LESSON 1

Light Illuminations

TIME

Groundwork: 30 minutes

Exploration: 4+ weeks

Making Connections: 60 minutes

MATERIALS

- GrowLab
- Fluorescent bulbs (cool-white, warm-white, and full-spectrum)
- Potting soil
- Pots
- Seeds (beans, lettuce, and herbs)
- Light meter
- Ruler
- Copies of student worksheets (pp. 9–11)

Overview

Students learn why light is important to plants, and how the quality and quantity of light affect plant growth.

Background

Light is among plants' most critical needs. Plants capture light energy for use during photosynthesis, the process by which they make food. Without light, plants starve and die.

Plants get light energy from two sources: the sun and artificial lighting. Plants grown on a space vehicle or the International Space Station rely on artificial light for survival. However, on both the moon and Mars, plants could derive some light energy from the sun. Mars has a regular day-night cycle similar to Earth's (about a 25-hour day), so plants there could receive energy exclusively from the sun. The moon experiences a 14-Earth-day span of daylight followed by a 14-Earth-day span of darkness, so plants would need artificial light during the two-week lunar night.

Artificial light requires energy, and because energy is limited in space, lights must be as efficient as possible. To optimize resources, astronauts need lights that use the least energy while providing adequate conditions for healthy growth. When analyzing light to determine efficiency and impact on plant growth, scientists must determine the quality and quantity of light available.

Light Quality

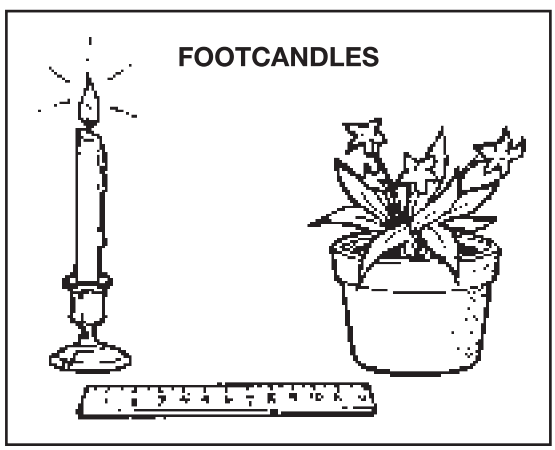
Light energy radiates from a source in waves of different lengths and frequencies. Some of these waves aren't visible to humans; those we can see are perceived as different colors. Visible light with the longest wavelength and lowest frequency is seen as red, and that with the shortest wavelength and highest frequency is seen as violet. Orange, yellow, green, and blue fall in between. When all visible wavelengths are combined, light appears white or colorless, like sunlight. However, when you separate visible wavelengths, as with a prism, you can see all the colors in the spectrum.

Light is either reflected or absorbed by objects. When you look at an object, the color you see is actually the color of light waves that the object reflects. If the object is white, it's reflecting all the waves and absorbing none; if it's black, it's reflecting none of the waves and absorbing them all. Thus, plants appear green because they reflect green light waves and absorb all the others.

Therefore, the most efficient lighting in space should mainly provide the wavelengths plants can use: the reds, which are important for photosynthesis; and blues, which direct plants' growth towards light (phototropism). A mix of 90 percent red light waves and 10 percent blue light waves would provide adequate light for healthy plant growth, but if the lights only radiate red and blue waves, the plants will appear purple! Adding some green light waves gives plants a familiar appearance, which helps astronauts accurately assess plant health; it also provides them with a familiar sight and a source of comfort.

Light Quantity

Light quantity is determined by intensity and duration. Light intensity is the measured amount of light hitting an object. This varies with the type of light (longer wavelengths produce less energy) and the distance between the light and an object. The closer the light is to an object, the higher the intensity. Light intensity is measured in terms of footcandles. One footcandle is the amount of light produced in a totally dark space by one candle shining on a 1-square-foot white surface, positioned 1 foot away from the candle.



To provide some perspective, the average amount of light in an office is 500 footcandles, whereas the light outside at noon on a sunny day may be as bright as 10,000 footcandles. Although the duration and intensity of sunlight far exceed the capacity of indoor lighting, many flowers, vegetables, and herbs can grow well with the 1,000 to 1,500 footcandles of light provided by GrowLabs.

Light Duration

Light duration is just as important as light intensity. Outdoors, common garden plants need an average of 6 to 8 hours of sunlight per day, but since light in a GrowLab is less intense, plants need 14 to 16 hours of light per day.

Light duration is hard to control in outdoor gardens, but with a GrowLab you can provide consistent light by turning the lights on and off at regular intervals, either by hand or with a timer.

Do not leave GrowLab lights on 24 hours a day — more light doesn't make plants produce more abundantly. Most plants require a daily period of darkness to complete respiration — the process whereby plants convert the products of photosynthesis into usable energy.

Laying the Groundwork

As a class, come up with a list of plant needs. Guide the discussion if necessary to be sure that light is on the list. *Do plants in space have the same needs as plants on Earth?* Explain that the experiments in this lesson focus on light, which plants use to make food through photosynthesis. *Where do plants get light on Earth? How do they get light on a spacecraft or the International Space Station? What about on the moon or Mars?*

Define light quality and explain how different wavelengths of light are either absorbed or reflected, thus determining the color of the objects we see. To demonstrate this for students, bring in a flashlight and pieces of red, green, and blue cellophane. Cover the flashlight head with one piece of cellophane at a time, and then, in a dark room, shine the flashlight on a plant (or another object of one color, such as an apple). *What color does the plant appear when each color of light shines on it? In each case what type of light is reflected and what is absorbed? What is the most important wavelength of light for plants?*

Next, define light quantity as intensity and duration. To demonstrate light intensity, take a tour of the school grounds and ask students to compare the light in several different locations. *Where did you find the strongest light? What places had the weakest light?* Use a light meter (that measures in footcandles) to gather hard data for these observations. To demonstrate light duration, monitor and record the length of time (hours and minutes) that light reaches several other locations, both inside and outside.

Exploration

Light Quality

A variety of fluorescent bulbs, emitting different wavelengths of light, will fit in a GrowLab. **Cool-white** bulbs emit wavelengths primarily from the blue/violent end of the spectrum. **Warm-white** bulbs emit wavelengths primarily from the red end of the spectrum. **Wide-spectrum** and **full-spectrum** bulbs emit wavelengths from all the colors of the spectrum — the closest that fluorescent lights come to mimicking actual sunlight.

1. Explore the differences among various bulbs. Buy enough of each bulb to dedicate an entire GrowLab shelf to a single type. If you have more than three shelves, try combinations of the bulbs as a variable. Make sure all the lights are positioned the same distance from the plant trays. (If you wish, keep your store receipts and include a bulb cost comparison in your analysis.)

2. Plant seeds in trays or pots and place them in the GrowLab. You are testing the effect of light quality on plants, so limit the number of variables that affect your data: Use the same size containers with the same number of seeds per container, place the containers in exactly the same location under the lights, and keep all the lights on for the same length of time each day. Although you can experiment with any type of seed, lettuce, beans, and herbs are easy to grow and are plants currently being grown in space.

3. Track the growth of your plants. Each student or group will need a copy of the Light Quality Experiment worksheet (p. 9) for each type of bulb tested. When you've collected all the data, compare and discuss the results as a class.

Light Intensity

1. For this experiment use the same type of bulb on multiple shelves. Using a light meter, students measure and record the intensity of light on each shelf. If the bulbs are all the same age, their output should be similar when the fixtures are hung at the same distance from the plant trays and the light meter is placed at the same spot on each shelf — for example, the number of lumens will be close to equal at the center of each tray when the bulbs are positioned 6 inches above the trays.

2. Now adjust the height of the fixtures to measure and record intensity at various distances, always taking readings from the same spot on each shelf (e.g., the center of the tray). Next find out if the light is equally intense at other spots on the shelf. Students should discover that light intensity is greater under the middle of the bulbs and at the center of the trays than it is towards the ends of the bulbs and the edges of the trays.

3. Finally, test the effect of light intensity on plant growth. Each student or group will need one copy of the Light Intensity worksheet (p. 12) for each growing shelf (e.g., three copies for a 3-tier GrowLab). Have students position the GrowLab fixtures at different heights, record light intensity readings, and then, as in Light Quality, Step 2, plant seeds and position the pots or flats identically on each shelf. Track plant growth on the worksheets and compare results.

4. For further comparison, position the light fixtures at the same height above each shelf and track the growth of plants placed at different locations on the shelf.

***Special note:** Do not angle fixtures so that one end is higher than the other. This is unsafe because water can condense and run down to the light terminal, creating the risk of electric shock.

Light Duration

1. Keep the type of light bulb used and the height of the fixtures constant, but on each shelf leave the lights on for different amounts of time.

2. Plant seeds and track their growth on the Light Duration Experiment worksheet (p. 11). You will need one copy of this worksheet for each different time period tested. Compare the results as a class.

Making Connections

- *What type of bulb resulted in the best plant growth? What explanations support your thinking?*
- *What light fixture height resulted in the best plant growth? Explain your answer.*
- *Which duration of lighting resulted in the best plant growth? Explain your answer.*
- *Which type of bulb is most economical? How well did the plants grow under it? In space, what would be more important: bulb cost or effect on growth? Why is it important to use highly efficient light bulbs when growing plants in space?*

- *What other qualities should scientists consider when choosing lighting for space?*

Branching Out

- Expand on the experiments above by testing different varieties or types of plants. *Did some plants grow better than others in less intense light? How is this information important for space travel?*

- Scientists are considering the use of light-emitting diodes (LEDs) for growing plants in space. LEDs last a long time, contain no mercury, and radiate little heat. Because they're so useful here on Earth for things like traffic lights and dashboard displays, researchers continue to find ways to make them more efficient. Read the NASA article, "Light-Emitting Diodes for ALS Crop Production"[1] and see photos of wheat under LEDs.[2] Then discuss this research as a class. *What is LED light? What are the benefits of LEDs for growing plants in space? Why do they make plants appear different?*

- Research other types of available lighting. As a class, discuss the merits of each type of light studied. You can use the Electric Lamp Considerations comparison chart (below) from Dr. Raymond Wheeler, NASA Plant Physiologist, to discuss efficiency.

Electric Lamp Considerations

Lamp Type	Conversion Efficiency[A,B]	Lamp Light (hours)[A]	Spectrum
Incandescent/Tungsten[C]	5%–10%	2,000	Intermediate
Xenon	5%–10%	5,000	Broad
Fluorescent[D]	20%	5,000	Broad
LEDs (red)[E]	20%	~100,000	Narrow
Metal Halide	25%	20,000	Broad
High Pressure Sodium	30%	20,000	Intermediate
Low Pressure Sodium	35%	20,000+	Narrow
Microwave Sulfur	35%–40%+	unknown	Broad

[A] *Approximate values.*

[B] *Efficiency determined by comparing watts of light produced for every 100 watts of electricity delivered (e.g., 10% efficiency means that 10 watts of light are produced by 100 watts of electricity).*

[C] *Tungsten halogen lamps have a broader spectrum.*

[D] *For VHO lamps; lower power lamps (e.g., T5, T8) last up to ~20,000 hours.*

[E] *Blue and green LEDs are 10% efficient.*

STUDENT WORKSHEET

Name____ **Date** __________________

Light Quality Experiment

You will need a copy of this worksheet for each type of bulb tested.

Date seeds planted: __________________________ Number of seeds under each light:________________

Plants grown:____

Light fixture height: _________________________ Daily light exposure (hours):____________________

Bulb type (e.g., warm-white):____________________ Predominant wavelengths (color): ________________

PLANT GROWTH DATA			
	Date:	**Date:**	**Date:**
% germination			
Average height			
Appearance (vigorous, healthy, fair, poor)			
Additional Notes			

STUDENT WORKSHEET

Name______________________________ Date ____________________

Light Intensity Experiment

You will need a copy of this worksheet for each level of light intensity tested.

Date seeds planted: ______________________ Number of seeds under each light:____________________

Plants grown:____

Light fixture height: ______________________ Daily light exposure (hours):____________________

Bulb height above soil level:______________________ Intensity of light (footcandles):____________________

PLANT GROWTH DATA			
	Date:	Date:	Date:
% germination			
Average height			
Appearance (vigorous, healthy, fair, poor)			
Additional Notes			

STUDENT WORKSHEET

Name______________________________ Date ______________

Light Duration Experiment

You will need a copy of this worksheet for each time duration tested.

Date seeds planted: ______________________ Number of seeds under each light: ______________

Plants grown: ____

Bulb type: ______________________ Fixture height (above flats or pots): ______________

Daily light exposure (hours): ______________ Intensity of light (footcandles): ______________

PLANT GROWTH DATA			
	Date:	**Date:**	**Date:**
% germination			
Average height			
Appearance (vigorous, healthy, fair, poor)			
Additional Notes			