UDL Teacher Guide: Intermediate Plants

Photosynthesis: it's a green thing

"What drives life is…a little electric current, kept up by the sunshine."
—Albert Szent-Gyorgyi, Nobel laureate

Driving Question: What do plants eat?

This unit explores how the leaves of a plant produce sugar for growth, flowers, fruits and seeds.

Introduction

Using the UDL approach, students actively explore the science of photosynthesis in multiple ways: from a fictional story to data collection with probes, and from hands-on inquiry experiments to testing conditions on computer models. Data collection, using Vernier probeware, is displayed using smart graphs, allowing students to dissect elements of the graph to further their understanding. Students are provided with scaffolded assistance to questions and offered choices for demonstrating what they've learned through text or drawings. Coaches offer prompts, hints, and models to engage students in the science content.

Each activity includes a discovery question to help students refine their understanding as they progress through the unit. They are:

- How do plants make food to grow?
- How do leaves make food for plants?
- What happens inside a leaf?
- Do plants breathe?
- How fast will a plant grow under different conditions?

The discovery questions are located at the top of each page of the activity, so students can refer to them often. Point them out occasionally if students need reminding about the focus of the activity.

Technology

The technology used in the UDL plant unit is designed for students to discover the story told by the data as they investigate photosynthesis. A relative humidity probe is used in "Monitoring a Living Plant" to gather real-time plant transpiration data.

The probes allow students to collect and view data in real time on smart graphs. Smart graphs allow students to analyze data in a meaningful and supported way. The graphing tools are the same, regardless of the activity.

The technology in UDL does not supplant the teacher. Instead, students are individually supported throughout the unit. One example of this support is that students can highlight the text and the computer will vocalize the words. Definitions for highlighted words (in blue) are also built into the program. A complete glossary for the unit can be found at the bottom each page using the book icon. In some of the units you will also find three robot helpers. These

"coaches" are there to help the student understand the material by asking them to make predictions, asking guided questions, and by clarifying or predicting what will happen next.

The teacher can manage certain features of the units for both the class and individual students. Once a class is set up the teacher can go to the UDL Portal-Info page and click on the "View a report on this class" icon. At the top of the report page there are two options, one that allows you to configure the parameters for students. This allows you to control the font and set the initial scaffolding level for students. The option on the class report page allows you to enable/disable activities within the units.

The default setting for lesson order when setting up your classes will be a sequenced order of lessons. When students enter the menu page they will complete the Pre-test. When they have submitted the Pre-test they will be able to access the next lesson in the sequence. If you want to allow students to choose their own sequence you can set up your class so that once they have completed the Pre-test and Introduction they can move between lessons in whatever order they like. (A more detailed explanation can be found at http://udl.concord.org/share/teacher-guides/Dashboard.pdf)

Scaffolding in UDL Units

Scaffolding in education has traditionally been done by the teacher as a way to assist students as they are learning new skills or content. The scaffolding is done not to provide answers or do the work for them but as a way for the students to gain confidence and develop understanding of skills and concepts. The goal of scaffolding is that over time the level of assistance that a student needs will gradually be reduced until the minimal amount of support is needed and used. To use a cooking analogy: a chef will use a recipe the first few times he makes a dish. After he has made it several times, he may have the recipe out for reference and then after more time, it becomes so natural he no longer needs the recipe.

In the UDL units different levels of support are offered to students when answering questions. As with the cooking analogy, the scaffolding is intended to provide support for those students who need it with the goal that with time they will be able to work with minimal scaffolding. When scaffolding prompts are available they are accessed by clicking on the green question mark icon. Students may answer the open-ended question as presented. Or, if they are unable to do so, they can click on the question mark and access the first level of support. At this level they are given a hint that may lead them to the correct response. If the student is still unable to answer the question, they can click the question mark again for the answer with key words left out and they can fill in the blanks. If they need additional help, they receive a multiple-choice list. The final level of scaffolding offers the student a model response; they are given the answer and asked to provide their own ideas about the response.

Standards

NSES Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry.
    - Identify questions that can be answered through scientific investigation.
    - Design and conduct a scientific investigation.
    - Use appropriate tools and techniques to gather, analyze, and interpret data.
    - Develop descriptions, explanations, predictions, and models using evidence.
    - Think critically and logically to make the relationships between evidence and explanations.
- Understandings about scientific inquiry.

- Mathematics is important in all aspects of scientific inquiry.
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.

NSES Content Standard C: Life Science

- Structure and Function of Living Systems
  - Living systems at all levels of organization demonstrate the complementary nature of structure and function. Important levels of organization for structure and function include cells, organs, tissues, organ systems, whole organisms, and ecosystems.
  - Cells carry on the functions needed to sustain life. They grow and divide, thereby producing more cells. This requires that they take in nutrients, which they use to provide energy for the work that cells do and to make the materials that a cell or an organism needs.

- Regulation and Behavior
  - All organisms must be able to obtain and use resources, grow, reproduce, and maintain stable internal conditions while living in a constantly changing external environment.

- The Cell (9-12)
  - Plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems.

Benchmarks for Science Literacy (AAAS)

- 5E Flow of Matter and Energy
  - Food provides the fuel and the building material for organisms. Plants use the energy from light to make sugars from carbon dioxide and water. This food can be used immediately or stored for later use. Organisms that eat plants break down the plant structures to produce the materials and energy they need to survive. Then they are consumed by other organisms. (6-8)

- 9B Symbolic Relationships
  - Graphs can show a variety of possible relationships between two variables. As one variable increases uniformly, the other may do one of the following: always keep the same proportion to the firs, increase or decrease steadily, increase or decrease faster and faster, get closer and closer to some limiting value, reach some intermediate maximum or minimum, alternately increase and decrease indefinitely, increase or decrease in steps, or do something different from any of these. (6-8)

- 9D Uncertainty
  - How probability is estimated depends on what is known about the situation. Estimates can be based on data from similar conditions in the past or on the assumption that all the possibilities are known. (6-8)

Alaska state standards (http://udl.concord.org/share/teacher-guides/TG_Plants-Intermediate-AK-Standards.pdf)

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Learning Goals

Understand that plants do not eat as animals do. They make their own food for growth by the process of photosynthesis, which takes place in their leaves.

Plants need sunlight, water, and carbon dioxide to make food. A lack of any of these will diminish the health and growth of a plant.

Photosynthesis is a complex process that takes place in chloroplasts inside the green leaves of plants. It includes the following parts:

- The energy of sunlight is absorbed in the leaves and changes the chloroplasts into an excited state. During this process the leaves take up water from the roots and release oxygen into the air.
- The excited chloroplasts use their energy to make sugar. During this process the leaves take up carbon dioxide from the air and more water from the roots. They also release water vapor into the air.
- During photosynthesis, plants use water, sunlight, and carbon dioxide.
- During photosynthesis, plants produce sugar, oxygen, and water vapor.

The sugar produced by photosynthesis is used throughout the plant as food for making more leaves, stems, bark, roots, seeds, flowers, and fruit.

The release of water into the air during photosynthesis is called transpiration.

All animals depend on the oxygen produced by plants for their own respiration. The source of energy for all animals is the food produced by plants.

Background Information

Plants are found in almost all environments on our planet. They come in many forms and have developed to survive in their particular niche. Even so most plants have some common characteristics. They are critical to our survival since they can produce their own food and so are at the base of most food chains.

The basic structure of flowering plants can be divided into two systems. The root system includes the primary root and the root hairs. There may also be lateral roots coming off the primary root. This system serves several functions. First the roots act as an anchor for a plant. They help hold the plant in place. They also absorb water that the plant uses as part of the process of photosynthesis and trace nutrients (minerals like nitrogen, phosphorus, or sulfur) that the plants use for their own growth and health. The roots also act as a storage system for the food (sugars) produced by the plants. For example, a carrot is the stored food in the root of the carrot plant.

The other system in most plants is the shoot system. This includes the stem, leaves, and flowering bodies. The stem (trunk) is a support system for the leaves and flowering bodies. The stem also contains tube-like structures that help transport water and nutrients. The shoot system also includes the leaves. The leaves take in carbon dioxide (CO_2) from the air and

release oxygen (O_2) through small pores. They also absorb light energy and transform it into chemical energy. The carbon dioxide, along with water that is absorbed by the roots and the chemical energy, is converted into sugars (food). The flowering bodies on the shoot system are the primary reproductive system of the plant. Through the interaction of the various reproductive parts plants produce seeds, which will carry the species forward to the next generation.

Photosynthesis is the process that plants use to take in minerals (H_2O and CO_2) and light energy to produce sugars (food) that the plant uses to support its own life processes, as well as the organisms that consume plants. The process of photosynthesis takes place primarily in the leaves of the plant. The process takes place in two reactions. The first is the light reaction. Light reactions occur when light energy is coming into the plant (usually from the sun). The light energy is converted and stored as chemical energy. Dark reactions don't require light, but aren't inhibited by it either. During the dark reactions the stored chemical energy and the minerals the plant has taken in are used to produce sugars. This process is called photosynthesis and involves chlorophyll in the chloroplasts, which are found mainly in the leaves of the plant.

Misconceptions about Plants

When students enter school they come with a set of understandings about science. Some of these ideas are well developed and accurate. Others may be just as well developed, but fail to accurately reflect true understanding about science concepts. There are a variety of reasons that students develop misconceptions about science and it is important to have some ideas about what some of these misconceptions might be. One reason for these misconceptions is that students are introduced to vocabulary without having a connecting experience. They may have also built these misconceptions through life experiences before entering the school setting. Misconceptions may also be held on to extremely tightly, with students giving the "correct" answer on a test, but when pressed they will fall back on the misconceptions that they held prior to instruction. While recognizing common misconceptions is important, it is also critical that teachers take the time to help students address these misconceptions through inquiry-based activities.

The misconceptions below relate to the topics explored by students in the plant unit.

Photosynthesis and Respiration:

a. Plants get their food from the environment rather than manufacturing it internally.
b. Food for plants is taken in from the outside. Soil supplies most of the "raw materials" for photosynthesis. (Students have difficulty accepting that plants make food from water and air and that this is their only source of food.)
c. Water and minerals are food for plants.
d. Soil is the plant's food. People put food (fertilizer) in the soil for plants to eat.
e. Respiration and photosynthesis are not seen as energy transfer processes.
f. Plants take their food in through the roots and then store it in their leaves. Plants convert energy from the sun directly into matter.
g. Plants change water and carbon dioxide into sugar (instead of plants convert carbon dioxide from air and hydrogen atoms from water into sugar).
h. Plants only give off oxygen.
i. Photosynthesis is a plant process and respiration is an animal process.
j. Respiration means breathing (not energy release).

A plant can be viewed as a manufacturing plant. The raw materials for manufacturing are water and carbon dioxide. The energy that runs the manufacturing process is light energy,

primarily from the sun. The water provides the hydrogen that makes up the sugars, and the carbon dioxide provides the rest of the atoms that make up the sugar molecules.

http://dese.mo.gov/divimprove/curriculum/science/SciMisconc11.05.pdf

Unit Overview

Activity Title	Activity Length	Materials	Overview
Pre-test	20 minutes	• Computer with Internet access	Students begin with a short pre-test that allows the teacher and student to assess prior knowledge.
Introduction	15 minutes	• Computer with Internet access.	Students watch a short video that shows 24 hours in the life of a sunflower. Students watch how the leaves and the flowers follow the movement of the sun.
A Plant Story	Two 45-minute sessions	• Computer with Internet access • Printout of story (optional) (http://udl.concord.org/share/teacher-guides/PlantStory56_v6.pdf)	Stories read a story about siblings Marc and Natasha who travel inside a plant—with the help of special instruments from their mother's friend, Elvira—to watch photosynthesis taking place.
The Plant Game	60-90 minutes for the game plus additional time to input data into the computer	Each Team • 0.5 liter plastic bottle • 1 straw or wooden splint • 1 teaspoon (5 ml) • 1 tablespoon (15 ml) • 1 small funnel • 1 measuring cup (250 ml) with metric scale • 1 small beaker or cup to as water reservoir • Weather Report Chart (http://udl.concord.org/artwork/plant_56/weather_report/	Students play "The Plant Game" in teams of 3-4 students. They use a roll of the dice and the Weather Report Chart to grow a plant. The goal of the game is to build a healthy plant that reproduces by producing flowers before the frost.

		weather_report.pdf) • Scorecard (http://udl.concord.org/artwork/plant_56/scorecard/scorecard.pdf) • computer with Internet access Each Class: • 30 (or more) small paper clips • 1 set of about 40 sugar tokens (laminated if possible) (http://udl.concord.org/artwork/plant_56/sugartoken/pl_56_sugartoken.pdf) • 1 set of about 30 leaf cards (laminated if possible) (http://udl.concord.org/artwork/plant_56/greenleaf/pl_56_greenleaf.pdf) • 1 set of about 20 flower cards (laminated if possible) (http://udl.concord.org/artwork/plant_56/flowercard/pl_56_flowercard.pdf) • scissors • one-hole punch • calculator or paper • 2 standard dice	Students can either record their data for the game on the scorecard on the computer, or they can write on the chart and then transfer the data to the chart on the computer.
Photosynthesis: The Big Picture	Two 40-minute sessions	• computer with Internet access	Students study a model of a leaf as it undergoes photosynthesis. By looking inside the leaf, students discover the work of the chloroplast—the factory where plants make their food. Students are introduced to the role of the leaf in the process of photosynthesis.
Photosynthesis: A Closer Look	Two 30-minute sessions	• computer with Internet access	In this activity, students refine their understanding of photosynthesis. Using the Leaf Model and video, students continue their investigation regarding how plants make food from water, carbon

			dioxide, and sunlight. The focus of this activity is the light-dependent (daylight) and light-independent (less light or darkness) portions of photosynthesis.
Monitoring a Living Plant	45-60 minutes	• small handheld mirror • humidity sensor • green construction paper • scissors • pencil • potted plant with large leaves • sandwich size resealable plastic bags (2 per student or team) • other plants, leaves, or flowers • computer with Internet access	In this activity, students investigate plant transpiration using a humidity sensor.
Rates of Growth	40 minutes	• computer with Internet access	In this activity students use math and science to analyze seven days of collected data to identify the affect of different light and water conditions on plant growth.
Wrapping Up	Ongoing	• computer with Internet access	In the "Wrapping Up" section students use what they have learned and evidence from their lab book to reflect on what they have learned.
Post-test	20 minutes	• computer with Internet access	Students complete the post-test, which contains the same set of question as the pre-test, as well as student feedback questions.

Unit Activities

Pre-Test

Time: 20 minutes

Materials: computer with Internet access

This unit begins with a short pre-test. The pre-test allows students to share what they already know about the learning goals. Students must complete the pre-test and press the "Submit" button before proceeding to any activity. The post-test at the end of the unit contains the same set of questions and allows the teacher to see student progress after completing the activities in this unit.

Introduction

The driving question "What do plants eat?" is introduced. In this unit, students explore how the leaves of a plant produce sugar for growth, flowers, fruit and seeds. In the Introduction students watch a short video showing the movement of a sunflower over the course of a 24-hour period. They are then asked to use their observations to decide what time of day still images of the sunflower show. This introduces the importance of the sun in the process of photosynthesis. As the students are working through this unit, it is important to continue to come back to the driving question. Posting it in the classroom is one way to accomplish this.

Time: 15 minutes

Materials: computer with Internet access

A Plant Story — Story

Siblings Marc and Natasha travel inside a plant—with the help of special instruments from their mother's friend, Elvira—to watch photosynthesis taking place.

Time: two 45-minute sessions (or can be read in chapters as time allows)

Standards:

NSES Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry.

- Think critically and logically to make the relationships between evidence and explanations.

NSES Content Standard C: Life Science

- Regulation and Behavior
  - All organisms must be able to obtain and use resources, grow, reproduce, and maintain stable internal conditions while living in a constantly changing external environment.

Benchmarks for Science Literacy (AAAS)

- 5E Flow of Matter and Energy
  - Food provides the fuel and the building material for organisms. Plants use the energy from light to make sugars from carbon dioxide and water. This food can be used immediately or stored for later use. Organisms that eat plants break down the plant structures to produce the materials and energy they need to survive. Then they are consumed by other organisms. (6-8)

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Materials:
Students can read this story online by clicking arrows to navigate from one page to the next. Or print a PDF version of the story from the Teacher Resources section of the Portal to read offline.

Student Activity:
Students read a story about Marc and Natasha who have planted a sunflower they have named "Sonny". With the help of a friend, Elvira, they observe the movement of Sonny as the sun moves across the sky. Using their observations they begin to think about how plants grow. With the help of some special tools Elvira takes them into the plant so they can see how photosynthesis works. As they read the story they are asked to summarize what they have learned.

Scaffolding is available using the "robot" helpers, which provide prompts to help students understand the story.

Teacher Notes:
Basic plant physiology as it relates to photosynthesis is integrated into the storyline. The sunflower demonstrates a phototrophic response—it keeps its leaves pointed toward the sun. The leaf is entered through the stomata. Chloroplasts are eventually found inside the plant's cells, and the reaction between sunlight and chlorophyll is observed. Differences in sugar production between light and night portions of the day are noted. Lots of good opportunity to

help students understand the vocabulary and to begin sketching a mental picture of the process of photosynthesis.

Further discussion could include different ways the plant responds to its environment (geotropism and chemotropism), structure of the leaf and chloroplasts, difference between chloroplast and chlorophyll, differentiating between atoms and molecules, and characteristics of a living organism.

The Plant Game — *Hands-on*

Discovery Question: How do plants make food to grow?

In this activity, students make decisions for the growth of a plant during a single growing season by tying its ability to produce sugar to producing new plant parts. Here, students direct the activities of a plant—making sugar and growing. The throw of the dice determines weather conditions and when freeze-up (end of the growing season) occurs. The winner is the plant with the most flowers and, therefore, most likely to ensure its own next generation. The purpose or function for the plant basic structures—leaf, flower, stem, and root—is introduced.

Time: 60-90 minutes, with additional computer time to input data, analyze graphs and answer questions

Standards/Benchmarks:

NSES Content Standard A: Science as Inquiry

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  - Develop descriptions, explanations, predictions, and models using evidence.
  - Think critically and logically to make the relationships between evidence and explanations.
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Advance Preparation: (Scissors and one-hole punch required for game card preparation.) Game cards must be prepared prior to the game. The weather report and the scorecard can be photocopied front to back, giving each student group only one paper. One set of cards (i.e., sugar, leaf, and flower) is just enough to support eight student set-ups. (However, a group might need to "buy" a plant part before there will be enough sugar tokens to "pay" a group.)

Note: In this game students are actively removing or adding water from their plant. Laminated cards work best. Consider the game play area and how to clean up the inevitable water spills. Make sure to read through the game so that you are comfortable leading it. This game is great! Students may ask to play it again.

Materials:

Each Team:

- 0.5 liter plastic water or soda bottle
- 1 straw or wooden splint
- 25 ml graduated cylinder OR
- 1 teaspoon (5 ml)
- 1 tablespoon (15 ml)
- 1 small funnel (optional)
- 100 ml graduated cylinder OR
- 1 measuring cup (250 ml) with metric scale
- 1 small beaker to act as water reservoir
- Weather Report Chart (download and print pdf file)
- Scorecard (download and print pdf file)
- paper towels for clean-up
- paper or calculator needed for scorecard calculations

Each Class:

- 30 small paper clips (roots)
- 1 set of about 40 sugar tokens/cards (laminated, if possible)
- 1 set of about 30 green leaf cards (laminated, if possible)
- 1 set of about 20 flower cards (laminated, if possible)
- 2 standard dice

Student Activity:
If students are comfortable and are able to independently log onto the UDL portal, use the login time to ask the discovery question: "How do plants make food to grow?" Record student answers.

Engage:
Basic game strategy is discussed. Directions for building the starter plant are given. Weather Report Graph is shown, correlating the dice throw with the weather and dictating the plant's response. Rules and strategies for buying roots, leaves, and flowers are given.

Explore:
The computer version of the game card is found here. At the end of the game, students will enter all their data from their scorecard onto this electronic scorecard. More days can be added beyond day 20 by clicking in the bottom row and entering the data. A blank row will always end the scorecard. Three individual bar graphs (number of roots, leaves, and flowers) will be automatically created from the data entered in the scorecard. Details regarding the ending of the game and how freeze-up are explained.

Explain:
Students review their data to answer the question, "How well did your plant grow?" Students are asked to use evidence found in their data to comment on the effectiveness of their game/plant growth strategy.

Elaborate:
Students are asked to compare root/leaf/flower ratios of different plants grown during the game to assess their level of success. It will be necessary to collect this data from each group for sharing. A review of ratios might also be necessary. Students analyze their choices and write a short report detailing their plan to produce the most flowers. This could be the strategy they used in the game, or a new strategy based on presented evidence.

Quick Check for Understanding: Ask students to support their claim with evidence as they answer the question: How well did their plant grow? You could also ask students to explain, using these questions: How did your game strategy help your plant to be successful? How useful was the plant leaf/root/flower ratio in determining the success of your plant? What evidence did you use to support your conclusion?

Quick Check for Understanding: Revisit answers for the discovery question: "How do plants make food to grow?" What new insights did students gain? Do they have other questions? Perhaps this activity helped them answer the question, "Why do plants make food?" and can relate this to the growth of a plant. The more leaves a plant has, the more it is able to photosynthesize and thus, make more food, which supports more growth. Lastly, ask students: What does the plant require to grow? Can it grow without water? Sunlight? This will help set the stage for the next activity.

Teacher Notes:
Have students read through the game. The images included in the program help them set up their plant. The rules and strategies are clearly presented. Remember, students are continually adding or removing water from their bottle. Dice rolls of three or higher require students to calculate water loss/gain per leaf.

Depending on the weather conditions, students may need to add more water than they have room for in their bottle. Students should not overfill their bottles. This extra water represents water the ground is not able to absorb and the plant is not able to use. This could represent a period of flooding while the extra water represents ground water runoff. Hopefully, a period of sun and warmer temperatures will soon follow, drying out the ecosystem.

Continually remind students to record their data, as they may become so involved in the game that they forget. Once the game is running smoothly, ask students how they are making their decisions on what to buy with their sugar tokens. Do groups have a strategy? Is sugar being hoarded? Make sure to have students write down their strategy on their scorecards. This is especially important if students cannot immediately get to the computers to complete this activity.

Set the stage for your students! In this game, their plant starts life as a baby, one that has just bolted (broken through the ground)—showing only its cotyledon leaves and a stem. Its roots aren't well developed. As a plant, it will need to put energy into growing before it can support reproduction (i.e., a flower). Success for a biological organism is defined as ensuring the next generation. The more flowers you have, the greater your chances for fertilization and seed production. Is your plant being successful? Have fun!

Discussion:
Lead the whole class in a discussion using the questions below to start the conversation. Allow students time to clarify their ideas and encourage them to explain their thinking.

"How is the plant model like a real plant?"

"How is the plant model different from a real plant?"

Photosynthesis: The Big Picture — *Computer model*

Discovery Question: How do leaves make food for plants?

In this activity, students study a model of a leaf as it undergoes photosynthesis. By looking inside the leaf, students discover the work of the chloroplast—the factory where plants make their food. Students are introduced to the role of the leaf in the process of photosynthesis.


Time: Two 40-minute sessions


Standards/Benchmarks:

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Materials: Computer with Internet access

This activity uses a model created with NetLogo, a general-purpose modeling language for complex systems. Based on the ideas behind Logo, NetLogo is easy to use yet very powerful. If students or teachers wish to investigate this model further, modify the model, write their own model, or look at other NetLogo models that cover a wide variety of phenomena, go to the links shown below the model in the activity.

Student Activity:
Discuss the question and record student responses to the question, "How do leaves make food for plants?" This could be done while students are logging into the UDL portal.

Engage:

Students respond to the question, "Where do the materials come from that makes up trees, grass and leaves?" Students could refer to the class chart for helpful hints or remind them to think about their experiences in the Plant Game—what did their plant need to do to get a new leaf? The Leaf Model is introduced as a scientific model for photosynthesis in plants. With little direction, students run the computer model of the leaf. Students should purposefully adjust the control buttons to observe the effect on photosynthesis.

Explore:
A general overview of the basic Leaf Model is explained. Graphic features and control buttons and sliders are presented.

Quick Check for Understanding: Make sure students understand this model. Review key features. The green orbs in the leaf are unexcited chloroplasts. What has to happen before they will turn orange (an excited chloroplast)? Once they are orange (excited) can they ever become green (unexcited) again—when would this happen?

Review the elements of the model. The "bumblebee" looking icons are CO_2 molecules. Sugar molecules are depicted as white stars and are only seen in the stem/principal vein area of the leaf. The gray O_2 molecules can be difficult to see. The light rays (white arrows) represent photons—small packages of light. Where do students see the various elements? Completing a two-circle Venn diagram (inside the leaf/outside the leaf) would help students understand what is needed and where it's found for photosynthesis to occur. How do they know that photosynthesis is occurring in our model? (Chloroplasts turn orange and sugars are produced.) Production rates of photosynthesis are shown in a line graph and show how quickly the plant responds to changes in its environment. This is a smart graph. The coordinates of any point on the graph are displayed by placing the cursor on the line.

In three separate explorations students run the Leaf Model, looking specifically at one element of photosynthesis: brightness of the sun, amount of available water, and amount of available CO_2.

There are many opportunities to quickly assess the student's understanding. For example:

- Ask students to identify the highest level of sugar production. And then, what were the levels of O_2 and vapor production? Is this a reasonable relationship?
- Ask students to identify areas on their graph when data was being recorded in the day and in the night. What evidence would a botanist look for to determine day or night on this graph?
- Is the production level of sugar, O_2, and water vapor affected by the brightness of the sunlight? How did they adjust the model to determine this, and what is their evidence?
- Are the production levels of sugar, O_2, and vapor production affected by the amount of available CO_2? How did they adjust the model to determine this, and what was their evidence?
- Are the production levels of sugar and O_2 affected by the amount of available H_2O? How did they adjust the model to determine this and what was their evidence? The level of water vapor produced is not recorded in this run of the H_2O Vapor model—is water vapor still being released?

Explain:
Students are asked what leaves require for photosynthesis and where each comes from.

Elaborate:
Finally, students are asked to think about the carbon that makes up most of the plant and identify the source of the carbon.

Quick Check for Understanding: Bring students back to the discovery question by asking them: How do leaves make food for plants? Are stems important? (They

position the leaf.) What is the function of the root? (To anchor the plant, provide storage for unneeded energy/sugar and supply the plant with liquid water.)

Teacher Notes:

Photosynthesis is the process by which light energy is converted to chemical energy. Specifically, sunlight, carbon dioxide, and water are, in the presence of chlorophyll, converted to simple sugars, oxygen, and water. All life depends on this energy, and it enters our biosphere in the form of sunlight. In fact, the oxygen on our planet continues to depend on photosynthesis. All the oxygen in the biosphere is renewed every 2,000 years through the process of photosynthesis.

Technology Note:

This computer model allows students to see the affect of environmental conditions on photosynthesis. Students can adjust the intensity of light and the amount of available CO_2 and water with the slide of a bar. A clear explanation of each button and slider bar of the computer model is found in the *Explore* section of this activity. Students need to become familiar with the controls of this model. They will use it again in the next activity, "Photosynthesis: A Closer Look."

Further discussions could include students' predictions concerning the effect of global warming (increased levels of atmospheric CO_2) on photosynthesis. NASA contractors are developing small lunar greenhouses (greenhouses to be used on the moon) for use during long-term extra-planetary explorations. In addition to producing oxygen, do you think that plants could be a necessary component in a space colony?

Photosynthesis: A Closer Look *Computer model*

Discovery Question: What happens inside a leaf?

In "Photosynthesis: The Big Picture," students discovered that plants need sunlight, water, and CO_2 in order for photosynthesis to occur (to make O_2 and sugar). In this activity, students refine their understanding of photosynthesis. Using the same Leaf Model, students continue their investigation regarding how plants make food from water, carbon dioxide, and sunlight. The focus of this activity is the light-dependent (daylight) and light-independent (less light or darkness) portions of photosynthesis.

Time: Two 30-minutes

Standards/Benchmarks:

NSES Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry.
  - Develop descriptions, explanations, predictions, and models using evidence.
  - Think critically and logically to make the relationships between evidence and explanations.
- Understandings about scientific inquiry.
  - Mathematics is important in all aspects of scientific inquiry.

NSES Content Standard C: Life Science

- Structure and Function of Living Systems
  - Cells carry on the functions needed to sustain life. They grow and divide, thereby producing more cells. This requires that they take in nutrients, which they use to provide energy for the work that cells do and to make the materials that a cell or an organism needs.
- The Cell (9-12)
  - Plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems.

Benchmarks for Science Literacy (AAAS)

- 5E Flow of Matter and Energy
  - Food provides the fuel and the building material for organisms. Plants use the energy from light to make sugars from carbon dioxide and water. This food can be used immediately or stored for later use. Organisms that eat plants break down the plant structures to produce the materials and energy they need to survive. Then they are consumed by other organisms. (6-8)

- 9B Symbolic Relationships
  - Graphs can show a variety of possible relationships between two variables. As one variable increases uniformly, the other may do one of the following: always keep the same proportion to the firs, increase or decrease steadily, increase or decrease faster and faster, get closer and closer to some limiting value, reach some intermediate maximum or minimum, alternately increase and decrease indefinitely, increase or decrease in steps, or do something different from any of these. (6-8)

Alaska state standards (http://udl.concord.org/share/teacher-guides/TG_Plants-Intermediate-AK-Standards.pdf)

California state standards (http://udl.concord.org/share/teacher-guides/TG_Plants-Intermediate-CA-Standards.pdf)

Materials: Computer with Internet access

This activity uses a model created with NetLogo, a general-purpose modeling language for complex systems. Based on the ideas behind Logo, NetLogo is easy to use yet very powerful. If students or teachers wish to investigate this model further, modify the model, write their own model, or look at other NetLogo models that cover a wide variety of phenomena, go to the links shown below the model in the activity.

Student Activity:

Discuss the question and record student responses on a class chart to the question, "What happens inside a leaf?" This could be done while students are logging into the UDL portal.

Engage:
Students describe what happens when H_2O, CO_2, and sunlight are present around a green plant. Photosynthesis as a two-step process is introduced.

Explore:
Students are shown a NetLogo model that shows the process of photosynthesis. They use the model to identify the parts of photosynthesis. Students should understand this information before moving on.

Explain:
Students watch a movie that shows the light-dependent processes; they reflect on what they observe. The movie labels the various steps in this process. Then students watch and reflect on a movie that shows the light-independent processes. When have become familiar with both processes, they run the computer model, slowing the process of photosynthesis to the point where they can see individual events. Students are asked to focus on each step and what is produced or used up. Remind students to always click the Setup button to reset the model. Students should be focusing on the reactions that are being modeled.

Quick Check for Understanding: Ask students what is needed and what is made in each portion of photosynthesis (light-dependent and light-independent). Is there a connection between these processes? Constructing a concept map would help students see connections. See Concept Map, Selected Websites, below.

Elaborate:
Students are asked to summarize what they discovered about the light-dependent and the light-independent steps of photosynthesis and their relationship between oxygen and sugar production.

Teacher Notes:

This is a fairly straightforward lesson. Students should be familiar with the models and the controls by this time. They may need help in focusing their observations and adjusting the control panel with purpose—not just because the switches move.

Further discussion could include placing plants in bedrooms or in hospital rooms. This is an area that can hold a major misconception: simply, plants steal oxygen at night.

Monitoring a Living Plant — *Hands-on (relative humidity sensor)*

Discovery Question: Do plants breathe?

In this activity, students investigate plant transpiration using a humidity sensor.

Time: 45 to 60 minutes

Standards/Benchmarks:

NSES Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry.
  - Identify questions that can be answered through scientific investigation.
  - Design and conduct a scientific investigation.
  - Use appropriate tools and techniques to gather, analyze, and interpret data.
  - Develop descriptions, explanations, predictions, and models using evidence.
  - Think critically and logically to make the relationships between evidence and explanations.
- Understandings about scientific inquiry.
  - Mathematics is important in all aspects of scientific inquiry.
  - Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.

NSES Content Standard C: Life Science

- Regulation and Behavior
  - All organisms must be able to obtain and use resources, grow, reproduce, and maintain stable internal conditions while living in a constantly changing external environment.

Benchmarks for Science Literacy (AAAS)

- 5E Flow of Matter and Energy
  - Food provides the fuel and the building material for organisms. Plants use the energy from light to make sugars from carbon dioxide and water. This food can be used immediately or stored for later use. Organisms that eat plants break down the plant structures to produce the materials and energy they need to survive. Then they are consumed by other organisms. (6-8)

- 9B Symbolic Relationships
  - Graphs can show a variety of possible relationships between two variables. As one variable increases uniformly, the other may do one of the following: always keep the same proportion to the firs, increase or decrease steadily, increase or decrease faster and faster, get closer and closer to some limiting value, reach some intermediate maximum or minimum, alternately increase and decrease indefinitely, increase or decrease in steps, or do something different from any of these. (6-8)

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California state standards (http://udl.concord.org/share/teacher-guides/TG_Plants-Intermediate-CA-Standards.pdf)

Materials:

Each Team:

- small handheld mirror
- relative humidity sensor with GoLink
- green construction paper
- scissors
- pencil
- small potted plant with broad leaves
- two sandwich size resealable plastic bags (for Investigation Chamber)
- other plants, leaves, or flowers

Advance Preparation:
Students need access to a sturdy broad-leafed plant for this activity. Broad leaves (about three inches long) work better than small, thin leaves, although with patience, virtually any size leaf will work. Leaves must be able to fit into the resealable plastic bag along with the end of the Relative Humidity (RH) sensor. Expect some leaves to be broken during this activity. Access to plants and the number of plants needed for this activity must be considered. Four plants for a class of 28 worked, but it is uncertain how many classes would have plants with leaves if multiple classes were to share only these four plants.

Note: In the Elaborate portion of this activity, students are given the opportunity to design their own investigation. Students will need access to other living organisms that can safely fit inside their resealable plastic bag Investigation Chamber.

Student Activity:

Engage:
Students are asked several questions about photosynthesis. These could be used as a review of previous activities or as a way to gauge the students' level of understanding and check for misconceptions. Students are also asked to predict how long a plant can live in a sealed jar. This is a multiple-choice question and students could "vote" for their choice. Recording this piece of data on the board helps students to commit to their prediction and would serve as a class baseline on changing understandings.

Explore:
Note: Students should read all the directions for data collection before starting to take their data.
Students are investigating the concept of Relative Humidity (RH), using a mirror, their own breath, the classroom, a paper leaf, and a real leaf. Using a mirror, students are introduced to the concept of relative humidity. Our breath contains water vapor and if we can quantify moisture in the exhaled air, then we can document the act of respiration. To do this, students connect the Relative Humidity sensor to the Go-Link and then to the computer USB port. Results are displayed on a smart graph. Students need to be aware where they place the sensor. The effect of their breath is still measurable if the sensor is held at mouth level even at arm's length—be aware!

Teacher Notes:
What's really going on in this lab? Students are documenting gas exchange ("breathing") in a plant by quantifying the amount of water vapor in a sealed bag holding one living leaf. To measure water vapor, students use a Relative Humidity (RH) probe. In this lab, we are

specifically referring to humidity in the air inside the sealed bag. Humidity implies a humid condition: moistness or dampness. The warmer the air is, the more water vapor it can hold.

Scientific control needs to be addressed for the paper leaf model to make sense. Placing a paper leaf and sensor into a resealable plastic bag (the Investigation Chamber) is the control in our investigation. Comparing the amount of water vapor produced between a paper leaf and a living leaf in the bag is the essence of this investigation. If RH is measured with both a paper leaf and a living leaf, and a difference is recorded, then the change must be a result of the function of the living leaf.

Explain:
Students are now shown their graphs with the data from the paper leaf and the real leaf. They are asked to compare the graphs and explain how they are different. Using the comparison they use the data to decide if plants "breathe" and to support their answer with the data they collected.

Elaborate:
Students are given the opportunity to design their own inquiry by looking at what happens with other plants/plant parts." Students will need access to a variety plants, leaves, or flowers to collect data on.

 **Teacher Notes:**
Students are investigating if plants "exhale" (or give off) water vapor? Students are asked to gather evidence to support/refute their prediction. It is an exciting lab, offering students the opportunity to document the more general event that has not been concretely addressed in this unit—do plants breathe?

Discussion:
Lead the whole class in a discussion using the questions below to start the conversation. Allow students time to clarify their ideas and encourage them to explain their thinking.

"What are some of the factors that may affect the amount of transpiration that takes place in a leaf?"

Ask students to consider factors including surface area, weather, and time of day.

Rates of Growth *Math*

Discovery Question: How fast will a plant grow under different conditions?

How fast will a plant grow under different conditions? In a seamless integration of math and science, students analyze seven days of collected data on the effect of different light and water conditions on plant growth.

 **Time:** 30-45 minutes

Standards/Benchmarks:

NSES Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry.
  - Develop descriptions, explanations, predictions, and models using evidence.
  - Think critically and logically to make the relationships between evidence and explanations.
- Understandings about scientific inquiry.
  - Mathematics is important in all aspects of scientific inquiry.

NSES Content Standard B: Physical Science

- Transfer of Energy
  - In most chemical and nuclear reactions, energy is transferred into or out of a system. Heat, light, mechanical motion, or electricity might all be involved in such transfers.

NSES Content Standard C: Life Science

- Regulation and Behavior
  - All organisms must be able to obtain and use resources, grow, reproduce, and maintain stable internal conditions while living in a constantly changing external environment.

Benchmarks for Science Literacy (AAAS)

- 9B Symbolic Relationships
  - Graphs can show a variety of possible relationships between two variables. As one variable increases uniformly, the other may do one of the following: always keep the same proportion to the firs, increase or decrease steadily, increase or decrease faster and faster, get closer and closer to some limiting value, reach some intermediate maximum or minimum, alternately increase and decrease indefinitely, increase or decrease in steps, or do something different from any of these. (6-8)

- 9D Uncertainty
  - How probability is estimated depends on what is known about the situation. Estimates can be based on data from similar conditions in the past or on the assumption that all the possibilities are known. (6-8)

Alaska state standards (http://udl.concord.org/share/teacher-guides/TG_Plants-Intermediate-AK-Standards.pdf)

California state standards (http://udl.concord.org/share/teacher-guides/TG_Plants-Intermediate-CA-Standards.pdf)

Materials: Computer with Internet access

Student Activity:

Engage:
Students meet up with Marc and Natasha as they try to apply all that they've learned on their trip inside the leaf with Elvira. Although they are convinced that plants (in particular, sunflowers) need water and sunlight to grow, they wonder what would happen if either of these were taken away.

Explore:
Students analyze data from four ivy plants grown in different conditions. Reading the data presented in the tables, students answer questions.

Explain:
The data represented in the table is then expressed in a smart graph, and students answer questions. Remind students to use all the smart graph tools at their disposal when interpreting the line graph.

Teacher Notes:
This lab itself is very straightforward. Using skills typically learned in a math class, students analyze tables and graphs. The smart graph technology allows the student to predict changes in the graph when adjusting data in the table.

Wrapping Up

Driving Question: What do plants eat?

Time: Ongoing

Materials: computer with Internet access

Having completed the investigations in this unit, students review what they have learned about photosynthesis and respond to the discovery question for each activity with text, drawings, snapshots, or data they have collected. Students can revisit any activity except the pre-test. When students are ready, they need to input a password to unlock the post-test.

The password is: **plants**

Post-test

Time: 20 minutes

Materials: computer with Internet access

In the post-test students have an opportunity to rethink their answers to the same set of questions as the pre-test. Once the post-test has been unlocked, students will not be able to revisit any previous activities.

Note: When the students finish the post-test, a box comes up saying they have finished and should tell the teacher. At that moment, their data is *not yet saved*. They must close the unit for the data to be saved. The student cannot just walk away. Students can close the unit by going to the File menu and selecting Exit or by simply clicking the red circle (upper left).

Additional Resources

Vocabulary

Atom: the smallest bit a piece of matter can be and still retain its properties. Several atoms joined together are called molecules.

Chloroplast: an organelle inside the cell of a green leaf that contains chlorophyll. It is where photosynthesis takes place.

Chlorophyll: the green pigment that is found inside chloroplasts. It is necessary for photosynthesis.

Computer Model: a computer program that attempts to simulate an abstract model of a particular system

(Scientific) Control: allows for the study of one variable at a time in a scientific inquiry. In a controlled experiment, two identical experiments are conducted. In one, the test is applied (the experiment). In the other, the test is not applied (the control).

Energy: the ability or power to work or do things. Energy can come from many sources, including chemical, electrical, mechanical, nuclear, and solar. The total amount of energy in an isolated system doesn't change.

Evidence: what you observe or measure to support an idea. Evidence is often used to make a prediction.

Humidity: the moisture content of the air. Warmer air can hold more water vapor than cooler air. Relative Humidity (RH) is the ratio between how much water vapor is in the air and how much it can hold at that same temperature. RH is expressed as a percentage.

Molecule: a group of atoms that are held together.

Photosynthesis: the process that green plants and certain other organisms use to transform light energy into chemical energy. During photosynthesis, light energy is captured and used to convert water, carbon dioxide, and minerals into oxygen and simple sugars.

Products: what is made or produced during a process or reaction.

Predict: to make a thoughtful guess about what will happen in the future. Predictions are often based on present events, collected evidence, and past experience.

Scientific Model: a detailed picture of an object or process. One purpose of scientific modeling is to observe a complicated process, breaking it down into its principal parts with the hope of seeing details that may have gone previously unnoticed. Scientific models may also be used to predict future events.

Stomata: microscopic pores in the outer layer of leaves and young stems. They permit gas exchange (water, oxygen, and carbon dioxide) between the outside air and the gases found inside the leaf. There are usually more stomata on the underside of leaves.

Sensor: an electronic measuring tool. A sensor is a device that is able to detect or respond to a specific condition such as movement, light, humidity, or heat.

Temperature: the measure of how fast molecules in a material are wiggling or vibrating. This molecular movement is one way to create heat – the faster the vibration, the warmer the object.

Selected Websites

Concept Map: Photosynthesis
http://www.fed.cuhk.edu.hk/~johnson/misconceptions/concept_map/photosynthesis.html