H O P S

Hands On Plant Science

Welcome to HOPS! The following 16 hands-on lessons serve as the curriculum for HOPS (Hands-On Plant Science). For the last decade, this program has immersed urban youth in the natural world. These modules can be taught as individual lessons, grouped by theme (water and the environment, how plants work, nature through art, and plant forensics), or can serve as the curriculum for a multi-day immersive experience. Each lesson builds on the next while the plant forensic case challenges students to demonstrate their understanding of the previous 12 lessons and apply this knowledge to a real-life situation.

This curriculum grew from years of teaching students about plants and the environment, while learning from so many educators in the botanic garden and environmental world along the way– people who share their ideas so passionately, and freely. It is in this same spirit that we share the HOPS program with you. Whether you are at a school, in a backyard, in a park, or at a botanic garden, we invite you to use these lessons to turn your green spaces into living laboratories, and to connect students to the wonders of the natural world.

Vocabulary

OVERVIEW OF HOPS LESSONS

WATER	**Observation and Temperature** *Observe a body of water, test water temperature at different locations* **Big Idea –** Scientists make observations and take measurements to assess the health of an aquatic ecosystem	**Testing for Dissolved Oxygen and pH** *Test a body of water for dissolved oxygen (DO) and pH content* **Big Idea –** Scientists can determine the health of an aquatic habitat by measuring DO and pH	**Under the Microscope** *Observe organisms with a microscope and sketch them* **Big Idea:** Healthy water supports growth and development of all sizes of organisms, including plants, algae, fish, insects, and microscopic bacteria	**Runoff and Watersheds** *Simulate runoff pollution using miniature models of watersheds* **Big Idea:** We all live in a watershed. How we use the land influences the watershed and all living things within it
PHOTOSYNTHESIS	**Viewing Stomata Under the Microscope** *Make hypotheses about air, gas, and leaves. Observe stomata with a microscope* **Big Idea –** Plants exchange water vapor, oxygen, and carbon dioxide in order to undergo photosynthesis and transpiration	**Plants Make their Own Food** *Predict and then test glucose levels in grape juice, tap water, and liquid from the jade plant leaves* **Big Idea –** Most plants photosynthesize in their leaves to make sugar. They can burn this glucose for energy, or store it for later	**Power of the Sun** *See the effect of the sun's energy on solar-powered insects and solar paper* **Big Idea –** Plants make their food through photosynthesis, which would not be possible without the power of the sun	**Seed Balls** *Make seed balls, which can be used to plant flowers and vegetables* **Big Idea –** With a little soil, seeds, water, and sunshine we can all make the earth a little greener
NATURE AS ART	**A Microscopic Look** *Explore and sketch plants seen under the microscope, create botanical buttons or bookmarks* **Big Idea –** Nature is beautiful, especially at a microscopic level	**Plant Morphology** *Dissect a flower and learn about the functions of its parts, model a butterfly proboscis* **Big Idea –** Flowers and their many parts are beautiful, functional, and essential	**Slow Looking & Botanical Illustration** *Paint and draw the micro and macro views of plants* **Big Idea –** When you take the time to really look at a plant and illustrate its parts, you better understand how it works and its beauty	**Sundials** *Create your own sundial and use it to tell the time* **Big Idea –** There is much to learn from nature. Nature is not only beautiful but can be used to tell direction and time
PLANT FORENSICS	**How Seeds Travel** *Observe seeds and figure out how each one travels* **Big Idea –** Plants have many strategies for seed dispersal, and seeds are of many shapes and sizes	**Soil Testing** *Explore compost to see what it is made of* **Big Idea –** Soil is the immediate surface of the earth that serves as a natural medium for the growth of land plants. Soil is alive with plant, animal, and bacterial life	**Pollen Under the Microscope** *View the structures of pollen samples under a microscope* **Big Idea –** In order for plants to reproduce sexually, they must be pollinated. Pollination is the transfer of pollen by pollinators, wind, or other means	**Nectar and Pollinators** *Test the sugar content of nectar samples* **Big Idea –** Pollinators are lured to flowers by a number of things, one being nectar. Different flowers have different nectar types and quantities

Acidic – A solution with a higher concentration of hydrogen ions than water; pH less than 7
Accuracy – How close a measured number is to the true number
Adaptation – A trait that makes an individual better able to survive and reproduce compared to an individual that does not have that trait
Aquatic - Living or growing in water
Basic – Containing very few to no acids; pH greater than 7
Botany – The scientific study of plants
Brix refractometer – A special tool scientists use to measure the sugar content of liquid samples
Canopy – The cover formed by the leafy upper branches of trees
Carbon dioxide – A gas in the atmosphere that plants use in photosynthesis and which we exhale
Cardinal directions – The four compass points; north, south, east, and west
Cellular respiration – The process through which ALL living organisms get their energy by breaking down food
Chlorophyll - Green pigment in plants, photosynthetic
Chloroplast – An organelle within a plant cell that contains chlorophyll and in which photosynthesis takes place
Compass – An instrument used to tell direction, containing a magnetized pointer that shows the direction of magnetic north and the bearings from it
Compound microscope – A microscope that uses two lenses, an optical lens (eyepiece) and an objective lens
Cellular respiration – The process through which nearly all living organisms turn oxygen and sugar into energy; plants use the byproducts of photosynthesis (glucose and oxygen) to fuel cellular respiration
Cross pollination – The pollination of a flower from pollen that comes from the flower of another individual
Dead zones – Areas of water that are so low in oxygen (often the result of nutrient/fertilizer pollution) that animals cannot live there
Decomposer - An organism, especially a soil bacterium, fungus, or invertebrate, which breaks down organic material
Dicots – A shortened name (from dicotyledon) for the artificial assemblage of plants that typically have two seed leaves (cotyledons), flower parts in multiples of four or five, and netveined leaves
Disposable pipette – A tube that is used to transfer liquids from one container to another
Dissolved oxygen (DO) – The amount of oxygen (O_2) gas in water
Ecology – Science that studies the relationship between organisms and their environment
Ectotherm – An organism whose body temperature is dependent on external sources
Embryo – Immature plant in a seed
Endosperm – An embryo's temporary food supply in the seed
Eutrophication – When a body of water becomes overly enriched with nutrients, causing the excessive growth of algae and plants
Fertilization – The uniting of sperm and egg cells to form an embryo
Floret – A small flower
Flowering plant – A plant that produces flowers and fruit
Fossil fuel – A fuel that comes from the remains of ancient plants and animals (e.g., coal, natural gas, oil).
Fructose/glucose/sucrose – Different types of sugars in nectar
Function of a flower – Reproductive organ of seed plants in the angiosperm lineage
Germination – Process by which seeds or spores begin to grow
Glucose – Sugar
Gnomon (said 'no-min) – The central rod of a sundial that casts a shadow
Green algae – Mainly aquatic plants that lack true roots, stems or leaves
Guard cells – Specialized cells surrounding the stomata that control water and gas exchange
Habitat – The place where a plant and/or animal naturally live.

Hypothesis – A proposed explanation of a phenomenon based on limited evidence, which leads to prediction and further study

Impermeable – Does not allow liquids to pass through

Leaf – Primary location of food production (photosynthesis) and transpiration

Local solar time – time determined by the sun, noon is the time at which the sun is highest in the sky; it is local because it depends on longitude, and it differs from standard time that synchronizes time across several longitudes

Macro – large

Magnification – Making an image larger

Micro – small, microscopic

Microorganisms – Organisms living in the soil that you cannot see with the naked eye

Microscope – A piece of special scientific equipment that magnifies objects so we can see what we cannot see with the naked eye

Monocots – A shortened name (from monocotyledon) for the lineage of plants that usually have one seed leaf (cotyledon), flower parts in multiples of threes, and parallel-veined leaves

Morphology –'Morph' means shape or form and *–ology,* means the study of something. The term is used in botany as the study of forms and structures of plants

Mutualism – When two organisms exist together such that their actions or physiology benefit each other

Nectar – Sweet liquid made by flowering plants as a reward for pollinators

Nectaries – Special glands in plants that produce nectar

Non-Flowering Plant – A plant that does not produce flowers and fruit

Observation- An act or instance of noticing

Organic matter – Material in the soil that has come from recently living organisms

Oxygen – Colorless, odorless gas that is essential for plants and animals

Permeable – Allows liquids to pass through pH – A measure of how acidic or basic a substance is on a scale of 0 -14 Photosynthesis – The process plants use to make their own food (glucose)

Pollen – Small, powdery, and generally yellow grains that contain the male gametes that fertilize the eggs in the ovules of flowers

Pollination – Transfer of pollen from male reproductive organs to the stigma of female reproductive organs

Pollinators – Organisms that transfer pollen; e.g., birds, bats, and insects like bees and butterflies

Pollutants – Harmful substances to the environment

Pollution – Substances or materials that are harmful to the environment

Prediction – A stated idea of what will happen based on observation; different from hypothesis

Proboscis- A long, thin tube that forms part of the mouth of some insects (such as a butterfly)

Refractometer – A device used to measure the amount of sugar in a liquid Sample – A small portion of something.

Seed – The sexual reproductive structure in which the embryo is housed

Seed coat – Layer of thin tissue covering a seed

Self-pollination – The pollination of a flower from pollen that originates from that same plant. If a plant can self-pollinate, it is self-compatible

Soil erosion – The loss or removal of topsoil

Soil texture – The relative amounts of sand, silt, and/or clay in a soil

Solar energy – Heat and light energy derived from the sun

Stamen – The male part of the flower that produces the pollen

Standard time - the synchronization of time within a geographic area, as established by government laws or customs

Stigma – A female part of the flower – the uppermost part of the pistil, which receives the pollen

Stomata – Openings in plants (primarily in leaves) that allow for gas exchange – carbon dioxide gas in and oxygen gas out

Sundial – A device that shows the time of day by the movement of shadows from the sun

Temperature – A measure of warmth or coldness of an object or substance
Texture –The physical characteristics of a surface
Timepiece – Any instrument used to measure time
Transpiration – The evaporation of water from leaves and stems Qualitative data
– Information that has no numbers, e.g., color, texture, etc.
Quantitative data – Information that is numerical, like temperature, distance, etc.
Understory – The shrubs and plants growing beneath the canopy
Watershed – The area of land that drains into a main body of water, such as a river, lake, bay, or ocean

Observation and Temperature

Big Idea: Scientists rely on observation to ask questions about the natural world. Observations can be made using our senses and scientific equipment. In this lesson, water health is observed and assessed by taking temperature measurements.

Water: Observation and Temperature

Objectives:

After participating in this lesson, students will better understand the following:

- Scientists test water for many reasons.
- The temperature of water can affect the survival of many aquatic organisms.
- Temperature can influence the ability of water to hold oxygen. Healthy water usually has high levels of dissolved oxygen. If the temperature in a body of water gets too hot or too cold, some organisms will die.
- Plants cannot live without water.

Background:

Scientific Observation

The lessons in the Water module focus on the first step of the scientific method: observation. Observation is the use of senses or scientific instruments to collect information; these various forms of collected information serve as a basis for asking questions and developing hypotheses. Ultimately, observation is the first step in scientific discovery. In this lesson, students will observe and collect qualitative data to describe color, shape, and texture. Students are encouraged to sketch and take notes detailing their qualitative observations. Students will also collect quantitative data like temperature and distance. Throughout these units, be aware that observations are not always explicitly right or wrong but can have more than one interpretation. It is important that students develop the skills to defend a hypothesis. [1] [2] Students will conduct this lesson at a local body of water. Encourage students to use all of their senses while observing the body of water but note that sometimes our senses are not always accurate. Help students understand that the introduction of scientific equipment, in this case a thermometer, allows us to make more accurate observations by taking numerical measurements.

Water Temperature

Temperature is one of many indicators of water health. It is directly linked to the amount of dissolved **oxygen** (DO) in the water. [3] **Aquatic** organisms, including fish, rely on this oxygen to breathe and undergo **cellular respiration** (where nutrients are broken down into usable energy). Cellular respiration itself is controlled by temperature for fish, whose body temperature is determined by the temperature of their surroundings (ectothermic). Warmer temperatures cause cellular respiration to speed up, meaning that fish need more oxygen and more food to

[1] Martin, M. (1985). *Concepts of science education: A philosophical analysis*. University Press of America.

[2] Smith, B. K., & Reiser, B. J. (2005). Explaining behavior through observational investigation and theory articulation. *The Journal of the Learning Sciences*, *14*(3), 315-360. https://doi.org/10.1207/s15327809jls1403_1

survive[3] [4]. Temperature also influences photosynthesis, the process by which plants make their own food. Warmer temperatures increase the rate of photosynthesis, meaning plants need more resources. Temperatures that are too hot are not conducive to either cellular respiration or photosynthesis. There is a temperature range in which each organism best survives. If ambient temperatures increase beyond that range, the enzymes involved in metabolism denature and the organism will perish.[5] [6] Ultimately, temperature influences the life of every living organism, including aquatic plants, animals, and even bacteria. The interconnectedness between the physical and natural world is the focus of the field of **ecology**.

When water temperature is quickly changed by humans to be hotter or cooler, the water is said to be thermally polluted. The removal of trees over bodies of water, which provide shade and thus cooler water temperatures, is one contributor to thermal pollution[7]. Think of other ways humans affect water temperature. What are the effects of these changes on aquatic life? Based on our knowledge and observations, how can we make our bodies of water healthier?

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[3] Rounds, S.A., Wilde, F.D., and Ritz, G.F., 2013, Dissolved oxygen (ver. 3.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6.2, https://doi.org/10.3133/twri09A6.2

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[3] Clarke, A., & Johnston, N. M. (1999). Scaling of metabolic rate with body mass and temperature in teleost fish. *Journal of Animal Ecology*, 68(5), 893–905. doi: 10.1046/j.1365-2656.1999.00337.x

[4] Schulte, P. M. (2015). The effects of temperature on aerobic metabolism: towards a mechanistic understanding of the responses of ectotherms to a changing environment. *Journal of Experimental Biology*, *218*(12), 1856–1866. http://doi.org/10.1242/jeb.118851

[5] Factors affecting photosynthesis. (2020). BBC. https://www.bbc.co.uk/bitesize/guides/zx8vw6f/revision/2

[6] Berry, J., & Bjorkman, O. (1980). Photosynthetic Response and Adaptation to Temperature in Higher Plants. *Annual Review of Plant Physiology*, 31(1), 491–543. doi: 10.1146/annurev.pp.31.060180.002423

[7] Dodds, W. K., & Whiles, M. R. (2010). Freshwater ecology: concepts and environmental applications of limnology (2nd ed.). pp 399-436. Amsterdam: Academic Press. doi: https://doi.org/10.1016/B978-0-12-374724-2.00016-7

Vocabulary:

Supplies:

Small buckets on strings

Thermometers on strings

Pencils

Temperature data sheets

Poster-size Fahrenheit/Celsius chart

Access to body of water

Talking Points:

- There are many ways scientists can measure the health of water. Measuring dissolved oxygen levels and water temperature are two of those ways. Many conditions can affect water temperature such as the water's depth and speed, weather, etc. As students observe, ask them to thin k about the things that could affect water temperature and discuss.
- Dissolved oxygen (DO) is something we can't see but is essential to aquatic life. Aquatic animals need the oxygen dissolved in water (e.g., fish, aquatic insects, aquatic spiders, tadpoles, mollusks, etc.). Note that too little dissolved oxygen will not support life, and too much can be toxic!
- Water temperature affects the level of dissolved oxygen which in turn affects the health of the water. Warmer water has *less* DO while cold water has *more.*
- Many characteristics of aquatic systems are linked. If the water is fast moving this can increase the DO but can also increase the water's cloudiness or *turbidity*. This cloudiness increases the amount of heat absorbed in the water, increasing the temperature.

Accuracy – How close a measured number is to the true number

Aquatic- Living or growing in water

Cellular Respiration – The process through which ALL living organisms get their energy by breaking down food

Ecology – Science that studies the relationship between organisms and their environment

Ectotherm – An organism whose body temperature is dependent on external sources

Observation- An act or instance of noticing

Oxygen – Colorless, odorless gas that is essential for plants and animals

Photosynthesis – The process plants use to make their own food (glucose)

Qualitative data – Information that has no numbers, e.g., color, texture, etc.

Quantitative data – Information that is numerical, like temperature, distance, etc.

Temperature – A measure of warmth or coldness of an object or substance

Activities:

1. Introduce this lesson by relating it to something your students already know. Ask your students what happens to their bodies when they do not feel well. Inquire if anyone has used a thermometer and for what a thermometer tests. Explain that like our bodies, aquatic ecosystems have a healthy temperature range. Prior to sending students out to take temperature readings, review how to use and read a thermometer.

2. Have your students conduct water observations. What do they see? What do they see that might affect the water temperature? How deep is the water? Is it moving or still? Shaded or in full sun? Why would these things matter to the temperature of the water? What can they predict the temperature of the water?

3. After students have made observations, provide each student with a bucket, thermometer, and temperature chart. Have them take turns getting water in their buckets. Have them take two temperature readings. Have them record their temperature readings on their temperature chart. Ask students whether they might get different temperature readings by placing the thermometer directly in the body of water. What might be the cause of the different temperature readings?

4. Have your students note the weather conditions at the time they took their readings. Why does this matter? What other things might be affecting their temperature readings?

5. Proceed to a second location on the body of water and have your students take two additional readings. Discuss with your students why you are asking them to take two readings at two different locations.

6. As you return to your station, have your students record their temperatures on the enlarged thermometer chart. Engage students in a discussion about their findings. Based on the qualitative and quantitative data they have collected, what can they say about the health of the body of water?

Temperature Chart:

Name of Tester	Location Sampled	Water Temperature	Weather Conditions at Time of Testing

Objectives:

Testing for Dissolved Oxygen (DO) and pH

Big Idea: Scientists are constantly testing aquatic ecosystems to determine their health. Dissolved oxygen (DO) and pH are two things scientists measure to determine the health of water -based habitats such as lakes, streams, and bogs.

After participating in this lesson, students will:

- that too much DO is not healthy).
- Understand that pH (potential for hydrogen) has a range from 0-14 and a healthy body of water has a pH between 6.5 and 8.5.
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Background:

Water: Testing for Dissolved Oxygen (DO) and pH

Understand that a healthy body of water has high levels of dissolved oxygen (but note

Learn that pollution can change both the pH and the amount of dissolved oxygen in water and therefore, the health of our aquatic ecosystems.

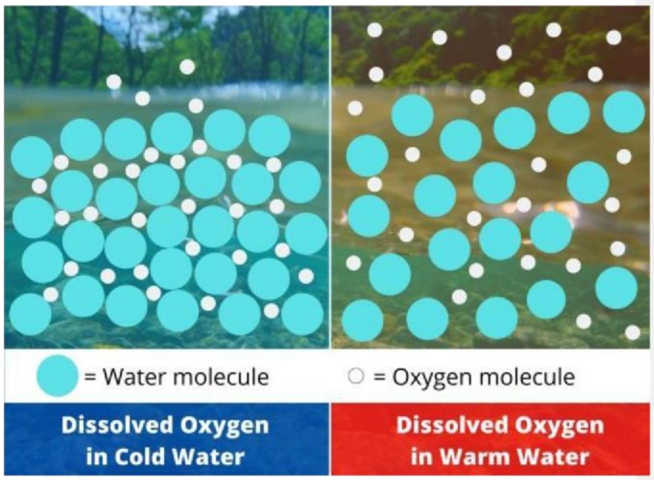

Figure 1. *In warmer water, molecules spread out, allowing oxygen gas to esc ape. In cold water, H_2O molecules are held more tightly together and there are fe wer open spaces for the oxygen gas to escape*

Dissolved oxygen is the amount of oxygen present in water and is measured as milligrams of oxygen per lit er of water (mg/L – also called parts per million or ppm). Some students will understand that oxygen exists as a chemical component of water (the O in H_2O). Dissolved

At this station, students have

the chance to further hone observational abilities and learn how to take direct measurements from the environment through a descriptive field investigation. It is through measurement and investigation that scientists learn about and describe nature. Here, students should discover how to test two factors linked with water quality: **dissolved oxygen (DO)** and **pH**, and they should be able to explain how these two qualities influence the wellbeing of aquatic organisms and the environment.

Dissolved Oxygen (DO):

oxygen does not refer to the oxygen atoms bound into water molecules. Rather, dissolved oxygen is oxygen gas, or O_2, that occurs throughout the water intermixed with water molecules. This gaseous oxygen may enter the water through the atmosphere, especially as water passes over rocks and pebbles or as wind creates waves. During the daytime, oxygen also enters water from plants and algae, which produce oxygen gas as a product of photosynthesis. Aquatic vertebrates like fish, invertebrates like insects, and bacteria all use this dissolved oxygen to live and develop.

In cold water, H_2O molecules are held more tightly together and there are fewer open spaces for the oxygen gas to escape (see Fig. 1). If students have completed the Water: Observation and Temperature lesson, they might recall the association between dissolved oxygen and water temperature. Based on their earlier temperature readings and on the current season of the year, do they anticipate dissolved oxygen levels to be high or low? How might DO levels be different at the top vs. the bottom of the body of water (again, think about which parts are warmer/cooler)?

DO and Pollution

When a body of water receives an excessive amount of nutrients, often due to runoff from the land, the aquatic plant and algal life within the water can increase rapidly. This is called eutrophication. Plants and algae may create a thick layer at the top of the water, preventing light from allowing photosynthesis at lower depths, lowering oxygen production. This lack of oxygen can have negative impacts on the fish and other animal life and create dead zones where few to no animals can live. [8] [9] *pH*

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[8] Dissolved Oxygen and Water. (n.d.). United States Geological Survey. https://www.usgs.gov/specialtopic/waterscience-school/science/dissolved-oxygen-and-water?qt-science_center_objects=0#qtscience_center_objects

[9] Conley, D. J., Paerl, H. W., Howarth, R. W., Boesch, D. F., Seitzinger, S. P., Havens, K. E., et al. (2009). Controlling Eutrophication: Nitrogen and Phosphorus. *Science*, *323*(5917), 1014.

pH is the measure of how **acidic** or **basic** (also called alkaline) a substance is. This relates to the amount of hydrogen ions (H+) in the solution and is measured on a scale of 0 to 14. A substance with a high pH (greater than 7) is said to be basic and has fewer hydrogen ions. A substance with low pH (less than 7) is acidic and has more hydrogen ions. Within the scale, each one number change represents a ten-fold change in acidity. In other words, a pH of 0 is ten times more acidic than a pH of 1. Pure water has a pH of 7.0 and is said to be neutral. It is around this value that most aquatic organisms thrive. Highly acidic and highly basic water is inhospitable for most aquatic life, though some organisms do well in those ranges. These organisms are often called "extremophiles".

A variety of factors can influence the pH of a body of water. One of these is the amount of calcium carbonate (e.g., limestone) in the water, a substance which easily binds to acidifying hydrogen ions (H+) and alkalizing hydroxide (OH-) and prevents changes in pH caused by these ions. Any solution that prevents changes in pH is called a buffer. The amount of photosynthesis occurring in the water by plants and algae also affects pH. Carbon dioxide (CO_2) is acidic and is used in photosynthesis. Thus, as photosynthesis occurs, CO_2 is removed from the water and pH increases. Knowing this, during which time of the day do you expect pH to be highest (when are aquatic plants photosynthesizing most)?

Humans can also modify the pH of Earth's waters. Acid rain from polluted air as well as agricultural runoff can easily influence pH, and are only two examples of the many ways we modify aquatic ecosystems.[10] The ways by which pollutants enter streams, rivers, and the ocean is explored in the Water Runoff and our Watershed lesson.

Supplies:

- 1ml disposable pipettes
- Container of tap water
- Container of water from a natural or humanmade body of water
- Small vials with tops for DO testing * Larger glass vials with lids for pH testing pH Strips pH chart (enlarged and laminated)
- DO tablets
- DO chart (enlarged and laminated)
- Buckets for dumping and rinsing
- DO & pH data collection sheets
- Poster board with pH scale
- Glue dots
- Orange juice
- Milk of magnesia

*It is useful to order a kit to ensure the correct amount of DO tablets per container. Thereafter you simply can order replacement DO tablets.

[10] Water Quality. (n.d.). Utah State University Extension. Retrieved from https://extension.usu.edu/waterquality/learnaboutsurfacewater/propertiesofwater/pH

Dissolved Oxygen (DO) – The amount of oxygen (O_2) gas in water

Talking Points:

- Measuring dissolved oxygen (DO) can tell us how much oxygen gas is available in the water for aquatic animals like fish and insects to breathe.
- Typically, healthy waters have higher levels of DO than unhealthy waters.
- Temperature, speed of running water, and plant/algal life all affect how much oxygen is in the water.
- pH ranges from 0 – 14. Zero is very acidic and 14, very basic. Seven is neutral. Healthy waters range between 6.5 and 8.5.
- The pH of water can be altered by pollution, which might be detrimental to the plants and animals in the water.

Vocabulary:

Acidic **–** A solution with a higher concentration of hydrogen ions than water ; pH less than 7

Alkaline/Basic – Containing very few to no acids; pH greater than 7

Dead zones – Areas of water that are so low in oxygen (often the result of nutrient/fertilizer pollution) that animals cannot live there

Eutrophication – When a body of water becomes overly enriched with nutrients, causing the excessive growth of algae and plants pH – A measure of how acidic or basic a substance is on a scale of 0 -14

Pollution – Substances or materials that are harmful to the environment **Activities:**

1. Explain to your students that they will be testing for both dissolved oxygen and pH in order to test the health of the water in the aquatic system. Explain that there are many ways scientists measure the health of aquatic ecosystems. DO and pH are two of those ways. Both tests have a scale and healthy water is somewhere on those scales. For pH, healthy water should be in the middle of the 0–14 range (6.5–8.5). With DO, the darker coloring of the water test indicates there is more oxygen in the water. Water with less than 5 parts per million (ppm) of DO will support only a small amount of life. More than 5 ppm will support a greater abundance of life. If water becomes too saturated with DO and other dissolved gases (>110% total saturation), the gases can be harmful to aquatic organisms.

2. Show your students how to use a disposable pipette and then let them practice.

3. Using the disposable pipettes, have each student take the already collected water from the body of water and fill one small vial. The vials should be filled so that no air is in the vial. The water should form a little dome at the top. Ask your students why they think the vial needs to be this full of water. How would the results be different if the container was only filled partially with water? Have your students place in the vial the number of DO tablets indicated on the test kit package and close the top of the vial. Have them place the vial on the table and let it sit while you turn your attention to the pH testing. Explain to your students that it takes five minutes to get a DO reading.

4. Instruct your students on how to use a pH strip and have them test orange juice and Milk of Magnesia. Have each student use glue dots to place their pH strips on the pH scale poster board in the location corresponding to their strips' colors so they can see where the two tests fall in the range. Discuss acidic and basic by explaining how they are two ends of the scale.

5. Using pH strips, have your students test tap water and then aquatic system water. Again, have them place these strips on the corresponding colors on the pH scale poster board. Discuss how the pH of water is different from the pH of orange juice or milk of magnesia. Are there conclusions they can make about the aquatic system water?

6. Have your students turn their attention back to the vials testing for DO. Have them compare the color of the water in their vial with the DO chart and record their levels. Ask them what their DO levels might tell them about the health of the aquatic system.

Testing for pH

Substance	**pH level**

Tap Water	
Milk of Magnesia	
Orange Juice	
Aquatic System Water	

DO Collection Sheet

Name of Tester	**DO Level of Water**

Water: Under the Microscope

Big Idea: Healthy water supports the growth and development of aquatic organisms, including vascular plants, algae, fish, invertebrates like insects, and microscopic bacteria.

Water: Under the Microscope

Objectives:

After participating in this lesson, students will:

- Know how to use a microscope
- Understand that all plants evolved from a common ancestor shared with green algae
- Learn that the diversity of life in an aquatic system can be an indicator of its health

Background:

A healthy and productive aquatic environment is teeming with life. This life ranges from macroscopic vertebrates and invertebrates to the microscopic life that we must use tools to observe. Can your students name some of these “macro” life forms that we can see with our naked eye? What about “micro” organisms we cannot see with our naked eye? The health of an aquatic system can be assessed not only chemically, as in other lessons, but also by examining the number of species found in a **sample** from that aquatic system. *Using the microscope*

Microscopes are used to **magnify** images, and the word itself means “small view.” At this station, students utilize **compound microscopes** to view aquatic organisms. It is called a *compound* microscope because it has two lenses: the ocular lens is the removable lens closest to the eye, and the objective lens is closest to the specimen, on the revolving nosepiece. The ocular lens has a 10X magnification. The objective lenses have magnifications of 4X, 10X, and 40X. Some compound microscopes also have 100X lenses. To calculate the total magnification, multiply the ocular lens magnification by whichever objective lens magnification you are using. The lowest magnification on these microscopes is 40X (10X ocular multiplied by 4X objective).[11]

When first viewing a specimen, ensure the light source is on and that your slide is properly fitted and positioned on the stage. *Always* start at the lowest

[11] The Compound Microscope. (n.d.). Miami University. Retrieved from http://www.cas.miamioh.edu/mbiws/microscopes/compoundscope.html

objective lens magnification (4X). Use the coarse adjustment knob to bring the specimens into rough focus. Then, use the fine adjustment knob to make minor focal changes. Sometimes aquatic life can move quickly across the slide and out of view. In this case, you may use a viscous quieting solution to slow the movement of organisms on your slide. *Species Richness as an Indicator of*

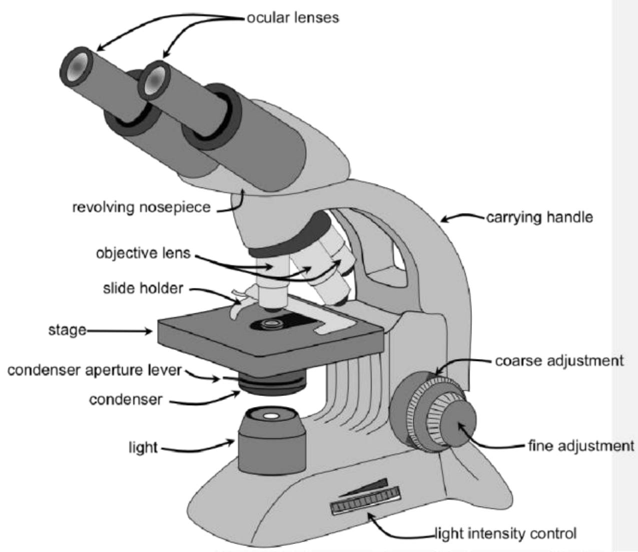

Figure 3 Diagram of a standard compound micr oscope

If students have completed other water lessons, they should recognize that many species require specific environmental conditions to survive. For example, the temperature should be suitable, there should be dissolved oxygen (DO), and the water shouldn't be too acidic or basic. In the body of water sam ple, if there is a high abundance of organisms that tolerate low DO (like nematodes and maggots), the water may be polluted. Likewise, large numbers of bacteria and parasites might also be an indication of poor aquatic system health. On the other hand, a large number of aquatic organisms, especially ones that *cannot* tolerate pollution (e.g. dobsonfly and mayfly larvae), is suggestive of a healthy system. The more biological diversity, the better![13] [14] Simply keep in mind that the type and number of organism s found in an aquatic system may speak to how polluted it may be and to its overall health.
This station is also a great opportunity to introduce students to using identification keys to identify organisms. A simple search of "aquatic invertebrate key" reveals thousands of keys that may be of use.

Nicholson, M., Rosenberg, L., & Shaffer, T. (n.d.). Lesson 2 - Aquatic Indicator Organisms. Muhlenberg College. https://www.muhle nberg.edu/media/contentassets/pdf/about/graver/outreach/aquatic_ecology_lesson2_indica t

13 [ors.pdf](ors.pdf)

14 Aquatic Insects. (2019). National Park Service. Retrieved from https://www.nps.gov/sitk/learn/nature/streamecology-the-aquatic-insects.htm *Algae*

The water that you observe might have one or more species of algae growing in it. If so, there are probably aquatic invertebrates, including snails, feasting on those algae. Perhaps there are also toads who might eat the snails! The myriad of all life, including that which lives in this aquatic system, is connected by numerous food chains. Green algae and other photosynthetic plants are the primary producers at the base of almost all food chains!

In addition to any aquatic algae, you may find in your exploration, included in this station are prepared slides of two types of algae: *Spirogyra* (or water silk) and *Volvox* (globe algae). *Spirogyra* is a genus of **green algae** in the plant kingdom. Their cells are long, filamentous, and cylindrical. *Spirogyra* easily floats, as the oxygen gas produced by this alga during photosynthesis acts as a natural buoy. Inside the cell, chloroplasts are arranged in a striking helical arrangement. Chloroplasts are the parts of the plant that use sunlight and water to power the fixation of carbon dioxide into sugars.[12]

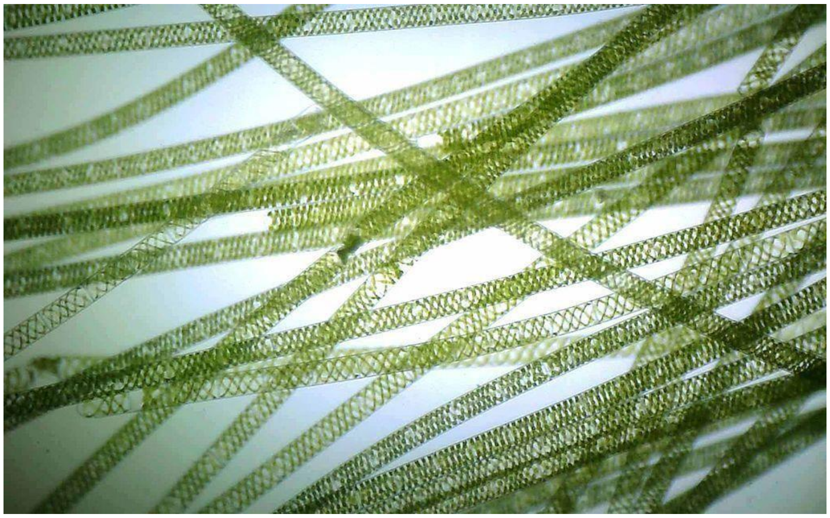

Figure 4. Micrograph of *Spirogyra*, showing long cells with chloroplasts inside. 1024 px. *Image by Bob Blaylock*

Volvox forms giant spheres of individual cells, called colonies, and there may be as many as 50,000 cells in one colony! Each individual cell has a pair of flagella, whip-like structures that help propel the colony through water. Each cell also has an eyespot used for light detection.

[12] Kelly, C. D., Fellers, T. J., & Davidson, M. W. (2015). Filamentous Algae (Spirogyra). Florida State University. Retrieved from https://micro.magnet.fsu.edu/optics/olympusmicd/galleries/brightfield/spirogyr

Using their eyespots to find light and their flagella to move, *Volvox* can position themselves

where there is the best light for photosynthesis. *Volvox* is yet another group of organisms that can be used as a measure of aquatic system health.[13]

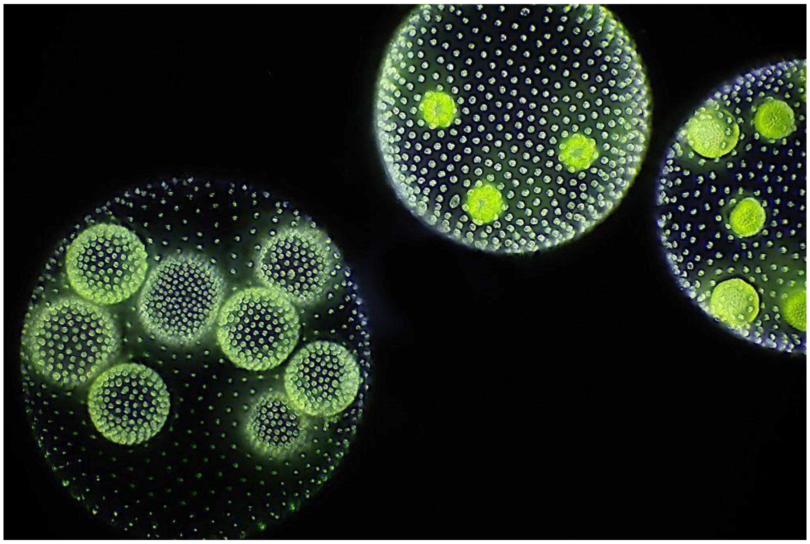

Figure 5. *Volvox* colonies, each consisting of thousands of cells *Evolution of plants*

The diversity of all plant life did not exist in its current state through all time, rather life is under the continuous process of evolution. In fact, 500 million years ago the earth had no land plants at all.[14] [15] Rather, all photosynthesizing life was in the ocean or in freshwater systems. Over time, freshwater green algae slowly evolved to colonize land. Land, of course, is much dryer than water, so the first land plants were small and stout and had several other features that reduced water loss. Eventually, plants evolved longer roots as well as a vascular system (xylem and phloem) that, like the system of veins and arteries in a human, enabled plants to transport that much-needed water, as well as nutrients and sugars, throughout the plant. All living things, including plant species, change over time – this is the process of evolution.
Evolution is possible because in all species there exists variation. Some individuals are better at

Figure 6. Tree depicting the evolution of plant life. From ancestral green algae sprang the diversity of all plant species, alive and extinct.

[13] Kelly, C. D., Fellers, T. J., & Davidson, M. W. (2015). Volvox (Protists). Florida State University. Retrieved from https://micro.magnet.fsu.edu/optics/olympusmicd/galleries/moviegallery/pondscum/protists/volvox/

[14] Morris, J. L., Puttick, M. N., Clark, J. W., Edwards, D., Kenrick, P., Pressel, S., et al. (2018). The timescale of early land plant evolution. *Proc Natl Acad Sci USA*, *115*(10), E2274.

[15] Pennisi, E. (2018). Land plants arose earlier than thought-and may have had a bigger impact on the evolution of animals. Science. https://www.sciencemag.org/news/2018/02/land-plants-arose-earlier-thought-and-may-havehadbigger-impact-evolution-animals

Vocabulary:

Compound microscope – A microscope that uses two lenses, an ocular lens (eyepiece) and an objective lens
Disposable pipette – A tube that is used to transfer liquids from one container to another
Green algae – Mainly aquatic plants that lack true roots, stems or leaves
Magnification – Making an image larger
Microscope – A piece of special scientific equipment that magnifies objects so we can see what we cannot see with the naked eye

surviving and reproducing in their environment than others . These individuals tend to have more offspring who themselves survive and have more offspring. The traits that positive ly influence survival and reproduction are generally selected for, while traits that cause a negative effect are generally elected against. Random change through genetic mutation may also result in a more or less fit individual or population. In this way, new species arise, and even more go extinct! Indeed, over 99% of all species that ever existed on Earth are now extinct!

Commented [CL1]: Figure 6:Insert attached PDF here

Phylogeny - The evolution of a related group of organism

Sample – A small portion of something **Supplies:**

Variety of microscopes

Laminated, diagram of microscope parts

Depression slides

Disposable pipettes

Sterile water

Plant phylogenetic tree

Viscous quieting solution

Buckets

Aquatic life information cards

Water from a natural or human-made source

Volvox and spirogyra slides

Talking Points:

- Using a microscope to look at the natural world is exciting. A whole new world exists that is not visible to the naked eye.
- A healthy aquatic ecosystem is filled with life.
- Green algae and other photosynthetic plants are the primary producers at the base of almost all food chains.
- All living things, including plant species, change over time. This is part of the evolutionary process.

Activities:

1. Provide students with a brief overview of how a microscope works. Ask who has used one and what they saw. There is no need to provide too much detail. The big idea is that they are special pieces of scientific equipment and have to be used with care. Assist with the change of magnification.

2. Show students how to use a disposable **pipette**. Have them take some water from the tap water container and place it on a slide. Prior to having the students look at the water microscopically, ask them what they think they will find in the water they drink. What do they see?

3. Next, using their disposable pipettes, have them take water from the buckets that contain already collected water. Is this water alive? What do they see? Using the aquatic information cards, see if students can identify the life on their slides. Now let them look at both *Volvox* and *Spirogyra* slides.

4. Have your students draw a picture of what they see. Note: Use the viscous quieting solution on slides if organisms are moving too quickly to see.
5. Allow students to try both kinds of microscopes.

6. Together, look at the plant phylogenetic tree and have students find green algae and explain the evolution of plant life.

Runoff and Our Watershed

Big Idea: We all live in a watershed. How we use the land influences our watersheds and all the living things within it.

Water: Runoff and Our Watersheds

Objectives:

After participating in this lesson, students will:

- Know that they live in a watershed and what a watershed is
- Understand that the treatment of the land we live on affects our rivers and larger bodies of water
- Learn that each of us can make a difference
- Understand that even through filtration, some pollutants such as fertilizers and antibiotics cannot be removed

Background:

A **watershed** is any area of land that drains, down-slope, into rivers, lakes, and/or the ocean. All precipitation that falls on this area of land will eventually drain out to these lower points due to gravity. All humans, since we are land-dwelling organisms, live in a watershed! For example, one major watershed in Washington, D.C. is the Anacostia River watershed, which drains into the much larger Potomac River watershed. Much of this water will make it to the Chesapeake Bay. Regardless of which watershed we live in, its care is of utmost importance. This is because not only do we rely on this water for drinking, bathing, and recreation, but we share it with wild animals and plants. Thus, the decisions we make with our water and land can affect the wellbeing of all organisms around us.

The health of a watershed depends on the **habitat** quality (for example, how much vegetation there is, how stable the soil is, etc.), water quality, and biodiversity. If students have completed Water: Observation and Temperature, Water: Testing for Dissolved Oxygen and pH, or Water: Under the Microscope, they should have some knowledge of how water health can be assessed. The majority of **pollutants** that affect these metrics begin on land – in the watershed! These pollutants include nitrogen-based fertilizers (run-off from cropland), industrial waste, pet waste, automotive leaks, and trash. Antibiotics and hormones that we use on ourselves as well as our livestock can also enter water. Human activity has negatively affected many watersheds in the U.S.

Gardens and other green spaces play an important role in the conservation and protection of water resources. In cities, impervious surfaces like roofs, streets, and sidewalks prevent rainwater from soaking into the ground. Greenspaces absorb water and specially engineered rain gardens even more efficiently capture water allowing it to soak into the ground even during large rain storms. [16]

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[16] Healthy Watersheds Protection. (2020). United States Environmental Protection Agency. Retrieved from https://www.epa.gov/hwp

Watershed models

Miniature houses, animals, people and cars

Spray bottles with water

Bags of litter

Tubes of powdered gelatin (antibiotics)

Chocolate sprinkles (dog poop)

Cocoa powder (to be used as soil) or soil

Large plastic soda bottles – cut in two

Leaves and straw mix

Sand and pebbles

Enlarged and laminated

Have your students brainstorm ways people alter the watersheds in which they live. How are watersheds changing as the world becomes more populated? What are some ways we can reduce our impact and keep the watershed we live in healthy?

You can find your watershed here: https://cfpub.epa.gov/surf/locate/index.cfm **Supplies:**

map of your watershed

Talking Points:

- A watershed is an area of land that drains into a main body of water, such as a river, lake, bay, or ocean.
- Watersheds come in many shapes and sizes
- Human activities such as construction, agriculture, and pollution can affect watersheds.
- Pollution affecting our watersheds begins in our own backyards, our streets and parking lots.

When land is more than 10% paved, the water in nearby rivers is affected.[17][18] The Anacostia watershed is one of the most urbanized in the U.S. Over centuries, it has lost over 70% of forestland and 6,500 acres of wetlands. Impervious surfaces now cover 25% of this watershed.[18]

- Due to soil erosion, the average depth of many streams is shallower than it used to be. This shallow water means less oxygen and this results in less healthy water. Lack of oxygen, increased algae, and pollutants in the water have negative impacts on fish, including causing death and, in some cases, cancerous tumors.[19]

Vocabulary

Habitat – The place a plant and/or animal naturally live
Impermeable – Does not allow liquids to pass through
Permeable – Allows liquids to pass through
Pollutants – Harmful substances to the environment
Watershed – The area of land that drains into a main body of water, such as a river, lake, bay, or ocean

Activities:

1. Lay out the enlarged maps of your watershed. Have students find where they live on the map or where they attend school. Identify the boundary of your watershed, showing them that we all live in a watershed.

2. Show them the sample watershed. Using the miniatures, have students place trees in their landscape and, using cocoa powder, add the soil. Then let them place people, cars, and buildings in their model. Next, using powdered gelatin for antibiotics and fertilizers, chocolate sprinkles for dog poop, and candy wrappers for litter, let them pollute their watershed.

3. Next, have your students spray water as if it was raining and have them watch where the water goes – from the land to the streams, to the rivers and eventually to a larger body of water.

4. Collect this water and pollution into a beaker and have the students look at the water.

[17] Protecting Water Quality From Urban Runoff. [PDF] (2003). United States Environmental Protection Agency. Retrieved from: https://www3.epa.gov/npdes/pubs/nps_urban-facts_final.pdf

[18] Urban Waters and the Anacostia Watershed (Washington, DC/Maryland). (2019). United States Environmental Protection Agency. Retrieved from https://www.epa.gov/urbanwaterspartners/urban-waters-andanacostiawatershed-washington-dcmaryland

[19] Brown, E. R., Hazdra, J. J., Keith, L., Greenspan, I., Kwapinski, J. B. G., & Beamer, P. (1973). Frequency of fish tumors found in a polluted watershed as compared to nonpolluted Canadian waters. *Cancer Research*, *33*(2), 189- 198.

5. Explain that when water runs off buildings and parking lots, most of this water and pollution ends up in the rivers. Discuss the difference between **permeable** and **impermeable**. Ask them to predict what would happen if the watershed was mostly gardens and other green spaces.

6. Have your students work in teams and build a filter using the soda bottle. Have them place the top upside down on the bottom half. Let students layer inverted top half of the bottle with a cosmetic cotton pad, sand, gravel, leaves, grass, and moss.

7. Have students pour the water that has come through the watershed into the beaker to filter it. Have them describe what happened. Did all the water run off? What color is the water that ran off? What did the filter catch?

8. We often think of pollutants as what we can see, but things that we can't see (like medications and some other chemicals like fertilizers and gas residue) cannot be filtered out and may be even more harmful. Ask your students: what are some ways we can ensure that we all live in a cleaner, healthier watershed?

9. Have your students reflect on what they learned.

Viewing Stomata under the Microscope

Big Idea: Plants exchange gases through pores in their leaves called stomata. This exchange is mostly of water vapor, oxygen, and carbon dioxide and is important for the processes of photosynthesis and transpiration.

PHOTOSYNTHESIS: Viewing Stomata under the Microscope

Objectives:

After participating in this lesson, students will:

- Understand that plants make their own food through a process called photosynthesis;
- Learn that plants have openings called stomata that let out oxygen and take in carbon dioxide and that many plants have more stomata on the underside of leaves than on the top;
- Learn that plants have unique adaptations that allow them to survive;
- And be able to make hypotheses and predictions.

Background Information:

Biology of Stomata

Stomata (singular, stoma) are small pores in the surface tissue (called epidermis) of leaves, roots, and stems that allow for the movement of gases (mostly oxygen, carbon dioxide, and water vapor). They are connections between the inside of the plant and the outside environment. These stomata include two **guard cells** that function as gatekeepers of the pore. Guard cells may swell up and block air/water flow, or they may contract and open the stomata. The activity of guard cells is controlled by light, water availability, and how much carbon dioxide (CO_2) is in the epidermis. Generally, daylight, ample water, and low CO_2 all induce opening. On most plants, stomata are concentrated on the leaves and occur on both surfaces, but there are generally more on the bottom surface, where it is cooler and more shaded. This is so that the plant loses less water from its leaves. More stomata on the top surface of leaves would cause water vapor, heated by the sun, to more easily escape (evaporate) from the interior of the leaf. While some of this evaporation is useful to the plant, as it helps to pull water and nutrients from roots to leaves, too much water loss is detrimental. As species evolve, some traits allow organisms to be better suited to their environment. The abundance of stomata on the underside of leaves is one example of such a trait, and is called an **adaptation**. Note that some plants, like floating aquatic plants, have more stomata on the top surface of their leaves, the only side exposed to air! Whether on land or in water, plants have adapted to their environments.

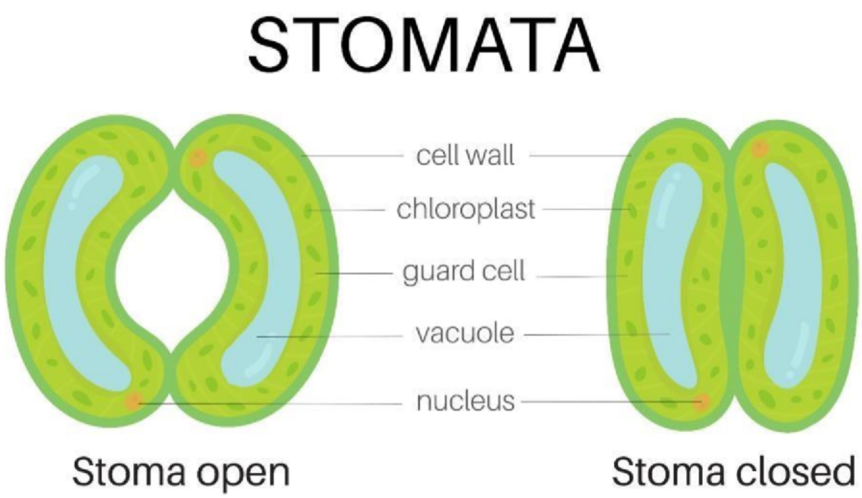

Figure 7. The pore is the stoma, and it is surrounded by two guard cells which open or close depending on environmental conditions.

Why are Stomata Needed?

When plants evolved to survive on land (see Water: Under the Microscope), they developed thick waxy cuticles around their leaves to keep the leaves from drying out. While this solved the problem of water loss, it hindered movement of one important gas that all plants need: **carbon dioxide**. For most plants, stomata remain open to allow carbon dioxide to enter leaves during the day, and then close at night. Carbon dioxide is most -needed during the day when plants are photosynthesizing. **Photosynthesis** is the process through which plants use **carbon dioxide** and water, with the help of sunlight, to produce sugars and oxygen. While some oxygen is needed by plants to burn those sugars in **cellular respiration** (just like in animals), plants generally produce more oxygen than they need during photosynthesis; this oxygen is waste and is released through the stomata. [23]

There are exceptions to the apparent rule of stomata being open during the day and closed at night. Consider plants adapted to extreme dryness, like those found in deserts. Many desert plants utilize CAM (crassulacean acid metabolism) photosynthesis, in which stomata are closed during the day and open at night. [24]

[23] Kirkham, M. B. (2014). *Principles of soil and plant water relations* . Academic Press. 431-451.

[24] Ting, I. P. (1987). Stomata in plants with crassulacean acid metabolism. *Stomatal Function.* Stanford University Press, Stanford, CA, 353-366.

In prior water lessons, students became experts on observation, the first step of the scientific method. Now students, through investigation of stomata, have the opportunity to learn how to create **hypotheses** and **predictions**. A hypothesis is much more than an educated guess. It is an *explanation* of a phenomenon that requires some testing. Constructing hypotheses is a creative process based on observation. A prediction, on the other hand, is a specific, *anticipated outcome* from an experiment and it emerges naturally from a hypothesis. Some examples pertaining to this lesson are below.

Observation: Plants have stomata on their leaves. Environmental conditions are not usually the same on both sides of leaves.
Hypothesis: Stomata are not equally dense on both sides of leaves.
Prediction: I predict there are more stomata on the undersides of *Tradescantia* leaves compared to the top, and this helps the plant reduce water loss.
With evidence from this experiment, new hypotheses and predictions can be made. For example:

Observation: There are indeed more stomata on the underside of *Tradescantia* leaves than on the top.
Hypothesis: The number of stomata on leaves is linked to temperature.
Prediction: I predict plants exposed to high temperatures have fewer stomata than plants exposed to low temperatures.

How could students test this in the future? What other variables might affect the overall number and placement of stomata? Light intensity? The amount of CO_2 in the atmosphere? Maybe students have heard that the atmosphere is becoming richer in CO_2. What are some hypotheses and predictions about stomata that could come from this knowledge? Allow students to be creative with this process of making hypotheses, predictions, and then explaining how they might test them. Of course, there are limitations (equipment, time, etc.) involved in testing every prediction, but there are far fewer limitations in the exercise of making these hypotheses and predictions – skills that all scientists practice![20]

Supplies:

Microscopes
Tradescantia leaves
Scissors
Flashlights
Air-tight containers with pumps
Marshmallows
Enlarged laminated pictures of stomata
Enlarged laminated diagram of photosynthesis
Containers of baking soda and vinegar
Glue sticks
Paper leaf cutouts and tiny circles

Vocabulary:

Adaptation – A trait that makes an individual better able to survive and reproduce compared to an individual that does not have that trait

Carbon Dioxide – A gas in the atmosphere plants use in photosynthesis and which we exhale
Chlorophyll -Green pigment in plants, photosynthetic

[20] Strode, P. K. (2015). Hypothesis Generation in Biology: A Science Teaching Challenge and Potential Solution. The American Biology Teacher, 77(7), 500–506. doi: 10.1525/abt.2015.77.7.4

<u>Chloroplast</u> –An organelle within a plant cell that contains chlorophyll and in which photosynthesis takes place

<u>Guard Cells</u> – Specialized cells surrounding the stomata that control water and gas exchange

<u>Hypothesis</u> – A scientific explanation of nature based on some evidence, which leads to prediction and further study

<u>Photosynthesis</u> – The process plants use to make their own food

<u>Prediction</u> – A stated idea of what will happen based on observation

<u>Stomata</u> – Openings that allow for gas exchange – carbon dioxide in oxygen, water vapor out

<u>Transpiration</u> – The evaporation of water from leaves and stems

Talking Points:

- A mixture of gases makes up the air we breathe. We need oxygen that we get from plants, and plants use carbon dioxide that we produce in order to photosynthesize.

- Plants have pores called stomata in their leaves and stems. Stomata open and let carbon dioxide in and oxygen and water vapor out.

- Each stoma has guard cells that regulate the size of the pore opening.

- Have students predict where stomata are most abundant: the top or the bottom of the leaf. After investigation, talk about how plants would lose too much water (through the process of transpiration) if they were on top where the sunlight is most intense.

- Plants in the desert have adapted to only open their stomata at night to cut down on **transpiration**. They are able to store CO_2 overnight and use it the next day for photosynthesis.

Activities:

1. Talk with your students about air. Show them the empty plastic container and ask them what they think is inside. What makes up air? How do you talk about something you cannot see?

2. Allow students to pump the empty, plastic container. What is being pumped out?

3. Next, place a marshmallow inside the container and ask students for a prediction. What do they think will happen to the marshmallow when they pump out the air? Let students help pump. Ask students how they think this experiment relates to plants. (You are trying to spark a discussion about air, oxygen, etc.) Emphasize that scientific inquiry is not only important, but that it can be fun!

4. Provide each student with a container of vinegar and one of baking soda. Ask students what they believe each substance to be and how they know this. Remind them that we bring a lot of previous knowledge to each experience. Let them add the containers together to see carbon dioxide and vinegar react. Ask students to explain what happened. (The fizzing and bubbling is a reaction between the vinegar and baking soda that releases CO_2 and water.)

5. Explain that air is made up of carbon dioxide and oxygen. Plants require carbon dioxide, which they use to make their own foods during the process of photosynthesis. Plants

make oxygen. The oxygen that they don't use is released, and this oxygen is what all animals, including humans, need to survive! These gases move in and out of plants through tiny pores in the leaves called stomata. Water from inside the leaf also can evaporate through these stomata.

6. After reviewing how to use a microscope, have the students take a leaf from the *Tradescantia* plant. Let them rip off a piece from the leaf and place the leaf bottom side up. Help them identify a stoma (each will be surrounded by two green guard cells).

7. Ask: is the environment around the leaf the same on both sides? Which side gets more sunlight and is hotter? Would a side that gets more sun have more or less evaporation of water from inside the leaf? Is a lot of water loss good or bad for the plant? Help the students make a hypothesis about the number of stomata on the leaf. One might be: the number of stomata is not the same on the top and bottom sides of a leaf. Predict which side has more stomata?
8. Students could then test this by counting the stomata on each side – just remember to keep the magnification the same for both sides. It may be helpful to peel off a section of outer epidermis of both leaf surfaces if viewing under a compound microscope. Use a light source on the microscopes to better illuminate the stomata.

9. Show students the picture of the stomata and explain that when a plant has enough water and sunlight, the guard cells contract, creating the opening through which oxygen and water vapor are released and carbon dioxide is taken in.

10. Have your students capture what they see in the microscope on paper. They can use color pencils to add color. Ask students if they know why most leaves are green. While they are coloring, introduce chlorophyll and chloroplasts.

Plants Make Their Own Food

Big Idea: The majority of plants photosynthesize in their leaves. The process of photosynthesis produces glucose, a form of sugar. Plants can burn this sugar for energy, or they can store it.

Photosynthesis: Plants Make Their Own Food

Objectives:

After participating in this lesson, students will:

- Understand that photosynthesis occurs mainly in the leaves of plants and that photosynthesis produces a form of sugar
- Form a prediction and test it
- Learn that scientists have many tools to understand plant science

Background: *Photosynthesis*

Unlike humans and other animals, plants can make their own food. They do this via the process of **photosynthesis**. In photosynthesis, plants use water, which is usually obtained from the soil; carbon dioxide, which enters leaves through stomata (see Photosynthesis: Viewing Stomata under the Microscope); and sunlight to make the simple sugar **glucose**, as well as oxygen. The simplified equation for photosynthesis is:

carbon dioxide + water ——(light energy)——> glucose + oxygen

(by having 'light energy' over the arrow, scientists indicate that this is what activates (or catalyzes) the reaction)

The sugar that is made by the plant can be stored and utilized later to produce the chemical energy plants needs to survive. Photosynthesis relies largely on the green pigment chlorophyll. Most of this chlorophyll is found in chloroplasts, which you could easily see in the *Spirogyra* viewed during the Water: Under the Microscope lesson. Humans cannot make their own food but rather we get our food from plants, or from animals who eat those plants. Note that only the green parts of the plant photosynthesize, and they only do it when there is sunlight.[21]

[21] What Is Photosynthesis. (2018). Smithsonian Science Education Center. Retrieved from https://ssec.si.edu/stemvisions-blog/what-photosynthesis

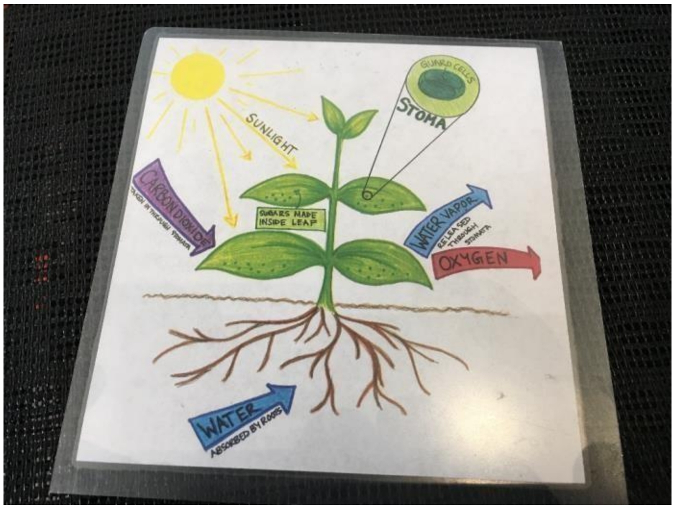

Figure 8. Diagram of photosynthesis. Plants use light energy to drive photosynthesis. The energy made here is used to fix carbon dioxide as glucose, a food source for plants. Oxygen is released as waste.

Refractometers

The amount of sugar present in a liquid sample can be measured using a **refractometer**. Refractometers measure how much a substance bends light, and this property is called a refractive index. A Brix refractometer can measure the bending of light, primarily by the sugars that plants produce (though the final reading will incorporate some effects of other plant products, like proteins). You can demonstrate how dissolved sugar bends light by looking at how sunlight passes through water-filled glasses, one with a pinch of sugar and one with a couple tablespoons of sugar. More sugar in a solution will cause more bending of light. This is because light travels through substances more slowly as they become more dense. Brix refractometers measure how much light is bent by passing through a liquid and use that information to determine how much sugar the liquid sample contains. This is measured in degrees Brix, where 1 degree Brix is equal to 1 gram of sugar in 100 grams of solution, or 1% by mass. The refractometers used here range from 0-30 degrees Brix. Brix measurements can be used as indicators of fruit and vegetable quality – for example one could measure the sweetness of grapes before harvest. What are some other ways refractometers might be useful to you or to farmers?[22]

[22] Kleinhenz, M. D., & Bumgarner, N. R. (2013). Using °Brix as an Indicator of Vegetable Quality: An Overview of the Practice. Ohio State University Extension. Retrieved from https://ohioline.osu.edu/factsheet/HYG-1650

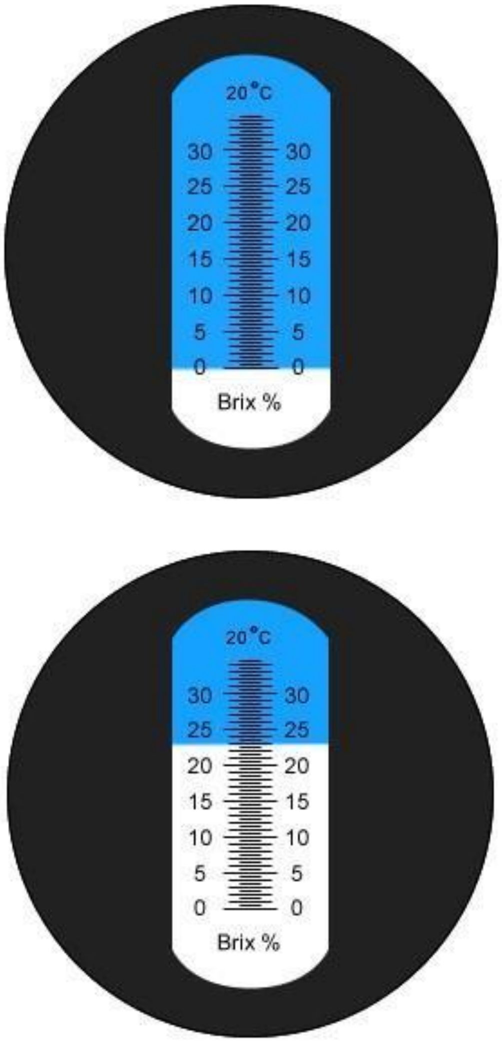

Figure 9. Two examples of standard refractometer readings. A properly calibrated unit (left) will read 0 in pure water. A solution with sugar will produce a reading greater than 0, e.g. 23 (right). *Photos provided courtesy of Brant Burgiss*.

Activities:

Vocabulary:

<u>Brix Refractometer</u> – A special tool scientists use to measure sugar content of liquid samples

<u>Cellular Respiration</u> – The process through which nearly all living organisms turn oxygen and sugar into energy:

<u>Glucose</u> – Sugar

<u>Photosynthesis</u> – The process plants use to make their own food

<u>Prediction</u> –A stated idea of what will happen based on observation

Supplies:

Brix refractometers

Refractometer screen cut outs

Garlic presses

Jade plant

Water

Orange Juice

Tissues

Small vials for water

Pipettes

Grape juice and cups

Small garbage can

Talking Points:

- What is photosynthesis? The process by which plants make their own food. It is mainly done in leaves. People grow or buy our food because our bodies cannot make food.
- Photosynthesis cannot occur without sunlight. Plants use the energy of sunlight, along with carbon dioxide and water to make the sugar glucose.
- A Brix refractometer is a special tool that scientists use to measure sugar concentration.
- We know that photosynthesis produces the sugar found in plants. If the refractometer shows that sugar is present in the plant sample, then photosynthesis must be occurring.

1. Provide each student with a cup of grape juice. Have them taste the juice and then describe how it tastes. Have students explain where grape juice comes from.

2. Explain that people who grow grapes need to know the right time to pick their grapes. They will use their observational skills and senses but they also use a scientific tool called a Brix refractometer. Show the students how a refractometer works. First, have them look through the refractometer and simply notice the blue screen with numbers. Make sure the numbers are in focus for them. Also, ask them what numbers they see between 0 and 5, 5 and 10, etc. They should know that each mark represents a number.

3. Have your students **predict** the percentage of sugar in tap water. Next, let them test their prediction by using a disposable pipette to place a drop of water on the screen of the refractometer. To get their reading, they should look through the refractometer for where the white line meets the blue line. Have them record their finding. Clean off the screen and screen shield with a tissue.

4. Next, have them predict what the percentage of sugar will be in the grape juice they tasted. Have them follow the above steps but this time with grape juice instead of water. Is the percentage reading reasonable given how they described the juice when they tasted it? Have them record their finding. Clean off the screen with a tissue. Ask your students how their results might be different if they did not clean their screen between tests.

5. Review photosynthesis with them. You want to make sure they understand the process and that plants make glucose (sugar). Ask students where most plants make their own food (sugar). Finally, have them predict what they think the sugar percentage will be in the leaf of a jade plant.

6. Have each student take a leaf from a jade plant and put it in a garlic press and squeeze the ‘juice’ on to the refractometer. What is the sugar percentage? Greater or smaller than they predicted?

7. Discuss that for most plants the process of photosynthesis takes place in the leaf.

8. What do they think would happen if they tested a leaf that had not been exposed to light for a day, several days, a week? Deprived of water? Took in no carbon dioxide?

Power of the Sun

Big Idea: Plants make their own food through a process called photosynthesis and they cannot do this without the sun.

Photosynthesis: Power of the Sun

Objectives:

After participating in this lesson, students will:

- Understand that plants can make their own food and we cannot.
- Learn that photosynthesis occurs primarily in the leaves of plants and the leaves, just like solar panels, are gathering the energy from the sun.
- Almost all of the energy that we use on Earth originates from the Sun

Background:

Sunlight, color, and photosynthesis

Sunlight is a necessary component of photosynthesis. It provides the energy needed to convert carbon dioxide and water into sugar and oxygen (see Photosynthesis: Plants Can Make Their Own Food). For most plants, photosynthesis occurs primarily in the leaves. The chlorophyll in the chloroplasts of leaves makes them green and helps capture the light energy needed for photosynthesis. Chlorophyll is a pigment because it absorbs photons, or particles of light. Why is chlorophyll green? Pigment color is due to the absorption of photons of certain wavelengths, and the reflection of others! A green pigment is green because it absorbs light that is blue, red, yellow, etc. but reflects all green light. All of these colors are part of the visible spectrum, and sunlight contains them all.

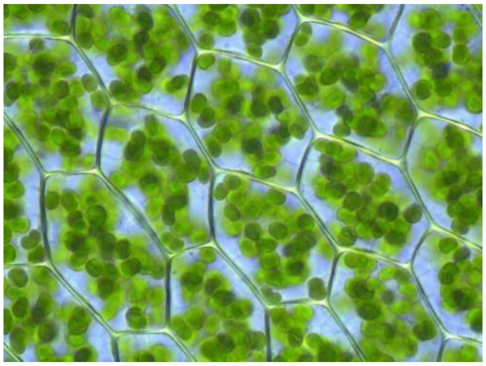

Figure 10. Photo of chloroplasts in plant cells. *Image by Kristian Peters*

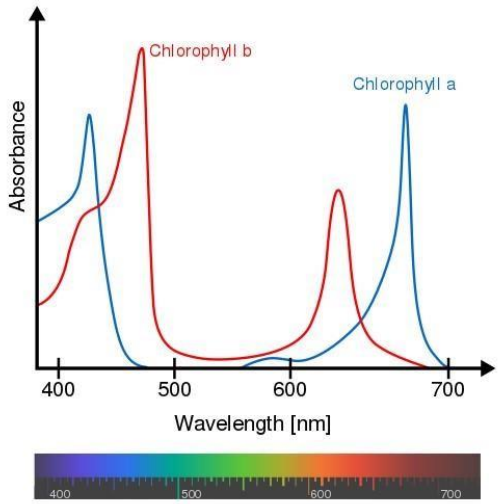

Figure 11. Diagram that shows which wavelengths, or colors of light, chlorophyll absorbs. Blue and red wavelengths are strongly absorbed, whereas green is reflected (absorbed the least). *Image by Daniele Pugliesi*.

The amount of photosynthesis that can occur in a leaf depends on light intensity (as well as temperature and CO_2 levels). Plants cannot capture all the light provided by the sun. The amount of light energy that can be converted to chemical energy is called photosynthetic efficiency and ranges from 1%-8% of the total available light in natural conditions. Some scientists are working on technologies that artificially mimic photosynthesis, and others are working to engineer plants to be more efficient.[23]

Sunlight and Earth's Energy

Except for nuclear energy, almost all the energy on earth comes from the sun. An indirect example of this is wind energy: the wind currents that turn turbines are the result of uneven heating of the Earth's surface by the Sun. A more direct example is solar cells, which capture the energy in sunlight to make electricity. Think of some other forms of energy and how they might be linked to the sun.

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As we know, plants can harness **solar energy**, and they have been able to do this for millions of years! When photosynthetic organisms die and become trapped and squeezed underground without oxygen, they can chemically change. Over the course of millions of years, the products of photosynthesis can be converted into oil, coal, and natural gas. These are called **fossil fuels**. Because fossil fuels take millions of years to become usable, they are considered nonrenewable

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[23] Nave, R. (n.d.). Light Absorption for Photosynthesis. Georgia State University. Retrieved from http://hyperphysics.phy-astr.gsu.edu/hbase/Biology/ligabs.html

resources.[24] The next time you drive your gas-powered car to the store, or build a campfire with wood, remember that the energy you are using was captured from the sun through the process of photosynthesis. When we combust these fuels, it is a bit like photosynthesis in reverse. What gases are released? What is visible? Brainstorm some other reasons why photosynthesis has been helpful to our energy needs? What are some modern issues that relate to the overconsumption of this stored energy from the sun?

Light Sensitive Insects and Paper

The light sensitive insects and the solar paper used in this station provide good demonstrations of how light contains energy, and how that energy can induce chemical change. The backs of the solar insects contain solar cells. As the sun hits the mini solar panel, the insect 'comes to life' as electricity is produced as electrons are separated from their atoms.

The solar paper is coated in a chemical called Berlin Green, which is sensitive to light and can be dissolved in water. When ultraviolet light interacts with the Berlin Green, it changes to a chemical called Prussian Blue, which is not dissolvable in water. The part of the paper exposed to light will have Prussian Blue that will *not* wash off, whereas the shaded paper with no light exposure will have Berlin Green that *will* easily rinse off with water, leaving behind a white impression of the figure that blocked the light.[25] To see the solar paper in action, set an object of natural history on top of a piece of light-sensitive paper in the full sun. The flatter the object, the better. Let the object and the paper sit in sunlight for a couple minutes, then remove the object and immerse the paper in water for one minute. The final image will be white to pale blue, while the paper exposed to the sun should be dark blue.

Vocabulary:

Adaptation – A trait that makes an individual better able to survive or reproduce compared to an individual that does not have that trait

Canopy – The cover formed by the leafy upper branches of trees

Fossil Fuel – A fuel that comes from the remains of ancient plants and animals (e.g. coal, natural gas, oil).

[24] Plant material and fossil fuel. (2015). Freie Universität, Berlin. Retrieved from https://www.geo.fuberlin.de/en/v/iwm-network/learning_content/watershed-resources/ressource_biomass/plantmaterial-andfossil-fuel/index.html

[25] Nature Sun Sensitive Paper. (2019). Steve Spangler Science. Retrieved from https://www.stevespanglerscience.com/lab/experiments/sun-sensitive-paper-experiment/

Solar Energy – Heat and light energy derived from the sun Understory

– The shrubs and plants growing beneath the canopy **Supplies:**

Solar powered insects and flat rubber insects	Low container to hold water
Black plastic tablecloth	String
Light sensitive paper	Clothespins
Containers for gathering objects	Large leaf from a tropical plant
Sharpies	Succulent plant with small or modified leaves

Talking Points:

- What is photosynthesis? The process by which plants make their own food. We grow/buy our food, but plants make their food through a process called photosynthesis.
- Photosynthesis cannot occur without sunlight.
- The leaves of plants, like solar panels, are constantly capturing sunlight and they use this energy to make their food.
- Desert plants' leaves are typically smaller (the spines of cacti are in fact modified leaves) because they get plenty of light and leaves are a source of water loss (via transpiration) which desert plants cannot afford. Photosynthesis, for most cacti, occurs in their stems. Tropical plants' leaves need to be large in order to capture the light they need for photosynthesis through the dense canopy.
- To talk more about the entire photosynthesis process, refer back to the diagram in Photosynthesis: Viewing Stomata under the Microscope.

Activities:

1. Gather your students in a shady area. Ask them to open their hand. Place a solar powered insect in their hands. Instruct them to walk out in to the sun. Ask your students to describe what they think is happening. Discuss solar energy and make the connection to plants, explaining that plants are doing this all the time.
2. Provide each student with a container. Take a walk in a natural setting, letting the students pick up items that are on the ground (sticks, fallen leaves, twigs, seeds, etc.). Please remind them to look for nature's litter and not to take from living plants.
3. Instruct students to be ready with their collections. Provide each student with a piece of photo sensitive paper and have them place their collection on the paper. Once their collection has been placed on the paper, they must not move it.
4. Wait several minutes. Have your students write their name on the paper with a Sharpie. After waiting the time designated on the paper's package, have students dump their collections off their papers into the buckets. Next, have them place their paper in water. This will seal the developing process. Talk with your students about photosynthesis.

Show them a tropical plant and a desert plant and ask them to explain why these plants have such different leaves.

Seed Balls: Mixing it all Together

Big Idea: With a little soil, seeds, water, and sunshine we can all make the ear th a little greener.

Photosynthesis: Seed Balls

Objectives:

After participating in this lesson, students will:

- Know that seeds contain plant embryos that grow into plants
- Understand that plants need water and sunshine to grow
- Learn how to become a steward of the Earth

Background:

In this lesson, students will make seed balls – one with native wildflower seeds and one with vegetable seeds. These seed balls will give students the opportunity to observe the life cycle of a plant, provide food plants for pollinators and themselves, and make their communities a little greener.

Seed Biology

Plants use some of the chemical energy produced in photosynthesis to reproduce (see Nature as Art lessons). The products of fertilization in plants are seeds. Seeds are young, embryonic plants enclosed in a seed coat. These embryos have access to endosperm within the seed, and this provides the food supply for the growing embryo until it can begin making its own food via photosynthesis. Growing embryos must obtain enough water to germinate. Some seeds can go into dormancy, preventing germination, until environmental conditions are favorable.[26]

Seed Balls

Seed balls provide an excellent way to safely disperse seeds without having to till or dig soil, which might disrupt the soil and the many beneficial organisms that live within it. The clay in a seed ball gives it structure and protects the seeds from animal consumption (seeds are rather tasty to birds and rodents). The rich soil will hold water when it rains, allowing the seeds to absorb the water and germinate! After germination, the growing plant will send roots down into the soil and leaves toward the sky, and hopefully get established as a healthy seedling. The idea for seed balls has been around for some time. Native Americans used seed balls to preserve and distribute seeds, and in the mid-1900's a Japanese farmer named Masanobu

Supplies:

Bucket of soil

Container of powdered clay

[26] Schalau, J. (2007). Backyard Gardener: How Seeds Work . College of Agriculture and Life Sciences – University of Arizona. Retrieved from https://cals.arizona.edu/yavapai/anr/hort/byg/archive/howseedswork.html

Wildflower seeds

Vegetable seeds

Cups

Wooden craft sticks

Water bucket for rinsing

Waxed paper bags

Wipes

Squirt bottles

Pre-soaked lima beans (at least

Fukuoka used seed balls in re -vegetating degraded land.[32] Have students brainstorm reasons why the planting of wildflowers or vegetables in their community is important. Reflect on the requirements of seed germination. What are the resources needed for germination? What is a seed? How does it turn in to a seedling? Where should the seed ball be put in order to germinate?

What is a **seed**? A sexual reproductive structure in which the **embryo** is housed. Seed balls are a way to disperse seeds by sealing them in a mixed ball of clay and soil. The soil will absorb the rain, the clay will keep the ball together until it rains and will deter birds from eating the seeds.
Seed balls are scattered directly on the ground, not planted. This makes them useful for reclaiming abandoned land in an attempt to ma ke an area more beautiful and more ecologically functional.

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24 hours before)

Lima bean parts diagram

Sharpies

Talking Points:

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-
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[32] 5 Cool Facts About Seed Balls. (2018). Student Conservation Association. Retrieved from https://www.thesca.org/connect/blog/5-cool-facts-about-seed-balls

- You can sow your seed balls on a sunny day and just leave them. When sufficient rain has permeated the clay, the seeds inside sprout and are aided by the nutrients and soil that surround them. Seeds have a protective coating and a built-in food source that support the enclosed embryos until they form their first leaves to begin photosynthesis and make their own food.
- In the 1970s seed balls were used in New York to revitalize abandoned lots and to start the first community garden.

Vocabulary:

Embryo – Immature plant in a seed

Fertilization – The uniting of sperm and egg cells to form an embryo

Germination – Process by which seeds or spores begin to grow

Photosynthesis – The process plants use to make their own food

Seed – The sexual reproductive structure in which the embryo is housed

Activities:

1. Provide each student with a pre-soaked lima bean and have them discover the "baby plant" inside. Use the lima bean parts diagram to help in identifying parts.

2. Have each student put their name on a waxed paper bag.

3. Gather your ingredients. Supply each student with a cup. Let them take one teaspoon of powdered clay and two teaspoons of soil and mix it together well in their cup with a wooden craft stick.

4. Have them take a half teaspoon of seeds and mix this into their cup.
5. Using water sprayers, have them add enough water just to hold the soil together. The consistency should be like cookie dough.

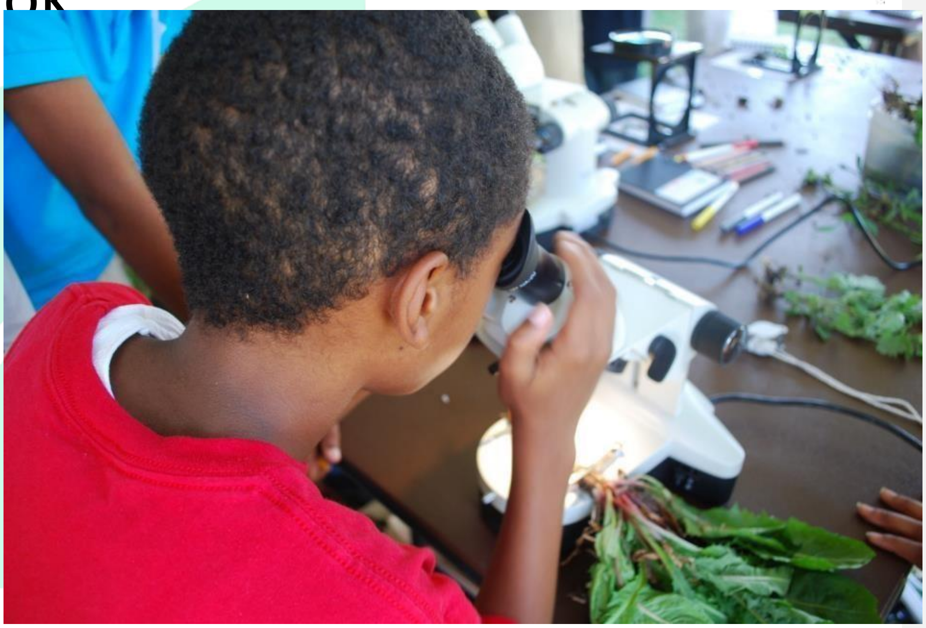
6. Have them pour the contents into their palm and roll into a ball. It should be rounded and have no cracks.

7. Place their seed balls in a waxed paper bag.

8. Ask your students what the seeds need to germinate, and what happens when the plants develop their own leaves?

9. Repeat the above process using the other s eed type. One garden provides food for the pollinators and one garden provi food for us.

Nature As Art: A Microscopic Look



Big Idea: Nature is beautiful especially at a microscopic level.

Nature as Art: A Microscopic Look

Objectives:

After participating in this lesson, students will:

- Understand that there are things we cannot see with our own eyes that are alive and beautiful
- Learn that nature's patterns and shapes are often used by artists as inspiration
- Create their own botanical art pieces

Background:

From Monet to Van Gough, artists have long-been interested in capturing nature, particularly plants! A scientist's work, in turn, is often inspired or informed by the arts. Despite this, there is a perceived division between the arts and the sciences.[27] One might suggest that the characteristics that define an artist are creativity and the ability to observe. But we now know through previous HOPS lessons that observation is at the heart of science. And, creativity is absolutely necessary to ask questions, as well as to devise hypotheses and predictions based on observation. Perhaps there is not a great difference between the cultures of art and science. Albert Einstein believed the greatest scientists were artists as well.[28] This lesson, as well as the others in this Nature as Art series, explores the realms of science and art *together*, and demonstrate that there are far more similarities between the two than there are differences.

Micrograph Photographs

Both scientists and artists can use **microscopes** to examine the natural world. Here, students have the chance to look at micrographic photographs, which were created using scanning electron microscopy (SEM). Unlike the light microscopes used in other lessons, where the highest magnification one could obtain was 400X, a conventional scanning electron microscope can magnify images up to 30,000X. These microscopes shoot beams of electrons down onto the subject to define its surface. Some of those electrons are absorbed by the specimen, and others are reflected. You might ask students to relate this to the earlier discussion about chloroplasts and light absorption and reflection. A detector measures the electrons reflected from the surface of the specimen to develop the image. Since electrons are extremely minute particles, the images produced have extraordinarily high resolution. These images are in black and white,

[27] Andreasen, N. C. (2012). Creativity in art and science: are there two cultures? *Dialogues in clinical neuroscience*, *14*(1), 49.

[28] Calaprice, A. (2000). The expanded quotable Einstein. *Princeton, NJ: Princeton*.

and then an artist colors the grayscale photo artificially using computer software to mimic the specimen's natural coloration.[29]

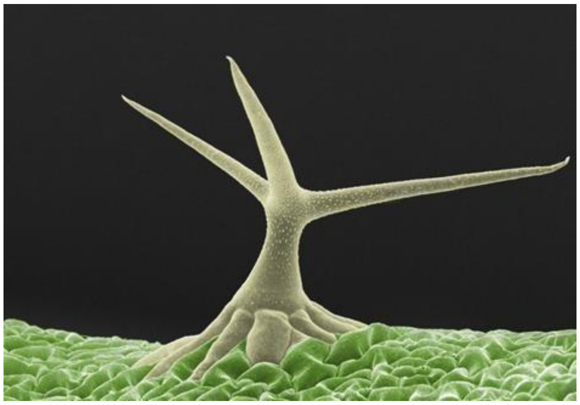


Figure 12. Micrograph of a trichome, a small hair protruding from the outer surface (epidermis) of an *Arabadopsis thaliana* leaf. The image was captured using a scanning electron microscope and later colored by an artist to appear realistic. Carol Flegler, Center for Advanced Microscopy, Michigan State University.

Botanical Collection

In this lesson, students have the opportunity to collect plant material to observe under the microscope. Botanists regularly collect plant specimens, which they later press, dry, and glue to pieces of thick paper to be stored in museums called herbaria (singular: herbarium). These herbaria are giant repositories of non-living plant material. Scientists can use plant specimens to better understand the evolutionary relationships between plant species, their distribution, and many other things. Botanic gardens have historically relied on these scientists to find and collect living plants from around the world to add to garden collections.[30] The first naval expedition in U.S. history was the U.S. Exploring Expedition of 1838-1842, a voyage that included six ships, hundreds of sailors, and a group of nine scientists and artists. Scientists on this expedition collected 50,000 dried and pressed plant specimens (which formed the U.S. National Herbarium at the Smithsonian Institution), as well as over 1,000 living plant specimens that formed the collection of the United States Botanic Garden. Without the efforts of collecting scientists, our understanding of plant diversity would be truly deficient.[31]

Supply List:

Microscopes

Slides

[29] Swapp, S. (2017). Scanning Electron Microscopy (SEM). Carleton College. Retrieved from https://serc.carleton.edu/research_education/geochemsheets/techniques/SEM.html

[30] What is a herbarium? (2010). Duke University Herbarium. Retrieved from https://herbarium.duke.edu/about/what-is-a-herbarium

[31] Philbrick, N. (n.d.). Learn More About The U.S. Exploring Expedition: The Scientific Legacy of the U.S. Exploring Expedition. Smithsonian Libraries. Retrieved from https://www.sil.si.edu/DigitalCollections/usexex/learn/Philbrick.htm

Paper

Colored pencils

Leaves

Florets

Micrographic photographs

Button making equipment

Card stock

Self-adhesive laminating sheets

Flower – Reproductive organ of seed plants in the angiosperm lineage

Leaf – Primary location of food production (photosynthesis) and transpiration

Microscope – An instrument used to produce a magnified image of a small object

1. Take your students on a walk and let them collect a sampling of items they would like to
2. With both the microscopes and magnifying glasses, let them look at plant parts, moving from the lowest to highest magnifications and back to the lowest.
3. Have them draw what they see under the microscopes.
4. Using the collected plant material, students can make a variety of creations:

Vocabulary:

<u>Floret</u> – A small flower

Activities:

explore under the microscope.

Botanical Buttons

- Students select small flat pieces from their collection and make button pins. Place the pin parts on the button machine. Place a white pre-cut circle on the top piece and let students add one or two plant items. Place a Mylar circle over their plants, rotate this side under, and have the student pull the red handle toward the table. This pull attaches the pin back to the top of the button. Swivel to the other side and remove finished button. Note: plants must lay flat on the paper for success.

Botanical bookmarks

- Students select several items from their plant collection and place them flat on a 3 inch by 8-inch pre-cut piece of cardstock. Using a self-adhesive laminating paper cut to the same size, students peel off the paper back and place the sticky side down on the cardstock. Students should gently press the top piece to ensure the two pieces adhere.
- Note: Having students press their plant material in advance using simple plant presses made with cardboard, blotting paper and sturdy rubber bands will ensure the plant material will lay flat for either of the above activities, and is a great activity to talk about plant collection and herbaria.

Vocabulary:

<u>Floret</u> – A small flower

<u>Flower</u> – Reproductive organ of seed plants in the angiosperm lineage

<u>Leaf</u> – Primary location of food production (photosynthesis) and transpiration

<u>Microscope</u> – An instrument used to produce a magnified image of a small object

NATURE AS ART: Plant Morphology

Big Idea: Flowers and their many parts are beautiful, functional, and essential to the majority of plant life on earth.

Nature as Art: Plant Morphology

Objectives:

After this lesson, students will:

- Understand the role of a flower
- Know the different parts of a flower
- Understand how seed development occurs

Background:

Reproduction and Pollination in Plants

All species of living things reproduce and, while reproduction is not essential to an individual's survival, creating new generations is necessary for the survival of a species. Plants can reproduce asexually or sexually. Asexual reproduction does not involve the fusion of gametes or change to the number of chromosomes. An example of asexual reproduction is vegetative reproduction where a part of a plant splits off and forms another plant that is genetically identical to the parent plant. This is why horticulturists are able to take a cutting of one plant, pot it, and have two individuals.[32] Most plants are also capable of sexual reproduction. Sexual reproduction involves the fusion of gametes, combining parental DNA to create a new individual. Sexual reproduction in angiosperms (flowering plants) requires special structures: flowers! Flowers produce gametes, reproductive cells which contain half the DNA of the parent plant's cells. Female gametes are called eggs and male gametes are called sperm. The eggs of flowering plants are within the ovule in the flower's ovary, and the sperm is within the pollen in the flower's anther. When a sperm cell reaches the egg cell within the ovule (see flower diagram), fertilization occurs![33] Many flowering plants have evolved double fertilization wherein two sperm cells are sent to the ovule. One sperm cell fertilizes the egg cell to make a zygote. The other sperm cell fertilizes two polar nuclei, created during the formation of the egg cells (oogenesis). The fused sperm and polar nuclei form the endosperm, which is the food source for the growing embryo. Think of white, fluffy part of a popped corn kernel, that is the endosperm.[34] Following fertilization of the egg, the ovule develops into a seed and the ovary

[32] Sorensen, D. C., & Garland, K. (n.d.). Plant Propagation. University of Maine Cooperative Extension. Retrieved from https://extension.umaine.edu/gardening/manual/propagation/plant-propagation/

[33] Reproductive Plant Parts. (2019). Oregon State University Extension Service. Retrieved from https://extension.oregonstate.edu/gardening/techniques/reproductive-plant-parts

[34] Bleckmann, A., Alter, S., & Dresselhaus, T. (2014). The beginning of a seed: regulatory mechanisms of double fertilization. *Frontiers in plant science*, *5*, 452.

Often toward the center and base of flowers are floral nectaries, which hold nectar to attra

develops into fruit. The plant that emerges from this seed is not identical to either parent, but a combination of the two. For more on pollination, see the CSI: Pollen Under the Microscope lesson.

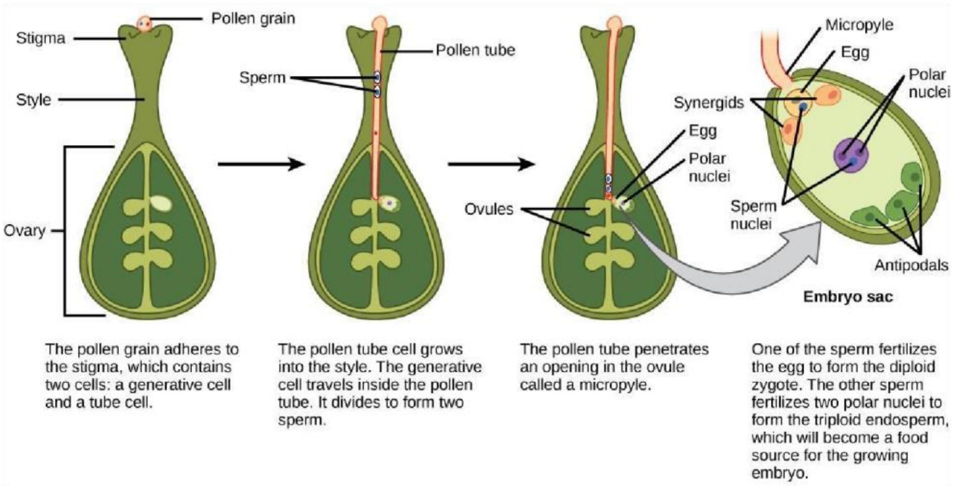


Fig. 13. The process of double fertilization in many angiosperms. [41]

Plant Reproductive Anatomy

The ovules are located in the ovary in the flower's female reproductive organ called the pistil . On top of the ovary is a stalk called a style. The style has a cap (sometimes multiple caps) on top called a **stigma**, which has a sticky surface that receives pollen. The ovary, style, and stigma are collectively called the carpel. A pistil can consist of one carpel or multiple carpels fused together. [42] When pollen from a compatible species lands on the stigma, a pollen tube develops down through the style, and eventually into the ovary, which contains one or more ovule. Sperm cells from the poll en travel down the tube to the eggs cells in an ovule. When egg cells receive the sperm cells, fertilization is complete and seeds begin to develop.
The male reproductive organ is called the **stamen**. It is comprised of the anther, which bears the pollen, and the supportive structure called the filament that holds the anther. [43] The lilies used in this lesson have six stamens.

[41] [Double Fertilization]. (n.d.). Lumen Learning. Retrieved from https://courses.lumenlearning.com/wm -biology2/chapter/double -fertilization/

[42] Carpel Pistil. (2012). Charles Sturt University Herbarium. Retrieved from https://science.csu.edu.au/herbarium/gyn oecium/about/carpel -pistil

[43] Reproductive Plant Parts. (2019). Oregon State University Extension Service. Retrieved from https://extension.oregonstate.edu/gardening/techniques/reproductive -plant-parts

pollinating animals. Generally, nectaries are located such that a pollinator is forced to come in contact with the reproductive parts of the flower, collecting or depositing pollen as it feeds. By providing nectar, a plant can help to ensure its own reproduction.[35]

[35] Brandenburg, A., Dell'Olivo, A., Bshary, R., & Kuhlemeier, C. (2009). The sweetest thing: advances in nectar research. *Current opinion in plant biology*, *12*(4), 486-490. https://doi.org/10.1016/j.pbi.2009.04.00

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Figure 13. *Diagram of floral parts*

Surrounding the reproductive parts is the perianth, which includes the corolla (made up of petals) and the calyx (made up of sepals). Petals are generally brightly colored and attract

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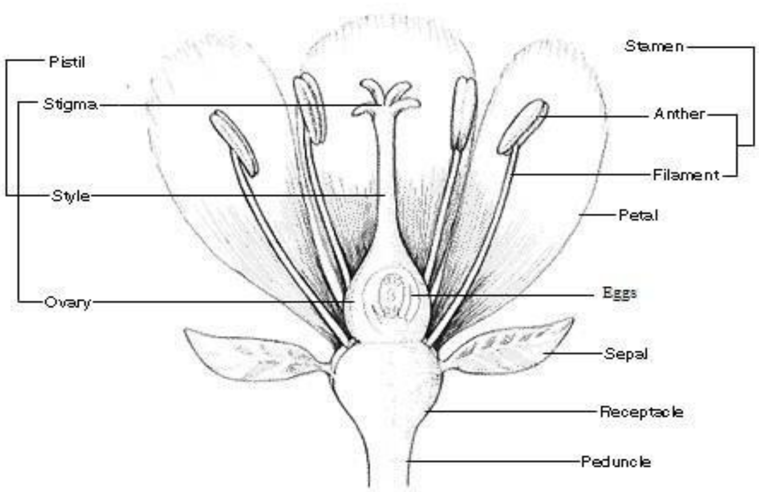


pollinators[36], and they also protect the reproductive organs. Sepals can be green, or they can be

[36] Plant Strategies: Visual Cues. (n.d.). United States Forest Service. Retrieved from https://www.fs.fed.us/wildflowers/pollinators/Plant_Strategies/visualcues.shtml

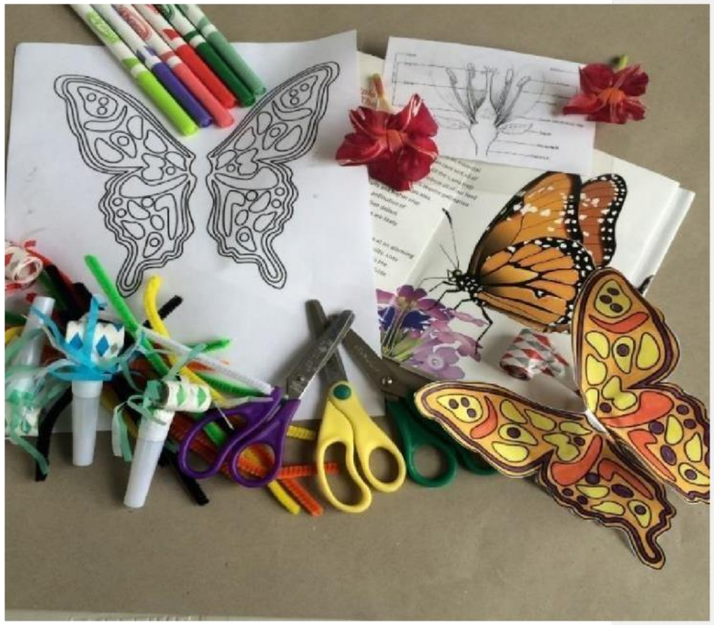
colored, as in the lilies, and also serve a protective purpose. The lilies in this lesson have similarly colored petals and sepals and have three of each. The sepals make up the outermost part of the perianth.

The entirety of the flower emerges from the receptacle. The stalk that bears this receptacle is called a peduncle.[37]

[37] Nelson, R. C. (2009). The Description of Flowers. University of Rochester. Retrieved from https://www.cs.rochester.edu/~nelson/wildflowers/glossaries/flowers/index.html

Morphology –'Morph' means shape or form and –*ology,* means the study of something. The

Supplies:



Lilies

Tweezers

Laminated plant flower morphology diagrams

Magnifying Glasses

Colored Pencils/Markers

Butterfly Wings

Party Blow Outs

Pipe Cleaners

Waxed paper bags

Sharpies

Tape

Talking Points:

- Why do some plants have flowers? How do plants attract pollinators?
- The flower is responsible for reproduction and eventually seed and fruit development.
- There are four main floral parts: sepals, petals, stamens, and carpels/pistils.
- How do flowers get pollinated? How does the pollen get from the anther (part of the stamen) to the stigma (part of the carpel)? Discuss pollination and seed development.
- Do pollinators intentionally move pollen?

Vocabulary:

Botany – The scientific study of plants

Fertilization – The uniting of sperm and egg cells to form an embryo

term is used in botany as the study of forms and structures of plants

Pollination – When pollen is transferred from one plant to another

Proboscis- A long, thin tube that forms part of the mouth of some insects (such as a butterfly)

Stamen – The male part of the flower that produces the pollen

Stigma – A female part of the flower – the uppermost part of the pistil, which receives the pollen

Activities:

1. Gather your students and ask them to name parts of a plant and the job of each part.

2. Next, provide each student with a flower and a diagram of the parts of a flower. Explain that they are going to do a flower dissection. Starting at the petals, have them remove the parts of the flower. Have them lay the flower parts on the diagram to better understand each part.

3. Have each student draw the parts of the flower, making sure to label each part.

4. Take the students on a walk and look at other flowers and point out that in many flowers, the parts are not as easy to see. Help your students find an inflorescence, or a structure made up of multiple flowers (any flower in the daisy family is actually an inflorescence). Have your students start to notice the other parts of the plants. Have them notice leaf arrangements (opposite, alternate, and whorled), leaf shapes (lobed, divided, blade-like, heart-shaped, etc.) stems, branches, trunks, etc.

5. Finally, provide each student with a pair of precut butterfly wings and allow them to color them using markers. Once they have their wings colored, provide them with a 'butterfly body' (party blower with a pipe cleaner twisted and taped on). Have them place their wings face down and then tape the ends of the pipe cleaner to each wing. As they unfurl their blower, this becomes their butterfly proboscis and they are now ready to dip and sip. Discuss the interaction of the flowers and the butterfly, and the coevolution of plants and animals. Help students think about how the location of nectar in a flower might affect the morphology of its pollinator. If the nectar is very far down into the flower, what might the pollinator's proboscis look like?

Slow Looking and Botanical Illustration

Big Idea: When you take the time to really look at a plant and illustrate its parts, you better understand how it works and its beauty.

Nature as Art: Slow Looking and Botanical Illustration

Objectives:

After participating in this lesson, students will:

- Learn techniques practiced by botanical illustrators
- Learn how to depict the features of a plant using watercolors
- Understand how to look at an object in different scales (macro/micro)

Background:

Botanical Illustration

In this station, students learn some techniques practiced by botanical illustrators. The field of botanical illustration truly bridges the gap between art and science, as an illustrator possesses the craftsmanship and attention of an artist, as well as the technical accuracy and botanical understanding of a scientist. In this way, botanical illustrators are experts at recording the forms, colors, textures, and shapes of the many plant species that exist on earth. Long before photography, botanical illustrations helped doctors better understand the parts and features of medicinal plants through their illustrations, and for plants destined for herbaria, captured the color and detail that would be lost in the drying of the herbaria samples. Through their art, botanical illustrators are able to bring forth plant details that might otherwise be overlooked, and they can highlight important plant features that would be otherwise indistinguishable in photographs alone. [38] These illustrations become

Figure 14. An example of botanically-illustrated plate _ flowers, fruits, and leaves of the coffee plant (*Coffea arabica*). By Mara Menahan

[38] Buck, J. (2010). A Brief History of Botanical Art. *The Botanical Artist*, *16*(1), 32-32.

change.[48]

History of Botanical Illustration

of greater importance as species go extinct and plant distributions are altered by climate

Humans have depicted animals and plants for millennia. Some of the first detailed botanical art was produced in ancient Egypt. A 15th century BCE stone painted with 275 plants of what is now modern-day Syria is credited as one of the first examp les of botanical illustration. Ancient Greeks utilized botanical illustration to keep track of plants that could be used as medicines. Later, during the 16th-18th centuries, botanical illustration was commonplace as scientists and wealthy European collecto rs employed artists to illustrate the exotic plants that were being brought to and sold in Europe. Some botanists and naturalists were themselves illustrators, and traveled to faraway countries to study and draw plants. Today, descriptions of newly - discovered plant species, are almost always accompanied by an illustration. Illustrations are also regularly found in floras (accounts of all the plants that exist in a specific place) and monographs (studies of one specific taxonomic group). Botanic gardens and museums employ illustrators to produce scientifically accurate portrayals of collections and to produce educational materials for the public. Truly, without botanical illustration, the study and classification of plants would be immensely hindered. [49]

Roth, K. (2019). Botanical illustration: Putting a timely focus on nature. ABC News. Retrieved from https://abcnews.go.com/Entertainment/wireStory/botanical -illustration-putting-timely-focus-nature-65821267

Supplies:

Watercolors
Paint brushes
Cups
Water
Firm watercolor paper
Pencils
Clipboards
String for hanging art
Clothespins for attaching art to string
Dump buckets

[48]

[49] History of Botanical Illustration. (2015). Botanical Artists of Canada. Retrieved from http://www.botanicalartistsofcanada.org/about/history-of-botanical-illustration.aspx

Activity:

1. Provide each student with a pencil, piece of watercolor paper on a clipboard, water colors, a cup of water, and a paintbrush.
2. Let students find a plant they wish to paint. Ask them to remember the **micro** views they have had (stomata, leaf textures/patterns, *Volvox,* filamentous algae) and to think of ways they can capture both the **macro** and **micro**. Perhaps they will want to draw a leaf and in a detailed illustration capture the texture of the stomata of the leaf. They may want to draw an entire plant and treat as micro the stem, leaf, branch, or roots.

Vocabulary:

<u>Macro</u> – large

<u>Micro</u> – small, microscopic

<u>Stomata</u> – Openings in plants (primarily in leaves) that allow for gas exchange – carbon dioxide gas in and oxygen gas out

<u>Texture</u> –The physical characteristics of a surface

Sundials

Big Idea: There is much to learn from nature. Nature is not only beautiful but can be used to help us tell direction and time.

NATURE AS ART : Sundials

Objectives:

After participating in this lesson, students will:

- Understand that from nature we can learn direction - the sun rises in the east and sets in the west
- Learn how to use a compass
- Learn that if you can find the direction North and the sun is strong enough to create shadows, you can tell time
- Understand there is a difference between local solar time and standardized time

Background:

Humans have long-been interested in telling time. Our nomadic ancestors likely measured timescales using the stars and seasons, which also helped them navigate. Later, farmers relied on an understanding of time in order to plant crops at the proper point in the year. The first primitive devices for telling the time of day were simple sticks placed in the ground whose casted shadows indicated how much of the day had elapsed.[39] These simple sticks evolved into the more accurate scientific instrument, the **sundial**. The first archaeological evidence of sundials is from Egypt and dates to 1,500 BCE. That sundial was delineated into different parts of the day. Later, Greek, Roman, and Arab scholars would refine the sundials further. Those sundials were the only means of accurately telling the time of day until the invention of the mechanical clock.

As the Earth spins, light from the sun casts shadows when it encounters objects, and those shadows change depending on the position of the Sun in the sky. The central rod of the sundial, or gnomon, casts a shadow. The direction that the shadow falls indicates the time of day.[40]

- caused by the earth rotating on its axis.
- the passage the time.

[39] A Walk Through Time - Early Clocks. (2004). National Institute of Standards and Technology. Retrieved from https://www.nist.gov/pml/time-and-frequency-division/popular-links/walk-through-time/walk-through-timeearlyclocks

[40] Short history of sundials. (2019). European Association for Astronomy Education. Retrieved from https://www.eaae-astronomy.org/find-a-sundial/short-history-of-sundials

•

1. Gather your materials to ensure you have enough supplies for each student or group of

Supplies:

Paper to cover tables

Plaster

Small plastic plant saucers

Water bucket

Bucket for mixing and stirrers

Beads/rocks/plastic insects

Wooden dowels

Sharpies

Compasses

Area map

Cardboard clock

Talking Points:

The sun can help us tell time! Solar time is measured by the sun crossing the sky and is

The gnomon casts a shadow which changes as the sun moves across the sky, indicating

Local time was part of daily life up until the nineteenth century. The main reason for moving from local time to standard time was to unify railway timetables. Prior to this, differences in time between different places were not very important.

Activities:

2. Ask your students what direction they would walk to get home. Let the students use the compasses to find north. Next, while they hold compasses flat in the palms of their hands, instruct students to walk east, south, and then west. Discuss how a compass

students. If possible, conduct this activity outdoors on a sunny day. If you must be inside, you will need to use a flashlight as your source of light. works.

3. Ask your students what in nature might help them with direction. This might lead to a discussion about the North Star and the rising and setting of the Sun. If not, discuss how the Sun rises in the east and sets in the west.

4. Next, have your students create their own sundials.

5. Provide each student with a plastic plant saucer and have them write their name on the bottom with a Sharpie. Let them select 12 items from the collection of rocks/buttons/insects.

6. While students are selecting their items, mix the concrete according to instructions. Please note safety instructions.

7. Fill each saucer with wet concrete and instruct them to use their objects to mark each hour on a clock. They should identify one more significant object as their 12 o'clock, for this will be their 'north.' Finally, have them place the dowel, their gnomon, in the middle of their clock.

8. With a premade sundial, show your students that if they can find north, they can tell solar time with their sundial. Using a premade cardboard clock, place the sundial in the middle with the selected 12 o'clock object facing north. The shadow of the dowel will represent the hour hand on a clock. Once your students understand this, explain that they can determine minutes by the position of the shadow between two numbers (if in the middle of 1:00 and 2:00, then the time is 1:30, etc.).

9. Remind your students that their sundials are recording local solar time. In order to match the time on their watches or cellphones, two adjustments are required– adjusting for the location of the sundial (longitude correction), and the sun's irregular movement.

Vocabulary:

Cardinal Directions – The four compass points; north, south, east and west

Compass – An instrument used to tell direction, containing a magnetized pointer that shows the direction of magnetic north and the bearings from it

Gnomon (said 'no-min') – The central rod of a sundial that casts a shadow

Local solar time – Time determined by the sun, noon is the time at which the sun is highest in the sky; it is local because it depends on longitude and it differs from standard time that synchronizes time across several longitudes

Standard time - The synchronization of time within a geographic area, as established by government laws or customs

Sundial – A device that shows the time of day by the movement of shadows from the sun

Timepiece – Any instrument used to measure time

Over the previous 12 lessons, students have learned the steps of the scientific process

Plant Forensics

Big Idea: Students, having learned and experienced the steps of the scientific methods, are ready to become forensic botanists. They will use their skills to collect data and work together to solve a case.

(observing, asking questions, hypothesizing, experimenting, and concluding). They have learned how to use a variety of tools that scientists use in the lab and the field, including microscopes, magnifying glasses, thermometers, chemical testing kits, and Brix refractometers. Now students, with their heightened observation skills, knowledge of scientific equipment, and heightened plant awareness, will be called on to apply what they have learned and aid in a plant forensics case. In the following four lessons, students will have the opportunity to be investigators. The young forensic botanists will be assigned kits that contain evidence that potentially incriminates two suspects. Using the observations and data students gather on seeds, soil, pollen, and nectar, they will determine if each suspect is suspicious or innocent. Just like real forensic specialists, they may conclude that they do not have enough information to make a determination based on their collected evidence. Follow the included scripts, try not to break character, and have fun!

Background

Students will learn that an important plant has gone missing. In this scenario, the plant went missing from the collection of a local botanic garden (to find a botanic garden near you go to https://www.publicgardens.org/about-public-gardens/gardens). Adapt the location and type of plant stolen for your site. Be sure to pick a plant that makes flowers and seeds. Fun plants to pick are Venus fly traps and orchids as they are botanically interesting, and available at area stores. Botanic gardens often have very special plants in their collections, some of which are rare, endangered, or even extinct in the wild. Unfortunately, there are people who want to keep and collect rare plants for themselves and will go to great lengths to take them from the wild, or even steal them from public gardens! With your students, discuss why plant collections are important. For the script that follows, we've used a Venus flytrap as the missing plant, but feel free to substitute it with the plant of your choice. (Many of the ideas for this plant forensics case were adapted from *Plants Are Up to Something*, Huntington Library).

Setting the Scene

- Last night, the Garden had a private event after the grounds closed to the public. When the gardeners came in to care for the plants in the morning, they found an important plant missing from the collections! They immediately called the authorities in the hope that with some investigation, the plant could be found and returned to the garden.
- Upon arriving at the scene, detectives observed a hole where the plant should have been, and a trail of soil.
  - When the botanists, gardeners, educators, and mechanics at the garden were interviewed, they told the investigators that the missing plant is very special to their collection. The missing plant is a Venus flytrap (*Dionaea muscipula*), which is endangered in the wild. To this day, the Venus flytrap is poached from its native range – a small area in North Carolina. Venus fly traps have adapted to the nutrient-poor soils of their swampy habitat by evolving the ability to 'eat' insects- trap and consume insects in their specialized leaves!
- Based on all the interviews of persons in attendance at the party, detectives have two possible suspects (Mr. Charlie Palm and Dr. Yvonne Cortez) however, each of the suspects has made a strong case for their innocence and say they would never have taken the plant.
- The local authorities heard that the students have been doing a great deal of work to develop their investigatory and scientific skills. To speed up the investigation they're asking the students to help solve the case.
- Testing evidence and information at four different labs, students will investigate the suspects and determine if their story is truthful or suspicious.

Logistics

Half the students will be investigating suspect Mr. Charlie Palm, while the other half investigates the second suspect, Dr. Yvonne Cortez. Each team will work through four CSI labs. Because we run this program with 50 students, we divide the students in to four groups, with two groups investigating Mr. Charlie Palm, and two teams investigating Dr. Yvonne Cortez.
(More teams, more data!)

As mentioned in the beginning of this manual, these lessons can be used in many different scenarios. If you are a classroom teacher, you might select one CSI lab for each science class. If you are running a summer camp and students are with you for the week, you might pose the missing plant scenario at the start of the week and have students work through a CSI lab each day with a drumroll and evidence analysis on the last day. You could challenge your scout troop to host a CSI program and invite other troops to participate with your scouts run the labs.

Evidence Kit Supplies

4 medium-sized plastic containers with lids that latch (two labeled *Suspect: Mr. Palm*, and two labeled *Suspect: Dr. Cortez*).

1 disposable pipette for each kit

1 magnifying glass for each kit

1 plastic microscope slide for each kit

4 sets of laminated evidence result cards – each set has four cards labeled 'suspicious,' four labeled 'innocent,' and four with question marks. One set for each kit (see Resources)

2 nectar samples (representing nectar from a lily flower) - one for each Suspect: Mr. Palm kit

- These samples are a sugar and water mix to represent the sugar percentage of lily nectar. Using a refractometer, the sugar density reading should be 20 percent (see Nectar and Pollinators Lab)

2 nectar samples (representing nectar from a coneflower) - one for each Suspect: Dr. Cortex kit

- These samples are a sugar and water mix to represent the sugar percentage of coneflower nectar. Using a refractometer, the sugar density reading should be 10 percent (see Nectar and Pollinators Lab)

2 burdock fruit samples (taken from suspect Dr. Cortez) – one for each Suspect: Dr. Cortez kit

2 milkweed fruit samples (taken from suspect Mr. Palm) – one for each Suspect: Mr. Palm kit

2 cups peat-like soil (taken from suspect Mr. Palm's house) – one cup for each Suspect: Mr. Palm kit

2 cups sandy soil like cactus soil (taken from suspect Dr. Cortez's house) – one cup for each Suspect: Dr. Cortez kit

2 Plant Forensic Scripts pertaining to suspect Mr. Palm – one for each Suspect: Mr. Palm kit

2 Plant Forensic Scripts pertaining to suspect Dr. Cortez – one for each Suspect: Dr. Cortez kit

Background

What do we know about the suspects?

SUSPECT ONE: Mr. Charlie Palm

- Charlie has visited the Garden for many years and was identified as having been at the Garden last night. When questioned, Charlie told detectives that he loves plants and would never have taken a plant from the garden.
- Charlie admitted to being at the garden last night.
- Charlie is a dessert chef. Instead of cooking with sugar, he uses honey. He used so much honey that last year he decided to raise bees in his own back yard to have his own honey source and has created a new garden with plants that will provide nectar and pollen for his bees.

Did Charlie Palm take this plant?

SUSPECT TWO: Dr. Yvonne Cortez

- Dr. Cortez is an entomologist (insect scientist) who specializes in butterflies. She admitted to being at the Garden last night.
- She told detectives that she loves to garden in her backyard and tries to grow plants that attract butterflies.
- While interviewing Dr. Cortez, the detectives noticed that she has a beautiful

SUSPECT: CHARLIE PALM

greenhouse and in her greenhouse she grows special kinds of plants called carnivorous (What are carnivorous plants?).

Did Dr. Cortez take the plant from the garden?

Both suspects have been interviewed by detectives. They both admitted to being at the Garden last night. They were informed that a plant, the Venus flytrap, was missing. Evidence was taken from both suspects' properties. Both suspects made statements.

You will need to print the following two scripts and place them in their respective Evidence Kits.

EVIDENCE: SEEDS

During a search of **Mr. Charlie Palm's** car, detectives found seeds in the back seat. When asked about the seeds, Mr. Palm said:

"I often take my dog, Buddy, for walks in the woods. With his curly hair, the seeds probably stuck to his fur and then to the seat when he got in the car."

DIRECTIONS

Most plants produce seeds. It is possible that the seeds in Charlie's car came from the stolen plant. Seeds have special features for traveling so they can grow in new places. Some travel on the fur of animals, while others blow in the wind or float in water.

1. Look at all the different kinds of seeds on the table and try to determine how they travel (wind, animal, gravity, water, etc.)
2. Draw a picture of these seeds and record how they travel (wind, animal, etc.) 3. Next, examine the seed in your Evidence Kit collected from Mr. Palm's car.
4. Do you think this seed travels by air? By animal? Gravity?
5. Use the magnifying glass in your evidence kit to take a closer look.

Do the seeds found in Mr. Charlie Palm's car:

TRAVEL BY ANIMAL? or TRAVEL BY THE WIND ?

Do you think Mr. Palm's story about these seeds being brought to his car by his dog is:

TRUTHFUL or SUSPICIOUS (circle one)

Enter your answer on the result board.

EVIDENCE: SOIL

When the detectives visited **Mr. Palm's** property, they found soil on his front steps. Thinking it might be soil from the missing plant, they took the soil as evidence. Mr. Palm told the detectives:

"My soil is not very good. It is filled with clay and as a result the water does not pass through easily. I purchased some different soils to mix in so that the water would drain better. I just bought the soil this past weekend and the bag ripped as I was carrying it to my garden."

DIRECTIONS

- Take the soil in your evidence kit, which is the soil found on Mr. Palm's steps, and pour it onto a white piece of paper. Using the magnifying glass in your evidence kit, examine the soil sample. Which of the following items appear in the soil sample (circle those items you find):

Rocks Moss Sand Twigs Leaves Perlite (white pieces)

Items like rocks, sand and perlite allow for good drainage – they let water move quickly through the soil. Items like moss, peat, and leaves help keep moisture in the soil, making for a wetter soil. From your visual observations do you think the soil found on Mr. Palm's steps is good for drainage? Let's do a test to find out more:

- Fill one of the measuring cups with exactly one (1) cup water.
- Now, pour the soil from your evidence kit into the measuring cup and stir.
- Take the other measuring cup and place the sieve on top. Now pour the measuring cup with the water and soil through your sieve. Measure how much water passed through.Does the soil hold on to the water or does the water move quickly through the soil?

How much water did you pour in, and how much passed through?

Does the soil found on Mr. Palm's steps drain quickly, like he said it should?

YES or NO

Based on your study of the soil, do you think Mr. Palm's story about having clay soil and needing to buy soil that drains quickly is:

SUSPICIOUS or TRUTHFUL (circle one)

Enter your answer on the result board.

Evidence: Pollen

When the detectives got to the home of Mr. Charlie Palm, they noticed yellow streaks on his jacket. They asked him if he was wearing the jacket last night and if he had washed it since the party. He told detectives that he had worn it last night and that he had not washed it. When asked about the large amount of what appeared to be pollen on his jacket, he told the detectives the following:

"I walked through my garden when I got home from the party and I must have brushed up against some plants and gotten pollen on my jacket. The pollen on my jacket will look nothing like the pollen from the Venus flytrap."

DIRECTIONS

- Flowers produce pollen. Different plants produce pollen of different shapes and sizes.
- We have made a slide with pollen from a Venus flytrap. Look at the slide and describe and sketch what you see.
- List three things to describe the pollen (shape/color/texture).
- Now, take the pollen and microscope slide from your evidence kit and prepare a slide. This is the pollen taken off of Mr. Palm's jacket.
- After viewing the slide with the evidence pollen, describe and sketch what you see.

Does the pollen found on Mr. Palm's jacket match the pollen of the Venus flytrap?

Pollen looks the same or Pollen looks different

Mr. Palm said the pollen taken from his jacket was from his garden and would not match the pollen from the missing plant. Based on your observations do you think Mr. Palm's story is:

SUSPICIOUS or TRUTHFUL (circle one)

Enter your answers on the result board.

EVIDENCE: NECTAR

Mr. Palm is well known for his honey desserts. The investigators think he may have taken the plant to attract honeybees to his garden to support his beehives. When asked about his garden, he told detectives the following:

"The Venus flytrap is of no use to me! It is not a plant that attracts bees. Why would I take it?"

NECTAR SUGAR TESTING DIRECTIONS
Flowers produce nectar. Nectar is sweet and attracts birds and insects—also called pollinators - that transfer pollen. Not all nectar is the same. Different flowers produce nectar with different levels of sugar. Different nectars attract different pollinators.

Measure the percentage of sugar in each of the following nectar samples using a refractometer (see the Photosynthesis lesson Plants Make Their Own Food):

Coneflower___________% sugar

Coneflowers are pollinated by **long-tongue bees and butterflies**.

Daylilies__________% sugar
Daylilies are pollinated by **hummingbirds.**

Next, take the nectar in your evidence kit taken from the Venus fly trap flower and using the refractometer, test the nectar.

Percentage of sugar in the Venus flytrap nectar ________________%

Compare the sugar content to the above plants. Given that pollinators visit certain flowers with a similar sugar content, what might the missing plant's likely pollinator be?

Pollinator: ____________________________

Would this nectar sugar content attract bees? Compare to your other tests and look for the pollinator.

Attracts Bees or Would Not Attract Bees

Mr. Palm said that the missing plant would not be good in his garden and that it does not attract bees. Do you think his statement is:

SUSPICIOUS or TRUTHFUL (circle one) Do not forget to put your answer on the result board.

said:

SUSPECT: DR. YVONNE CORTEZ

VIDENCE: SEED

While speaking with Dr. Cortez, detectives found plant material on her socks. Detectives thought hey could be seeds from the missing plant. When asked about the seeds, Dr. Cortez

went out in the fields around my house looking for wildflowers and those seeds must have stuck o my socks as I traveled through the tall grasses."

IRECTIONS

Most plants produce seeds. It is possible that the seeds on Dr. Cortez's socks came from the tolen plant, the Venus flytrap? Seeds have special features for traveling so they can grow in new laces. Some travel on the fur of animals, while others blow in the wind or float in water.

1. Look at all the different kinds of seeds on the table and try to determine how they travel (wind, animal, gravity, water etc.)
2. Draw a picture of these seeds and record how they travel (wind, animal, etc.) 3. Next, examine the seed in your evidence kit collected from Dr. Cortez's socks.
4. Do you think this seed travels by air? By animal? Gravity?
5. Using the magnifying glass in your evidence kit to take a closer look.

o the seeds found on Dr. Cortez's socks:

TRAVEL BY ANIMAL or TRAVEL BY THE WIND

(circle one)

ased on what you observed, do you think Dr. Cortez's story about getting seeds on her socks while collecting wildflowers is:

TRUTHFUL or SUSPICIOUS (circle one)

nter your answer on the result board

EVIDENCE: NECTAR

Dr. Cortez is well known for her butterflies. The detectives wonder if Dr. Cortez took the Venus flytrap to attract more butterflies to her garden and when on her property, they noticed she collects carnivorous plants.

When asked about her garden, Dr. Cortez said the Venus flytrap would not be a good addition to her garden because it does not attract butterflies.

DIRECTIONS
Measure the sugar content of each of the following nectar samples using a refractometer (see the Photosynthesis lesson Plants Make Their Own Food):

Coneflower___________% sugar

Coneflowers are pollinated by **long-tongue bees and butterflies**.

Daylilies__________% sugar

Daylilies are pollinated by **hummingbirds.**

Next, take the nectar in your evidence kit taken from the flowers of a Venus flytrap and using the refractometer, measure the percentage of sugar in the nectar.

Sugar content of the missing plant's nectar: ________________% sugar

Compare the sugar content of the evidence to the above plants, coneflower and lilies. Given that pollinators visit certain flowers with a similar sugar content, what is the missing plant's likely pollinator?

Pollinator: _____________________________

Would the sugar content in the nectar collected as evidence attract butterflies?

Would Attract Butterflies or Would Not Attract Butterflies
(circle one)

Based on your tests, does Dr. Cortez's story about the stolen plant not being attractive to butterflies seem:

SUSPICIOUS or TRUTHFUL (circle one) **Enter your answer on the result board.**

EVIDENCE: SOIL

When the detectives visited Dr. Cortez's house, they found soil in trays on her front steps. When asked about the soil, Dr. Cortez told the detectives the following:

> *"I grow many carnivorous plants that require soil that can stay very moist. I have pots of this kind of soil everywhere."*

The detectives took some of the soil as possible evidence.

DIRECTIONS

- Take the soil in your evidence kit, the soil found at Dr. Cortez's house, and pour it onto a white piece of paper. Using the magnifying glass in your evidence kit, examine the soil sample. Which of the following items appear in the your soil sample (circle those items you find):

Rocks Moss Sand Twigs Leaves Perlite (white pieces)

Items like rocks, sand and perlite allow for good drainage – they let water move quickly through the soil.

Items like moss, peat, and leaves help keep moisture in the soil, making for a wetter soil.

From your visual observations do you think the soil found on Dr. Cortez's steps is good for drainage? Let's do a test to find out more:

- Fill one of the measuring cups with exactly (1) cup water.
- Now, pour the soil from your evidence kit into the measuring cup and stir.
- Take the other measuring cup and place the sieve on top. Now pour the measuring cup with the water and soil through your sieve. Measure how much water passed through. Does the soil hold on to the water or does the water move quickly through the soil?
- How much water did you pour in, and how much passed through?

Does the evidence soil hold onto the water?

YES NO
(circle one)

Based on your test, do you think Dr. Cortez's story about keeping soil that can stay moist is:

SUSPICIOUS or TRUTHFUL
(circle one) Enter your answer on the result board.

EVIDENCE: POLLEN

Dr. Cortez told the detectives that she carries her backpack wherever she goes, including to the party last night. Detectives collected a large amount of pollen off of her backpack and when asked about it, she told them the following:

> *"I am always out looking for new plants and I am not surprised you found pollen on my backpack. However, the pollen you found on my backpack will not match the pollen from the Venus flytrap.*

DIRECTIONS

Flowers produce pollen. Different plants produce pollen of different shapes and sizes.

Detectives have produced a slide of the pollen from the missing plant. Look at the slide and describe and sketch what you see.

- List three things to describe the pollen and sketch the pollen you see in the slide in your journal.

Now take the microscope slide and pollen from your Evidence Kit, and prepare a slide with the pollen taken off of Dr. Cortez's backpack. Look at it under the microscope.

After viewing the slide, describe and sketch what you see.

Does the pollen found on Dr. Cortez's backpack match the pollen of the missing plant?

Both Pollens Match or Pollens Are Different
(circle one)

Dr. Cortez said she was not surprised she had pollen on her backpack as she is always around flowers, but that she is certain it would not match the pollen from the Venus flytrap. Do you think her story is:

SUSPICIOUS or TRUTHFUL (circle one)

Enter your answer on the result board.

How Seeds Travel Lab

Big Idea: Plants have many strategies for seed dispersal, and seeds are of many shapes and sizes.

How Seeds Travel Lab

Objectives:

After participating in this lesson, students will:

- Understand that there are many kinds of seeds, with the double coconut being the largest seed. Orchids (e.g., vanilla bean plants) have some of the world's smallest seeds
- Learn that most plants reproduce by seeds
- Learn that seeds travel in many ways (via wind, animals, water, and gravity), and that their structure aids in this dispersal

Background:

Seed Dispersal

Plants have evolved a variety of methods for dispersing **seeds**, and the structure of a seed can say much about how it is dispersed. Hook and loop fasteners, like Velcro, were originally inspired by the structure of burdock fruits. These fruits have long hooks that can attach to fur and clothing. Hairy beggarticks (*Bidens pilosa*), cocklebur (*Xanthium strumarium*) (Fig. 15), and many other plants are also infamous for their fruits' or seeds' abilities to stick to passers-by.[41]

Figure 15. The burs of the cocklebur (*Xanthium strumarium)*

Animals disperse fruits and the seeds they contain in many ways. Some plants, like the ones just described, stick to animals' fur or feathers, hitching a free ride over great distances. Other seeds are dispersed after passing through the guts of animals who eat the fruits the seeds are

[41] Voyle, G. (2012). The weedy-seedy plants of fall. Michigan State University Extension. Retrieved from https://www.canr.msu.edu/news/the_weedy-seedy_plants_of_fall

within. Most people are familiar with birds eating berries and other fruits from trees and shrubs, but other animals like rodents, deer, foxes, and bats also consume fruits and disperse seeds. The **seed coat** is an inner layer of the fruit called the endocarp (think of a peach or cherry pit) that protects the seeds as they pass through an animal's digestive system. Coming out the other side, the seeds are provided fertilizer in the form of poop, which

helps them grow! Another example of animal seed dispersal is seen with squirrels. Squirrels bury hundreds of acorns from oak trees each fall. While they eat some of them, squirrels also forget where they placed many of the acorns. The buried acorns will likely later germinate, thanks to the forgetfulness of squirrels. Ask students what the seeds within the acorns will grow into.

Seeds can also be dispersed by wind and water. Consider the winged structure of maple fruits, which fall to the ground like helicopters. This unique fruit is called a samara (Fig. 16) and can carry the two maple seeds inside it more than a mile away from the parent tree. Water can take seeds around the world! For example, coconuts can travel thousands of miles by ocean, before washing up on a beach and germinating (Fig. 17).[42]

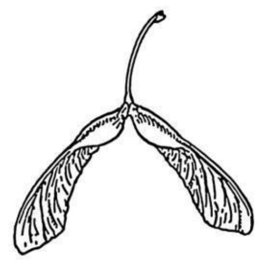


Figure 16. The winged fruit (samara) of a maple tree

Figure 17. Illustration of a coconut (drupe) showing the green outer layer (exocarp), brown husk (mesocarp), and dark brown shell (endocarp) that surrounds the seed.

Another means of seed dispersal is propulsion: some plant species are able to throw their seeds into the air with tremendous force! The capsules (a type of dry fruit) of the sandbox tree (*Hura crepitans*) can disperse their seeds hundreds of feet![43]

As you look at the seed examples in this station, consider how each seed might be dispersed in nature. Why is seed dispersal important, especially in terms of plant competition? Would a seed that falls directly below its parent be more or less likely to get sunlight than if it were dispersed further away? How might dispersing seeds far from the parent affect pollination? Plants cross pollinate to increase genetic diversity. Populations with more diversity can better withstand disturbances and disease because they can adapt more quickly (see the lesson Water: Under the Microscope).

[42] Chapter 14: Seeds and Fruits. [PDF]. (n.d.). University of California, Davis. Retrieved from http://wwwplb.ucdavis.edu/courses/bis/1c/text/Chapter14nf.pdf

[43] Stewart, M. (2017). National Geographic Kids Educator's Guide: A Seed is the Start [PDF]. (n.d.). National Geographic Partners. Retrieved from https://www.nationalgeographic.com/content/dam/books/pdfs/Seed-Is- Start-Ed-Guide.pdf

Supplies:

Variety of seeds

Magnifying boxes

Magnifying glasses

Ferns

Phylogenetic tree

Bucket with water

Oversized results board

Talking Points:

- Most plant species produce seeds, including angiosperms (the flowering plants) and gymnosperms (conifers, cycads, etc.). But, not all plants produce seeds. Mosses, ferns, and green algae are examples of plants that do not produce seeds.
- Seeds come in a variety of shapes and sizes. The physical characteristics of a seed determine how it travels. Most mature plants cannot move great distances on their own, but the seeds they produce often can! Seeds rely on animals, wind, and water to be dispersed. Why would it be beneficial for a plant to disperse its seeds over great distances?
- Inside a seed is the embryo, which eventually develops into a seedling. The embryo has access to **endosperm**, which is a food source for the developing plant inside the seed (see the lesson Nature as Art: Plant Morphology). Surrounding the embryo and endosperm is the seed coat, which protects the embryo from damage and desiccation (drying out).
- When a seed sprouts, the seedling's embryonic leaves, called cotyledons, unfurl. These are the first leaves that you see when a seed germinates. The number of cotyledons a seedling has was traditionally used to classify flowering plants into two groups. Species with one cotyledon are called **monocots**. Grasses like wheat, rice, and corn, as well as lilies,

arums, palms, and orchids are all examples of monocots. Species with two cotyledons are **dicots**. A few examples of dicots are beans, sunflowers, blueberries, oaks, and maples. More recently, DNA evidence has revealed that dicots are an artificial assemblage of plants, meaning that this group is made up of many unrelated lineages and is not reflective of evolutionary relationships.

- Humans rely on seeds of many plant species for food. Brainstorm some examples of plants whose seeds we eat. Note: remember not all seeds are edible.

Activities:

- Set up your station to display a wide variety of seeds. Place out the magnifying glasses and boxes and let the students freely explore.
- As they are exploring the various seeds, ask them how they think each seed travels – do they fall, do they float, fly, travel by animal, etc.?
- Once they have had a few moments to explore the idea of seeds and travel, turn to the task at hand – the Evidence Kit.
- Take out the script and see if any student would like to read. If a student reads, reread the section if needed to add emphasis and to ensure everyone at your station can hear. Follow the instructions on how to examine the evidence in the Evidence Kit.
- Once your students have examined the evidence and made a determination (suspicious or truthful or?), have them take the corresponding conclusion and place it on the shared results board.

Vocabulary:

Dicots – A shortened name (from dicotyledon) for the artificial assemblage of plants that typically have two seed leaves (cotyledons), flower parts in multiples of four or five, and netveined leaves

Embryo – Immature plant in a seed

Endosperm – An embryo's temporary food supply in the seed

Monocots – A shortened name (from monocotyledon) for the lineage of plants that usually have one seed leaf (cotyledon), flower parts in multiples of threes, and parallel-veined leaves

Seed – The sexual reproductive structure in which the embryo is housed

Seed Coat – Layer of thin tissue covering a seed

Soil Testing Lab

Big Idea: Soil, of which there are many kinds, is the immediate surface of the earth that serves as a natural medium for the growth of land plants. Soil is alive with plant, animal, and bacterial life.

Soil Testing Lab

Objectives:

After participating in this lesson, students will:

- Understand that soil is not totally abiotic (non-living). Soil contains a number of living and once living things, including insects and other animals, microorganisms like bacteria, and decomposing animals and plants.

- Learn that soil is made up of decomposing matter, living organisms, minerals (plant nutrients), and rocks.

- Understand there are many types of soils.

Background:

Soil

It is often said that plants require soil to grow, but this is not necessarily true. The nutrients and water held within soil are what are required for plant survival and growth. In fact, there are many plant species that do not send roots into the soil at all, but obtain water and nutrients from other sources. Some examples include epiphytes, which are plants that live on the surface of other plants, and lithophytes, which are plants that grow on rock.

Plants that grow in soil are called terrestrial plants. Depending on its texture and structure, soil can hold many of the essential nutrients that plants need to survive and grow, including nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium.[55] These nutrients are taken up by roots and used in a variety of plant processes. Nutrient retention is strongly dependent on the structural characteristics of the soil. For example, sandy soils, which are made up of relatively large particles, have equally large gaps between the grains. Water can easily wash nutrients out of these soils. On the other end of the spectrum, clay soils have extremely small particles which are negatively charged and attract ions of several nutrients that plants need. Clay, however, can become brittle and hard when dry, or it can become water-logged, preventing plant roots from acquiring oxygen. Silt soil particles are intermediate in size between sand and clay. Though plant species in nature may be adapted to specific soil types, many plants thrive in soils that are mixes of sand, silt, and clay.[44] A soil composed of an equal mix of sand, silt, and clay is called loam.

[55] Plant nutrients in the soil. (1992). New South Wales Government Department of Primary Industries. Retrieved from https://www.dpi.nsw.gov.au/agriculture/soils/improvement/plant-nutrients

[44] Needelman, B. A. (2013) What Are Soils? *Nature Education Knowledge* 4(3):2

So, how do nutrients get into soil? As organisms die and as plant material falls to the ground, bacteria and fungi in soil feed on that organic matter and recycle nutrients back into the soil. These bacteria and fungi are called **decomposers**. Students will make a connection with worms. Most students will relate the word **organic** to the food industry, but in biology and chemistry, "organic" means containing carbon. All living things are organic beings, and without **decomposers** to break them down, it would be extremely difficult for plants to acquire the nutrients they require to survive!

Vocabulary:

Decomposer - An organism, especially a soil bacterium, fungus, or invertebrate that breaks down organic material

Microorganisms – Organisms living in the soil that you cannot see with the naked eye

Organic Matter – Material in the soil that was once living plants or animals

Soil Erosion – The loss or removal of topsoil

Soil Texture – The relative amounts of sand, silt, and/or clay in a soil

Supplies:

Bucket of water

Bucket for dumping

Laminated soil mapping sheets

Soil sieves

Magnifying glasses

Peat Moss

Compost with worms

Measuring cups

Top soil

Oversized result board

Soil is made up of particles that vary in size, including sand, silt, and clay.

Five to 10 tons of animal life can live in an acre of soil (one acre is roughly the size of one and a third football fields). A single pinch of garden soil can contain *millions* of living things. Ask students to think about what kinds organisms might live in soil. Earthworms act as **decomposers**, helping to eat organic matter and recycle nutrients back into the soil.

57

Plants can sometimes adapt to live in poor soils that might not necessarily contain the nutrients they need to survive – an example is the Venus flytrap, which gets many nutrients from

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What On Earth Is Soil Fact Sheet. [PDF]. (2003). United States Department of Agriculture Natural Resources

Talking Points:

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- Plant roots help hold soil together and help prevent the **erosion** of soil.
-
- Over 70,000 kinds of soil have been identified in the United States.

consuming insects.

57

Conservation Service. Retrieved from
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_002430.pdf

Activity:

1. Prepare for your lesson. Place piles of compost on a table with magnifying glasses.

2. Welcome students and if coming from another station, ask them which suspect they have been asked to investigate, and what they are finding so far.

3. Next, let students explore the compost you have placed on the table. Soil is alive! Using compost ensures a diversity of organisms. Provide each student with pre-made laminated soil mapping paper and have them find items for each category (alive, once alive, never alive).

4. Next, turn your attention to the Evidence Kit. Have a student or two read the soil testing section of the script aloud.

5. Follow the directions in the script in the Evidence Kit.

6. After students place their evidence card on the results board, have them place the script back in the Evidence Kit and prepare for the next group of students.

Pollen Lab

Big Idea: In order for plants to reproduce sexually, they must be pollinated. Pollination is the transfer of pollen by pollinators, wind, or other means.

Pollen Lab

Objectives:

After participating in this lesson, students will:

- Understand that many plants have pollen and that the transfer of pollen to another flower is called pollination.
- Learn that pollination allows plants to bear offspring because the movement of pollen leads to the fertilization of egg cells and the development of seeds.
- Pollen comes in many different shapes and sizes.

Background:

In order for plants to sexually reproduce and set seed, **pollination** must occur. There are a number of ways that **pollen** from one flower can reach another flower to achieve pollination. In fact, there is an entire field of biology dedicated to this subject: pollination biology! Plants cannot move around much on the ground to pollinate each other. For this reason, many plant species are reliant on wind and, especially, on animals. In fact, approximately 90% of all flowering plants are pollinated by animals![45] Pollination by vertebrates like birds, bats, rodents, and other animals is called zoophily. Pollination by insects, which are invertebrates or animals without backbones, is called entomophily. Insects and plants have interacted with each other for millions of years, and they are often dependent upon one another. For this reason, they can influence the evolution of each other, a process called coevolution. Insects do not intentionally pollinate plants, but are interested in the nectar or pollen rewards that plants provide.[46] Students might brainstorm some ways in which plants attract insects and other **pollinators**. Color, odor, shape (for example landing platforms), and even floral mimicry of female insects are some examples. What are the rewards that pollinators obtain from pollinating? What is the ultimate benefit to the plant?

When two organisms benefit from each other, we say their relationship is **mutualistic**. But, there are some interesting exceptions to the way we think pollination normally occurs. For example, some flowers produce bright colors to attract insects for pollination but offer no nectar reward. Some animals can steal nectar without coating themselves in pollen. For example, flower piercers are a group of birds in the Andes that pierce the perianth (petals/sepals) of flowers that might otherwise be too long to obtain nectar from. Some bee

[45] Ollerton, J., Winfree, R., & Tarrant, S. (2011). How many flowering plants are pollinated by animals?. *Oikos*, *120*(3), 321-326. https://doi.org/10.1111/j.1600-0706.2010.18644.x

[46] Taylor, E. L., Taylor, T. N., & Krings, M. (2009). *Paleobotany: the biology and evolution of fossil plants*. Academic Press. 999-1025. https://doi.org/10.1016/B978-0-12-373972-8.00023-1

species have a similar behavior, effectively 'stealing' the nectar from the side of the flower without interacting with the reproductive organs of the flower. These are examples of nectar robbing, a process not conducive to pollination![47]

In some species, an individual plant may pollinate itself! This is **self-pollination**. When one plant pollinates another, it is called **cross-pollination**. Generally, pollination occurs within a species; for example, dandelions pollinate other dandelions.[48] But some plant groups are capable of interspecies pollination! This is called hybridization, and is common among lilies and oaks, for instance.[49] Clearly, the ways in which plants reproduce are many and varied.

There are a few plants in nature that are no longer pollinated by their associated pollinators and are self-incompatible – an example of this is cabbage on a stick (*Brighamia insignis*), a critically endangered plant native to Hawaii. It was originally pollinated by a hawk moth that went extinct, and now the species is only able to reproduce if hand-pollinated by humans.[50] **Vocabulary:**

Cross Pollination – The pollination of a flower from pollen that comes from the flower of another individual

Fertilization – The uniting of sperm and egg cells to form an embryo

Flowering Plant – A plant that produces flowers and fruit

Mutualism – When two organisms exist together such that their actions or physiology benefit each other

Non-Flowering Plant – A plant that does not produce flowers and fruit

Pollen – Small, powdery, and generally yellow grains that contain the male gametes that fertilize the eggs in the ovules of flowers

reproductive organs

butterflies

a plant can self-pollinate, it is self-compatible **Supplies:**

[47] Nepi, M., Grasso, D. A., & Mancuso, S. (2018). Nectar in plant–insect mutualistic relationships: from food reward to partner manipulation. *Frontiers in plant science*, *9*, 1063.

[48] Proctor, M., Martin, K., & Phelps, D. (2020). Pollination. University of California – Marin Master Gardeners. Retrieved from http://marinmg.ucanr.edu/Our_Projects/Leaflet/Pollination/

[49] Moran, E. V., Willis, J., & Clark, J. S. (2012). Genetic evidence for hybridization in red oaks (Quercus sect. Lobatae, Fagaceae). *American Journal of Botany*, *99*(1), 92-100. https://doi.org/10.3732/ajb.1100023

[50] Cabbage on a stick. (n.d.). United States Botanic Garden. Retrieved from https://usbg.gov/plants/cabbage-stick-0

Microscopes

Slides

Pollen from missing plant

Flowers, or models

Pollination – Transfer of pollen from male reproductive organs to the stigma of female

Pollinators – Organisms that transfer pollen; e.g., birds, bats, and insects like bees and

Self-pollination – The pollination of a flower from pollen that originates from that same plant. If

Pollination happens when pollen from a stamen (male reproductive part) reaches the stigma of a pistil (female reproductive part). Fertilization happens when sperm cells from the pollen grain join with the eggs in the ovule.

Most plants reproduce by seeds and rely on pollination for seed production, so it is a crucial aspect of the plant life cycle. Note that sometimes plants produce seedless fruits without pollination and this is called parthenocarpy.

Pollination of flowers is regularly carried out by insects, birds, and mammals. Pollen sticks to these animals as they move from flower to flower, usually in search of nectar.

Bees are responsible for more pollination than any other pollinators. Ask students to consider what other animals are common pollinators (think about what kinds of insects, birds, and mammals might be important).

Oversized result board

Talking Points:

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- When fertilization is successful, seeds begin to grow and develop.

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-

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- The plant cabbage on a stick (*Brighamia insignis*) is an example of how important pollinators are to a plant's survival.

Activity:

1. Welcome students and ask them which suspect they have been asked to investigate. If coming from another station, ask them what they are finding so far.

2. Next, ask them to tell you the different parts of the flower (they have dissected flowers as part of the Nature as Art lesson). You are working to hear the word "pollen." Talk a little bit about pollen and why a flower has pollen.

3. Turn your attention next to the Evidence Kit. Have a student or two read the pollen section. Follow the directions in the script.

4. After students place their evidence card on the results board, have them place the script back in the Evidence Kit and prepare your station for the next group of students.

Nectar and Pollinators Lab

Big Idea: Pollinators are lured to flowers by a number of things, one being nectar. Different flowers have different nectar types and quantities.

Nectar and Pollinators Lab Objectives:

After participating in this lesson, students will:

- Understand that nectar is made in flowering plants and attracts pollinators.
- Learn that nectar is an important part of the diet of insects and other animals.
- Understand and test that different nectar attracts different pollinators.

Background:

Many of Earth's flowering plants rely on animals for pollination (see CSI: Pollen Under the Microscope). The interactions between animals and plants are often influenced by **nectar**, the sweet sugar made up of **sucrose, glucose,** and **fructose**. The nectar produced in flowers is a reward for the animals that aid in pollination. This nectar comes from structures called floral **nectaries**, which often lie at the bottom of the flower – this means that animals usually first pass the stamens (coating themselves in pollen) or the pistil (delivering the pollen) on their way to acquiring the nectar. The type and amount of nectar produced by a species relates to the kind of visitor that pollinates it.[51] For example, flowers pollinated by hawk moths generally produce a lot of nectar, but with a small concentration of sugar. Flowers pollinated by bees tend to make less nectar, but that nectar has a high sugar concentration. Hummingbirdpollinated flowers fall somewhere in-between in terms of quantity and sweetness. These pollinators rely on nectar for food.[52]

Not all nectaries are found in flowers. Extrafloral nectaries occur outside of flowers on, for example, leaves and stems. These nectaries are not involved in pollination, but are used by insect mutualists. For example, *Pseudomyrmex* ants are attracted to the extrafloral nectaries of the bullhorn acacia (*Vachellia cornigera*) and rely on the nectar within. In return, the ants provide defense for the plant against herbivores and neighboring plants.[53]

[51] Tiedge, K., & Lohaus, G. (2017). Nectar sugars and amino acids in day-and night-flowering Nicotiana species are more strongly shaped by pollinators' preferences than organic acids and inorganic ions. *PloS one*, *12*(5). doi: 10.1371/journal.pone.0176865

[52] Josens, R. B., & Farina, W. M. (2001). Nectar feeding by the hovering hawk moth Macroglossum stellatarum: intake rate as a function of viscosity and concentration of sucrose solutions. *Journal of Comparative Physiology A*, *187*(8), 661-665. DOI: 10.1007/s00359-001-0238-x

[53] Bentley, B. L. (1977). Extrafloral nectaries and protection by pugnacious bodyguards. *Annual Review of Ecology and Systematics*, *8*(1), 407-427.

Vocabulary:

<u>Fructose/Glucose/Sucrose</u> – Different types of sugars in nectar

<u>Nectar</u> – Sweet liquid made by flowering plants

<u>Nectaries</u> – Special glands in plants that produce nectar

<u>Refractometer</u> – A device used to measure the amount of sugar in a liquid

Supplies:

Refractometers

Pipettes

Nectar sample from coneflower

Nectar sample from lily

Tissue

Coneflowers and lilies

Oversized result board

Preparation of Nectar Samples

- Prepare container of sugar and water mix to represent the sugar percentage of coneflower nectar. Using a refractometer, the sugar density reading should be

- Prepare container of sugar and water mix to represent the sugar percentage of lily nectar. Using a refractometer, the sugar density reading should be 20

Talking Points:

- Nectar is a sweet liquid that is made in nectaries of flowering plants, primarily in

- Nectar is an important part of the diets of many insects and other animals.

- Honeybees are important collectors of nectar.

10 percent.

percent. flowers.

- Nectar is the raw material used by honey bees to produce honey.
- Nectar is made of the sugars glucose, fructose, and sucrose, as well as a variety of salts, proteins, and acids.
- Sugar content of nectar varies from 3 to 80 percent.

Nectar, while mostly found in flowers, can also sometimes be found outside the flowers in extra-floral nectaries. Nectar is found on the traps (modified leaves) of the Venus flytrap.

Activity:

1. Welcome students and ask them which suspect they have been asked to investigate. If coming from another station, ask them what they are finding so far.
2. Ask students why insects seek out flowers and what they are interested in finding. Explain that like them, each flower is different and that each flower has a different amount of nectar and some nectars are sweeter than others.
3. Turn your attention to the Evidence Kit.
4. If there are students comfortable with reading, have them read the nectar section and then have all students follow the instructions for testing nectar.
5. Make sure students record their findings and return the script to the Evidence Kit.

Helpful Resources

- The United States Geological Survey has excellent information related to the abiotic environment. Their Water Science School is particularly helpful to understand the science in the Water lessons.
- State university extension systems are excellent resources, especially for information on a particular area (i.e. native plants and animals, local watersheds, etc). Additionally, extension agents are usually happy to help you find the information you need and can be resources themselves.
- The United States Environmental Protection Agency's site on Environmental Topics has links to information on water quality, waste in waterways, and scientific methods.
- The United States Forest Service and U.S. Department of Agriculture have useful information on pollinators and native plants
- The Smithsonian Science Education Center's site is full of science content as well as resources for educators.

- Museums, universities, public gardens, and herbariums are all excellent resources. Of particular note for botany and science information are:

  ○ The Royal Botanic Gardens, Kew ○ The Missouri Botanical Garden

  ○ The U.S. Herbarium at Smithsonian's Museum of Natural History ○

  The Duke Herbarium ○ The University of California Museum of

  Paleontology

  - Understanding Evolution

Printable Resources

The following charts and diagrams should be printed for use by students during the corresponding lessons.

- Fillable water temperature chart
- Thermometer with Fahrenheit/Celsius for enlarging
- Chart for filling in DO levels
- Chart for filling in pH levels
- pH scale for poster
- Microscope diagram with parts for enlarging
- Phylogenetic tree for enlarging
- Stoma image for enlarging
- Photosynthesis drawing for enlarging
- Flower parts diagram for enlarging
- Lima bean parts diagram for enlarging
- Soil mapping sheet
- CSI results boards for enlarging
- CSI Evidence Cards

Sample

From Water: Observation and Temperature Temperature Chart:

Name of Tester	Location Sampled	Water Temperature	Weather Conditions at Time of Testing

Temperature Chart:

Name of Tester	Location Sampled	Water Temperature	Weather Conditions at Time of Testing

From Water: Testing for Dissolved Oxygen (DO) and pH

Testing for pH and Dissolved Oxygen

Substance	pH level
Tap Water	
Milk of Magnesia	
Orange Juice	
Aquatic System Water	

DO Collection Sheet

Name of Tester	DO level