. Since water was lacking, germination did not occur. Mature seeds do not have chloroplasts or chlorophyll developed that would let them photosynthesize. Seeds are metabolically slowed or dormant, but they are living. Dormancy is a mechanism that keeps the seeds alive but uses minimal energy expenditure.

16c. The lack of change in mass was due to the light damaging the seeds so they could not germinate.

i. reasonable
ii. not reasonable
iii. not sure

ii. Radish seeds do not require light to germinate (although some other plants do). Even though radish seeds don't need light to germinate, light does not normally damage the seeds or prevent them from germinating. Water, however, is critical for germination as the cells of the embryo need to rehydrate to resume normal cell activity. The reason for the seeds not germinating was the lack of water, not too much light.

# Optional Supplemental Investigation:
# The Pea Growth Experiment

The radish seed experiment is convenient because the seedlings do not take up much space and the seeds grow rapidly. A more striking visual difference can be seen by using pea plants and the following procedure. *Even if you use the pea plants as a demonstration, you should still use the radish experiment with the class because it includes the needed mass measurements.* If desired, students can start the pea experiment after finishing this lesson and let it continue as they move forward with other lessons in the module.

a) Label 3 8-oz cups as follows:
    1. With Light; With Water
    2. No Light; With Water
    3. With Light; No Water
b) Fill each cup with vermiculite to a level about 3 cm from the top
c) Weigh out 3 batches of 1 gram of pea seeds.
d) Plant 1 batch of pea seeds in each cup.
e) Add water to Cup 1 and Cup 2.
f) Place Cup 1 and Cup 3 under a light source that can be kept on for the course of the investigation.
g) Place Cup 3 in a foil-lined box to keep it dark.
h) Check Cup 1 and Cup 2 every couple of days and add water if needed.
i) After approximately 6 days you should see clear differences among the 3 cups.
j) Take photos of the seeds/seedlings in each cup.

**Cup 1**

**Cup 2**

**Cup 3**

Teacher Page 5

# Results of the Pea Growth Experiment

**Cup 1**

**Cup 2**

**Cup 3**

**Cup 1:** Almost all seeds germinated (sprouted); seedlings; green leaves

**Cup 2:** Almost all seeds germinated; longer seedlings; pale yellow leaves

**Cup 3:** None of the seeds germinated

**Lesson 5**

# Open Inquiry: What Do You Want to Find Out about Photosynthesis and/or Cellular Respiration?

**Overview**
In this lesson, students conduct their own independent investigations about photosynthesis or cellular respiration. These investigations should build on or link to the guided inquiries they have completed earlier. Students will develop a specific research question, develop an experimental design, and draw conclusions from the data to refine their working model of photosynthesis and cellular respiration. Your role is to help students use sound reasoning and evidence to develop an experimental design that clearly addresses a research question. Students are challenged to construct explanations based on their experimental data while making connections to deeper concepts and scientific practices.

**Time Required:** Approximately 6 45-minute class periods

- **Day 1:** opening discussion, brainstorming
- **Day 2**: Finalize research question, connect with their mentors (partial class period)
- **Day 3:** Design experiments, connect with their mentors (partial class period)
- **Day 4:** Carry out experiments
- **Day 5:** Finish experiments, analyze data, connect with their mentors
- **Day 6:** synthesis board, connect with their mentors

Optimally, you will schedule this lesson so that scientist mentors have time to respond to team update posts before the students move on to their next step. The goal is for students to get feedback from mentors and be able to incorporate that feedback before moving on. Therefore, it is likely that the days for this investigation will not be consecutive class periods.

**Learning Goals**
During this activity, students will

- develop a testable research question;
- select experimental approaches best suited to answer a research question;
- design and carry out an experiment;
- use sound reasoning to construct explanations from data;
- communicate their research findings; and
- generate models for how photosynthesis and cellular respiration work.

## Getting Ready

***Student's Guide* Section Used in Lesson**

| | |
|---|---|
| How Does a Plant's Environment Affect Photosynthesis and/or Cellular Respiration? from *Student's Guide* | 1 copy per student |

***Teacher's Guide* Resources**

| | |
|---|---|
| Handout 15: *Asking a Testable Question* | 1 per student (optional)* |
| Handout 16: *Planning Your Investigation* | 1 per student (optional) |
| Handout 17: *Making Sense of Your Investigation* | 1 per student (optional) |
| Slide 9: *Features of Testable Questions* | 1 to project (optional)* |

*If students are using the *Student's Guide*, they will not need Copymaster 25 because the material is included as part of their instructions. Copymaster 26 provides more in-depth information about testable questions. You could give each student a copy of that instead of using Copymaster 25.

**Materials and Supplies**

| | |
|---|---|
| Computer access to the *Student Roadmap through an Investigation* resource on the PlantingScience website | |
| Materials from leaf disk floatation investigations | The type and amount of materials will depend on student investigations and what you have available for use. |
| Additional species, ages, colors, and so forth of plant materials may be helpful (for biological variation experiments) | |
| Growth chambers or cooling/heating units (for temperature experiments) | |
| Thermometers (for temperature experiments) | |
| Color filters or colored lightbulbs (for testing the effect of light wavelength) | |
| Automatic lighting timers (for testing day length or temporary darkness) | |
| pH test strips and dilute acid/base (for pH experiments) | |
| Table salt (for testing osmotic effects) | |

- Students will need to check with you regarding available materials and supplies before beginning their investigations. Depending on what is available, they may need to modify their investigation or experimental design.
- It may also be helpful to remind mentors of any time, materials, or equipment limitations so they can better respond to student ideas.
- For teams using the leaf disk floatation method, similar technical considerations will apply here as in the guided inquiry.
- Method-specific technical notes are available in the *Power of Sunlight Toolkit* for teams that wish to use one of the alternative methods therein.
- If you happen to have other materials and supplies that can be applied to answering research questions about photosynthesis and/or cellular respiration, then be sure to make students aware of this option.

**Preparations**

- Review the student and teacher procedures for the lesson.
- Gather a range of materials that students may use for their investigations.
- Students will post to their blog and receive feedback from their scientist mentors on their investigations at several points during this activity. Communicate with the mentors ahead of time to let them know when to expect online posts from students and to find out how

quickly they will be able to provide feedback. This information will help you schedule class time for completing the open-inquiry investigations.

## Procedure

### Part 1: Conducting an Independent Investigation

**Note to Teachers:** The procedure that follows provides a framework for using this lesson in the classroom. However, you should feel free to modify it based on your students' prior experiences, knowledge, and abilities. The step numbers listed in these procedural steps match those in the student pages.

**Defining Research Questions**

1. **Ask students to share what they have learned about photosynthesis and cellular respiration from the previous lessons. You could also review the synthesis board briefly. This would be a good time to revisit the question board started at the beginning of the module.**

   Students may have new questions that they could add to the list that they started at the beginning of the module. They may also identify questions that they have not been able to answer yet.

2. **Introduce students to the idea that this time they will be developing their own research question and then planning and conducting their own investigation to answer the question.**

   If not using the Student's Guide, read through the procedural steps in the Student's Guide and summarize them for students.

   **Allow time for students to read through all the procedural steps in their student guide for this investigation.**

3. **Introduce students to the *Student Roadmap Through an Investigation* resource (https://www.plantingscience.org/resourcelibrary/studentlibrary/studentroadmaps) on the PlantingScience website.**

   Students should refer to this resource at various times during their investigations for guidance.

4. **Students should begin thinking about what interests them about photosynthesis and/or cellular respiration. Instruct students to read through the information found at the *Explore Your Topic* link in the *Student Roadmap*.**

Students can spend some time individually thinking about their interests. If, during previous investigations, they wrote ideas for future investigations, they can refer back to those now. After working individually, teams can start discussing their ideas together.

5. **The research question that students investigate needs to be testable. This step provides information to students about the features of testable questions. Their question should also help them add to their understanding of photosynthesis or cellular respiration.**

   If helpful, hold a brief discussion about testable questions before students move on to the next step.

   If students are not using the student guide, you can display Slide 9: *Features of Testable Questions* and ask volunteers to read that information aloud to the class.

   Optional slide

   Alternatively, if you feel that students would benefit from more in-depth information about testable questions, you can give each student a copy of Handout 15: *Asking a Testable Question*.

   Optional Handout

6. **Students can consult resources on the PlantingScience website for ideas as they brainstorm:**
   a. **Students can find more information about testable questions by clicking on the *Research Question* section of the Student Roadmap.** This section has more to say about where good testable questions come from, deciding if the question is meaningful, and relating questions to predictions.
   b. **Students can also visit the Projects Gallery to see projects other students have completed in previous sessions.** Clicking the box for 'Starred' projects will narrow the search to projects that make good exemplars.

7. **Allow time for teams to work together to come up with 2–3 potential research questions to investigate. For each of their ideas, they should write answers to the questions listed in this step.**

   The questions (listed in the student guide) are:
   - What is the research question?
   - Why do you think this investigation will help you learn something new about photosynthesis and/or cellular respiration?
   - Write a brief outline of how you will do your investigation.
   - What data will you measure and record?
   - What supplies or equipment would be necessary for investigating this question?

   The questions should help students think more about their research questions and the possible investigations they would do. Because students will share this with their mentors, the questions also provide a framework for presenting ideas to the mentors.

As teams are working on their research questions, they may have questions and need more information. The *Power of Sunlight Toolkit* (https://plantingscience.org/resourcelibrary/planttoolkit) may be a valuable resource that provides information about different techniques and methods for investigating photosynthesis and cellular respiration.

One consideration related to potential research questions is relevance. Will this research question investigate something that has a real-world connection? For example, a common idea for student investigations is to see what happens to plant growth if they are watered with cola. Such a research question doesn't have a strong connection to real-world plant biology. Another problem with such investigations is that these beverages are complex mixtures of chemicals and vary depending on bottler, brand, and flavor. It would not be feasible in the classroom to identify which component of the beverage produced an effect. As the teacher, you can watch out for questions such as this, and the mentors will also help students make real-world connections and provide feedback if students present a flawed research question.

As students work, you may want to circulate among teams to check on their progress. Ask students to explain what makes their questions testable and how this might add to their understanding of photosynthesis or cellular respiration.

8. **Teams should post their proposed questions and answers to the Step 7 questions online to share with their mentors.**

Mentor

Each team should work together to reach a consensus about which information should be presented to the scientist mentor.

If possible and preferred, students could take photos of their science notebook pages with their research questions and answers to the questions and post those online for their mentor's review. (Note that mentors may take 2-3 days to repond, so prepare students for this.)

**Making Predictions and Designing Your Experiment**

9. **Based on feedback from their scientist mentor, each team should narrow their focus and decide on a single research question that they will investigate. Teams should:**
   - **add information and suggestions from their mentors to their notes from Step 7.**
   - **Consider the following:**
     - How does this research question build on what you have learned in this module about photosynthesis and cellular respiration?
     - What do you expect the outcomes of your experiment to be? Which prediction do you think is most likely? Why?
   - **update their project information in the PlantingScience platform**.
     - To do this, students need to log into their PlantingScience project page, click on 'Info' and then 'Edit Project'. (The edit project link is on the right-

hand side of the page after the introduction paragraph.) Students should enter their chosen research question and enter the predictions that they feel are the most likely outcome.

**Remind students to SAVE their entries.** If they do not save, their entries will not appear.

**10. Allow time for students to read the *Planning Your Study* section in the *Student Roadmap*.**

This information provides guidance on matching the experimental method to the research question as well as developing research and data collection plans.

**11. Allow time for teams to work on their experimental design for their chosen research question.**

The questions listed in the procedure should help teams think through details about their experiment. Encourage students to check with you about materials or supplies that they may want to use. If certain supplies are not available, they may need to modify their design.

The questions that will help students with their experimental design include:

- 11a. What is your research question?
- 11b. What conditions, plants, treatments, or other variables will you be changing in your experiment?
- 11c. What conditions will you keep the same throughout your experiment?
- 11d. Describe the steps you will follow to complete your experiment.
- 11e. What will you measure? What data will you collect?
- 11f. How will you present your data to others (charts, graphs, photos, and so forth)?
- 11g. What do you predict will happen in this investigation? Why do you think this?
- 11h. Describe how your experiment tells you something about plants in the world around us.

If not using the student guide, you could give each student a copy of Handout 16: *Planning Your Investigation*. This handout includes the questions listed above. Students could then add that to their notebooks.

**Optional Handout**

**12. After teams agree on their experimental design, they update their PlantingScience project page:**


- **12a. Post an update describing their plans to their mentor.** Mentors may be able to offer helpful suggestions for improving the design. Allow time for mentors to review the experimental designs and provide feedback before moving forward with the investigations.

12b. **Edit the Project Info field for 'Experimental Design'** with the design steps and description. This field can (and should!) be edited later if changes are made.

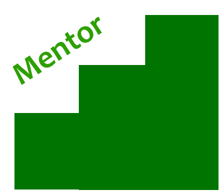
**Conducting the Investigation**

13. **Allow 2 class periods (45-minute periods—or perhaps 1 block schedule period) for students to conduct their investigations (after incorporating feedback from mentors).**

Be clear with students as to how much time they have to complete their investigations. Teams may need guidance about fitting their investigation into the available class time. For example, they may need to figure out whether they can complete their investigation in 1 day or whether they need to think about how they could do part on one day and the rest on the next day. If necessary, help students identify appropriate stopping points in their procedure.

Teams may need to spend some time testing parts of their procedure before beginning their real investigation. Encourage them to ask questions of their mentor if they run into problems.

**Teams should also share their observations and data with their mentor on the PlantingScience platform.** If possible, encourage them to upload photos of their setup and additional photos as they progress. They can also upload PDFs of documents and charts as long as no team member's last name is visible in the text. As always, encourage students to read any mentor responses carefully and to respond to questions the mentor asked.




**Data Analysis and Conclusions**

14. **Allow time for teams to begin working on the analysis of their data. They can review the plans they made for how to summarize and analyze their data. Now that they have done the experiment, they may want to revise or add additional strategies for summarizing their data.**

Encourage teams to think about the best ways to summarize their data. Sometimes, a photograph works well. In other cases, they may need a graph or diagram. Often, they may want to use multiple formats.

15. **Teams should work together to make sense of their results. The questions listed in this step in the student guide should help guide students' thinking and help them present their results to their mentors.**

If you choose not to use the student guide, you can give each student a handout of Handout 17: *Making Sense of Your Investigation*, to help them summarize their findings. They can add this into their science notebook when complete.

Optional Handout

16. **Teams should update their Project Page on the PlantingScience website. They should update the Conclusions field of their team's Project Page.**

Students can also upload additional documents to the Files section of their Project Page. This could include pictures of their experiment or of pages in their science notebook for mentors to review and discuss.

**IMPORTANT**; Do not post Google dos or Google Drive links in your project updates. Although this may seem convenient, this causes concerns with security and privacy. Instead, upload documents to the Project Files section.

Optimally, you will allow time for mentors to view posts from students and give their feedback. Teams may want to discuss the feedback with the mentors before moving on with the investigation.

**Communicating Your Findings**

17. **Ask teams to create a presentation about their investigation and the results. Explain your preferences regarding presentation format and time.**

For example, do you want students to prepare posters or PowerPoint presentations? All students should have a role in the presentation.

18. **Have each team present its research question and experimental results with the class. As teams present, discuss how these results add to the synthesis board that the class has been developing and how they are consistent (or inconsistent) with the results of other teams. After teams present, ask if there are things they could add to the synthesis board based on their results.**

Building Your

Discussing how different investigations add to students' knowledge of photosynthesis and cellular respiration helps students fit their experimental results into a larger conceptual understanding. Because different teams will investigate different aspects of cellular respiration and/or photosynthesis, this discussion can help students see how the results of their investigations relate to others. Do the results of their experiment make sense when thinking about other teams' experimental findings?

When conducting the discussion and adding to the storyboard, consider the following:

- How do these results relate to the previous investigations done in the module (thought investigations and guided investigations)?
- What is the quality of the evidence and reasoning for the explanation given?

- Are there weaknesses in reasoning that become apparent? (If this happens while presenting, assure students it is fine to reconsider their explanation.)
- How do the explanations developed by one team reconcile with data from other teams' investigations?

19. **If possible, have students share their final presentation with their mentors.** Photographs or digital files uploaded to the project page are a great way to showcase the whole project and close out the mentoring conversation with their scientist.

20. **Ask students to return to the model they have been developing in their science notebooks. Allow time for them to add to or revise their model now that they have completed their investigations into photosynthesis and cellular respiration.**

    Depending on your preference, you could ask students to work in teams to discuss and compare their models. Another possibility is to have a gallery walk where students visit a few other student's models and look for similarities and differences from their own.

    If time permits, allow students to conduct another investigation. This may be something from the original set of interesting research questions or a new idea that arose during the investigation.

    Often, one investigation will spark ideas for new investigations. If possible, allow time for students to experience the excitement of science by continuing with a new research question and continuing to interact with their mentors.

## Part 2: Revisiting Ideas about Scientists

21. **At the beginning of the module, students responded to a survey giving their ideas about what scientists are like. Now that students have had opportunities interact with a scientist mentor, students should independently review the list of words and phrases they wrote in their science notebooks about scientists.**

22. **Lead a short discussion to share these reflections across teams.**

    Students could consider the following questions:
    - Has anything surprised you about your scientist mentor?
    - How was your mentor similar to your first ideas and how was your mentor different from what you expected?
    - Do you have more or less in common with your scientist mentor than you thought you would?
    - Did other teams have mentors that seemed very different from their own mentors in terms of how they interacted or what they liked to do?
    - What did you find most helpful from your mentor?

Alternatively, instead of a full class discussion, this could be done as team discussions or as a jigsaw in which one team member from each team meets with one team member from all of the other teams.

Hopefully, through the online mentoring in this module, students got to know their scientist mentors. In addition to getting feedback on their science questions and investigations, they may have found out more about what their mentor likes to do in their free time, what drew them to becoming a scientist, what they like best about being a scientist, and so forth. In other words, students may learn that scientists are not that different from themselves or other people they know.

Having a group discussion about the scientist mentors lets the students hear from their classmates and appreciate the diversity of scientists working with the class. While some scientists could very well have some of the stereotypical characteristics the students expected they would, it's unlikely that every scientist will. Having a broader, less stereotypical, more diverse view of scientists may help students reevaluate how they view the relationship between themselves and scientists, and whether or where they can picture themselves personally thriving in a science or science-adjacent career. Even for those students with no interest in becoming a scientist, a more expansive idea of who scientists are and what they do may impact how students relate to science and scientists in the future, whatever their career path.

**23. To wrap up the module, ask students to take a short survey about their experience with their mentor on the PlantingScience website.**

The five-question project survey is extremely helpful to the PlantingScience team to evaluate how well the mentoring experience went from the students' perspective. It also requires students to personally reflect on the experience, which research shows can be key to whether the experience has an impact on future attitudes. In the survey, we ask students

a. whether and how the scientist mentor they worked with was what they expected a scientist to be like;
b. whether they felt working with their scientist impacted their learning or impacted how interested they were to study plant science;
c. how well they felt various aspects of the project went; and
d. if they have any advice for their mentor. (Answers to this last question will not be shared directly with the team's mentor, but their answers will help us develop training materials for mentors.)

**Have students go to their Project Page one more time to thank their mentor and say goodbye.**

Mentor

**Additional Resources (optional)**
***Science Matters: Plant Genetics and the Environment***
https://www.youtube.com/watch?v=fghFaDlgc-E
(30 minutes; University of California Television)

This video provides examples of social driving forces for understanding environmental impacts on plant productivity/growth and what some of these environmental factors are. Teachers are advised to preview the video and choose the best selection for the time available.

Background reading on photosynthesis and cellular respiration is available in the five reference readings in the *Power of Sunlight Student's Guide*. Additional videos, web pages, books, and articles to support teaching and learning about photosynthesis and cellular respiration can be found in the *Photosynthesis and Respiration Resources* document.

Handout 15

# Asking a Testable Question

People ask questions about a lot of things. Scientists need to think carefully about the questions they ask. For many of the things that scientists want to learn about, the questions need to be testable. A testable question is one that can be answered by designing and conducting an experiment. Through their experiments, scientists collect data and evidence that allow them to answer their testable question. It is important to note that not all questions that scientists want to answer are testable. Sometimes, scientists learn things by careful observation.

How do you know if a question is testable? What are the things you need to look for or think about when deciding whether your question is testable?

Testable questions are always about changing one thing to see what the effect is on another thing.
These "things" are called variables. There are two kinds of variables to be aware of.

- The **independent variable** is the one that a scientist changes during an investigation. There should be one independent variable.
- The **dependent variable** is the thing that you measure. It is the response to the change you make in the independent variable.

For example, if you wanted to find out how much weight your puppy gained each week, the independent variable would be time (weeks) and the dependent variable would be weight (the thing you are measuring).

There are some key things to think about when you are developing your testable question.

1. **The question includes variables that can be measured or observed.** A testable question will usually be specific and include what will be changed (independent variable) and the effect that it is expected to have (dependent variable). A testable question may be written something like the following:

    How does changing ___________ affect _________?
    (independent variable) (dependent variable)

    What happens to ___________ if we change __________?
    (independent variable) (dependent variable)

Consider the following questions. Are they testable? If so, what are the independent and dependent variables?

- How does the type of paper affect the distance a paper airplane flies?
- Do paper airplanes made from construction paper fly farther than paper airplanes made from notebook paper?
- How does increasing temperature affect the time it takes for fruit fly eggs to hatch?

2. **The question needs to be answered using available materials and in the allowed time.** Consider the question, "Will bean plants grown in Florida grow taller than bean plants grown in Colorado?" This question could be testable if you had the time and resources to be in both places, but that is likely not to be the case. You could potentially change the question to reflect something about the different places that you are interested in testing. Maybe you are interested in temperature differences or differences in humidity levels that you could adjust for the experiment.

3. **The question cannot be answered using an internet or book search.** If you are asking a question like "Why is the sky blue?" or "How do people grow?" you can look up answers from many different sources. You are not asking a question that you can answer with an experiment. These types of questions may be useful when you are starting to think about a phenomenon, but you would need to get more specific before you would have a testable question.

4. **The question does not include opinion works, such as better or best.** For example, the question, "Are red apples better than yellow apples?" is not a testable question. Different people would have different opinions about it. Another example would be the question, "Is it better to be right-handed or left-handed?" What does "better" mean? Sometimes, questions like these can be rewritten to be more specific, thereby making them testable.

5. **The question has a yes or no answer.** Will a radish grow from a radish seed is not a testable question. It does not call for any collection of experimental data. Testable questions require more than yes or no answers and generally result in learning something new about what we are investigating.

Perhaps the most important thing to remember about testable questions is that the goal is to help you find out more about how something works.

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Handout 16

# Planning Your Investigation

A successful investigation needs to be planned. Use the following questions to help you make a good plan.

A. What is your research question?

B. What conditions, plants, treatments, or other variables will you be changing in your experiment?

C. What conditions will you keep the same throughout your experiment?

D. Describe the steps you will follow to complete your experiment.

E. What will you measure? What data will you collect?

F. How will you present your data to others (charts, graphs, photos, and so forth)?

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Handout 17

# Making Sense of Your Investigation

What was your research question?

Did you make any changes to your experimental design as you were doing your experiment? If so, describe your changes.

Use the table below to describe evidence from your experiment that helps answer your research question.

| What evidence from your experiment helps you answer your research question? | Explain your reasoning. |
|---|---|
| | |
| | |
| | |
| | |

Write a sentence to summarize your findings (your answer to the question).

How do the data help explain photosynthesis and cellular respiration?

Did you notice anything during your experiment that seemed unusual or problematic? Please describe and explain why it might be a problem. Do any of the data you collected not support your claim?

If you did this experiment again, would you change anything in the procedure? Why or why not?

Write any other notes or comments you would like to share with your mentor.

## Features of Testable Questions

For the purpose of the investigation, you will do with your teammates, your research question must satisfy two main requirements:

1) the question must be testable and

2) the question must relate to photosynthesis and/or cellular respiration.

How do you know if a question is testable? Some characteristics of testable questions are listed below.

Testable questions

- ask about objects, organisms, and events that are part of the natural world;
- can be answered through collecting and analyzing measurable evidence;
- can be answered through investigations that involve experiments, observations, or surveys; and
- relate to scientific ideas and not preferences, morals, or opinions.

Testable questions are always about changing one thing to see what the effect is on another thing.

These "things" are called variables. There are two kinds of variables to be aware of.

- The **independent variable** is the one that a scientist changes during an investigation. There should be one independent variable.
- The **dependent variable** is the thing that you measure. It is the response to the change you make in the independent variable.

For example, if you wanted to find out how much weight your puppy gained each week, the independent variable would be time (weeks) and the dependent variable would be weight (the thing you are measuring).