National Aeronautics and Space Administration

NASA eClips™

Educator Guide

NASA'S REAL WORLD

THE LIGHT PLANTS NEED

NASA Partner

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EDUCATOR GUIDE

NASA eClips™

The Light Plants Need

NASA's REAL WORLD MATHEMATICS

National Standards:

Next Generation Science Standards (NGSS)

Life Science

- Life cycles of organisms
- Structure and function in living systems

Physical Science

Energy in Chemical Processes and Everyday Life

National Council of Teachers of Mathematics (NCTM)

Data Analysis and Probability

- Select, create, and use appropriate graphical representations of data
- Find, use, and interpret measures of center and spread
- Use conjectures to formulate new questions and plan new studies to answer them

Essential Questions

- What effect does light have on living things?
- How do different colors of light affect a plant's growth?
- How does technology advance science?

Table 1: **Sample Plant Experiment Planning Calendar**

Week	MON	TUE	WED	THUR	FRI
1				1-2 periods for lesson introduction and experiment set up	
2	soak seeds	plant seeds - Day 0	check for germination - observation 1	check for germination	
3	either day - observation 2: 10 min			either day - observation 3 & water plants: 10 min	
4	either day - observation 4: 10 min			either day - observation 5 & water plants: 10 min	
5	observation 6 - 10 min; 1 - 1.75 periods - data analysis and report preparation; 1 period for presentations				

Grade Level:
3-8

Subjects:
Life Science, Data Analysis

Teacher Preparation Time:
2 hours

Lesson Duration:
1-2 periods at the beginning and end, plus 15 minutes twice a week for 3 weeks. See Table 1 for a planning calendar.
Week 1 – 45 to 90 minutes to introduce lesson and have students design/prepare materials setup.
Week 2 – Soak seeds on Monday, plant on Tuesday, check for germination daily – Measurement 1: Upon germination, measure the plant, describe it briefly, set tripod and take digital picture.
Weeks 2-4 – 2 10-minute observations/week, measurements, pictures Mon. or Tues. and Thurs. or Fri.
Week 5 – Final 10-minute observation, measurement, picture Mon. or Tues., PLUS 45-80 minutes for team data analysis and report preparation + 45 minutes for team presentations.

Time Management:
Lesson duration can be reduced by 1 period if the report preparation is completed as homework.

Lesson Overview:

Students observe and compare three types of light sources. Students then conduct an experiment to determine how different colored light affects plant growth. Students analyze the data collected from this experiment by creating a line graph and calculating three measures of central tendency. Finally, students design a plant growth chamber to observe the effects of colored-plastic, filtered light on plant growth. Students have an inside look at an atmospheric chemist's career. This lesson is developed using a 5E model of learning.

Icons flag five areas of interest or opportunities for teachers.

- **Technology Icon** highlights opportunities to use technology to enhance the lesson.
- **Modification Icon** denotes opportunities to differentiate the lesson.
- **Resources Icon** relates this lesson to other NASA educator resources that may supplement or extend the lesson.
- **Connections Icon** identifies opportunities to relate the lesson to historical references and other topics or disciplines.
- **Check for Understanding Icon** suggests quick, formative assessment opportunities.

Essential Questions:

- What effect does light have on living things?
- How do different colors of light affect a plant's growth?
- How does technology advance science?

Instructional Objectives:

Students will:

- compare and contrast LED and incandescent lights;
- experimentally determine the effect of various colors of light filters on plant growth;
- collect and graph plant height data;
- calculate mean, median, and mode for plant height data; and
- based upon experimental observations, design an experiment to test conditions that will result in optimal plant growth in terms of number of flowers, seeds, leaf area, or other criteria determined by the class.

Materials List:

Engage (per class)

- 60 W white incandescent light

- 6 W white LED light

(both types of lights are available at department or home improvement stores)

- 1 light meter (optional)

SAFETY NOTE: Do not allow students to look directly into lighted bulbs. They can damage the eyes.

Explore (per group of 4)

- 4 bean seeds or other fast-growing seeds. The University of Wisconsin has developed plants with short life cycles called Fast Plants that are suitable for classroom experimentation. There is also a dwarf variety bred for space research called the AstroPlant (*https://www.astroplant.io*). More information can be found at the Wisconsin Fast Plants website *http://www.fastplants.org .*
- 4 250 mL foam or plastic cups
- 400 mL potting soil (100 mL/cup)
- 8-12 small rocks or pieces of gravel (2-3/cup)
- 1 plastic milk or water jug full of tap water (leave open to allow chlorine to escape)
- 1 100 mL or 250 mL beaker
- 1 100 mL graduated cylinder (a small size cylinder may be substituted)
- 1 30 cm x 45 cm piece of plastic wrap or cellophane in each of four colors: red, blue, green, and clear. NOTE: Be sure to use the same type of plastic wrap for all experiments, otherwise the intensity of the light may vary from group to group.
- 4 wooden dowels to help support the cellophane/plastic wrap tents
- 1 thin metric ruler (can be made by making copies of several rulers then photocopying onto heavy transparency plastic)
- 1 computer with spreadsheet program or graphing calculator
- 1 digital camera (optional)
- Any additional materials students may request to build plant growth chambers such as cardboard boxes and timers.

5E Inquiry Lesson Development

ENGAGE - What do you know about light bulbs and wavelengths of light? **(20 minutes)**

1. Have the class complete a KHWL chart to organize what your students KNOW, HOW they know this information, and what they WANT TO KNOW about incandescent and LED light bulbs and how they produce light. Use these questions to help guide the discussion:

- What do you KNOW about incandescent and LED lights? *(Answers will vary. Students may suggest ideas that are incorrect, such as an LED bulb uses a filament just like an incandescent bulb or that the wattage of different types of light is the same, i.e. the LED equivalent of a 60 W incandescent bulb is also 60 W. Do not correct these ideas at this time. You will come back to this KHWL chart throughout the lesson to correct any misconceptions and add more facts. Students may not know how each type of light bulb produces light or that an LED light has a lower wattage than a comparable incandescent light.)*
- Ask students to explain HOW they have learned the information stated about the different types of light bulbs. *(Answers will vary. This is the time to help students consider the validity of their sources for information.)*
- What do you WANT TO KNOW about incandescent and LED lights? *(Answers will vary. Encourage students to seek answers to their questions beyond this lesson.)*

2. (**TECHNOLOGY**) Show the NASA eClips™ video segment *Real World: Space Lighting* (5:31) to the students. This segment can be found on the NASA eClips™ page of the NASA web site:
https://nasaeclips.arc.nasa.gov/video/realworld/real-world-space-lighting
The video may be streamed or downloaded from the NASA eClips website; a captioned version is also available at the NASA eClips website.
(**MODIFICATION**) This video may be streamed from the NASA eClips You Tube™ channel:
https://youtu.be/z9hq92u0sl0
3. Have students update their KHWL chart to include information presented in the video.
4. Show students an incandescent light and an LED light without turning either light on.
5. Ask students to describe and record the differences between the two lights.
6. Turn off the classroom lights, turn on both lights, and ask the students to add to their observations.
7. (**TECHNOLOGY**) If available, use a light meter or a light meter app to measure the intensity of each light. Although the lights are different wattages, they both have an intensity of 800 lumens. A lumen is a measure of the brightness of a light. One lumen is defined as the amount of light emitted by one candle that falls on one square foot of surface located one foot away from one candle. A lumen was originally referred to as a foot-candle.

8. As a group, ask students to share what they have written. *(Answers will vary, but may include differences in size, shape, brightness, or perceived color tint of the light.)*
9. (**TECHNOLOGY**) Show the NASA eClips™ video segment *Our World: Plants in Space* (7:01) to the students. This segment can be found on the NASA eClips™ website:
   https://nasaeclips.arc.nasa.gov/video/ourworld/our-world-plants-in-space
   Our World: Systems to Grow Plants in Space explains how NASA grows plants on the International Space Station.
   https://nasaeclips.arc.nasa.gov/video/ourworld/our-world-systems-to-grow-plants-in-space
   The videos may be streamed or downloaded; a captioned version is also available.
   (**MODIFICATION**) The videos may be streamed from the NASA eClips You Tube™ channel:
   https://www.youtube.com/playlist?list=PL31002AD70975DC1B
10. (**CHECK FOR UNDERSTANDING**) Based upon new information presented in the video segment, ask students to classify the two lights used in the demonstration as incandescent, LED, or fluorescent. Lead a class discussion about additional differences between the lights discussed in the video.

EXPLORE - Plant Experiment (30 minutes on two days for set-up and then 10 minutes twice a week for observations until six measurements have been made. The last measurement would be around 20 days after planting.)

Scheduling Note: Ideally, have students SOAK soil and seeds on a MONDAY and PLANT on TUESDAY of a full week of school so that germination doesn't occur over the weekend. Days until germination is a data point your students will want to collect. See the Sample Planting Calendar on page 1.

Background
Light controls many plant processes. For example, blue wavelengths, 400-450 nm, and red wavelengths, 625-700 nm, are necessary for photosynthesis. Photoperiod responses, the physiological reaction of plants and animals to the length of day or night, are triggered by red wavelengths. Phototropic responses, the growth of plants toward a light source, are triggered by blue wavelengths.

In this EXPLORE activity students observe the effects of different wavelengths of light on plant growth.

Procedure
1. Organize students into teams of four.
2. Distribute the materials for the EXPLORE activity to each group.

3. Review the experimental procedure outlined on pages 6 and 7 in the Student Guide.
4. Each team will plant four seeds, one in each cup. Discuss how each team member will be responsible for observing and recording measurements for one of the four plants.
5. Remind the students to adjust the watering to ensure the soil remains moist but not flooded. Be sure to plan ahead for weekends, holidays, and absent partners. Some containers may require more water than others due to a drier position in the room. Decide how different amounts of water can be "controlled" for. If available, a wick watering reservoir system may be used to prevent plants from drying out.
6. Measure the height of the bean plants throughout the experiment. Encourage students to problem solve if plant height nears or touches the plastic wrap/cellophane light filters.
7. If available, you may wish to give students the option of placing the plants under a grow light instead of placing them in a sunny location. Note that some grow lights produce less optimal growth than fluorescent lights. You may also wish to allow students to use different colored lights rather than colored plastic wrap.
8. (**TECHNOLOGY**) If available, have students document the progress of their experiment using digital images. Students can then prepare digital portfolios for this activity.
9. (**MODIFICATION**) To reduce the data collection time to two weeks, use Fast Plant seeds (*Brassica rapa*). Fast Plant seeds will sprout within 48 hours and will produce flowers in 14 days under optimal conditions (continuous 24-hour, direct fluorescent lighting). Fast Plant seeds are available through science supply companies and can be ordered online. The AstroPlant is a dwarf version of the Fast Plant. AstroPlants are shorter and may be more manageable.

EXPLAIN – Analyzing Results (30 minutes)

During the EXPLAIN section, students analyze the data recorded during the EXPLORE activity. By creating a line graph, students look for patterns describing the changes in the plants' height over time.

Students also calculate mean, median and mode for the data. Students identify the data's range. These measures of central tendency are used to analyze differences in the heights of plants grown under different types of lights and colors of filters.

1. Ask students to graph their team's data and answer questions 2 and 3 on

page 9 in the Student Guide. The plant height data could be displayed in several other ways. You may ask students to display this data using a stem and leaf diagram or a double stem and leaf diagram.

2. (**TECHNOLOGY**) Ask students to use a spreadsheet program or graphing calculator to graph their data.
3. Make one copy of Table 3 found on the following page to gather a class set of data of the final heights of each plant. Once all data is added to this table, copy and distribute a completed table to each student.
4. Based upon the class data, ask students to answer questions 4, 5, and 6 on pages 9-10 in the Student Guide.
5. (**CHECK FOR UNDERSTANDING**) Use these questions to help lead a discussion about the EXPLORE activity:
    a. Why would your conclusions be more reliable based on the class set of data and not just your team's data? (*Plants, like people, do not all grow the same height even under the same conditions. Determining the measure of central tendency makes it easier to see the overall trend in the effect of each color on plant growth*).
    b. What are some possible sources of error in the experiment you conducted? (*Answers will vary but may include: some of the plants may never have sprouted or may have died during the experiment; teams may not have maintained constants/controlled conditions; etc.*)
6. (**TECHNOLOGY**) Ask students to create a multimedia presentation of the project using the digital images they took.

EXTEND – Design a new plant experiment (25 minutes class time for planning; students will complete experiment outside of class independently)

During the EXPLORE and EXPLAIN sections, students thought and acted like scientists and engineers. As engineers, students designed the setup in which to grow the plants. As scientists, students observed plants to gain an understanding of the natural world and how it works. In this EXTEND activity, students will continue to think and act like engineers as they apply what they learned to design an experiment to grow the healthiest plants in the shortest time.

1. (**RESOURCE**) Use the Engineering Design Packet to help students apply the engineering design process. This packet may be found at: *https://nasaeclips.arc.nasa.gov/resources/download/45*
2. Students can perform the experiment at home for extra credit or as a science fair project.

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Table 3. Class Plant Height Table

	Final Plant Height (cm) for different light or filter colors			
Plant Filter ➔ Team 🡻	A Blue	B Red	C Green	D Clear
1				
2				
3				
4				
5				
6				
7				
8				
Mean				
Medium				
Mode				

EVALUATE (20 minutes)

1. Use questions, discussions, and the Student Guide to assess students' understanding.
2. Ask students to review and update their KHWL chart.
3. Ask students to summarize their learning by answering these journal questions:
   a. Scientists use experimental design to guide discovery. Evaluate the experimental design of this activity using these questions.
      i. Why is it important to have a control group in experiments? What was the control group in this experiment? (*The control group was the group with the clear cellophane. The growth of the other groups was compared to the control to see if growing under different colors of light affected the growth of the plants*).
      ii. Every experiment has some experimental error. Which of the experimental errors do you think affected your results the most? Why?

      (*Answers will vary but should include observations such as:*
      - *if the ruler sank into the soil too far it would result in measured plant heights that are taller than they really are.*

- *if all conditions aren't the same between the four light setups (e.g., in one, plants are closer to the light, so they get more light intensity, or some are warmer than the others), these differences can result in plant heights that don't have anything to do with the light color in the setups.)*

b. How do different colors of light affect a plant's development? (*Answers will vary depending upon the light source. If colored light bulbs are used, red and blue light have the greatest impact on plant growth. Red light impacts seedling growth and plant height. Blue light is responsible for leaf growth, while reducing stem length. Blue and red light are both needed for flower germination. If cellophane is used in place of plastic wrap, results of the experiment may vary. The cellophane may be more opaque due to the pigment, thus limiting the amount of light the plant receives and could result in more spindly growth*.)

c. How does technology advance science? (*Advances in LED technology have allowed scientists and engineers to develop longer lasting and more durable lighting for space exploration. As LED technology develops it allows scientists to conduct new experiments, such as the one that scientists did with plants in the NASA eClips™ video. Research by NASA supports that plants can achieve optimal growth when exposed to high intensity red and blue LED lighting*.)

d. Ask students to answer the two questions on the Career Clip found on page 11 of the Student Guide comparing what they did in their plant experiments with what Dr. Fishman, a chemist, does for a living.

References

Astroculture3

http://www.nasa.gov/centers/marshall/news/background/facts/advasc2.html

Farming the Future

http://www.nasa.gov/missions/science/biofarming.html

LED Systems Target Plant Growth

https://spinoff.nasa.gov/Spinoff2010/cg_1.html

Solid State Light Evaluation in the US Lab Mockup

https://ntrs.nasa.gov/citations/20090005099

Wisconsin Fast Plants

http://www.fastplants.org

AstroPlant

https://www.astroplant.io

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The Light Plants Need

Essential Questions:

- What effect does light have on living things?
- How do different colors of light affect a plant's growth?
- How does technology advance science?

Background

Engineers at companies working with NASA have developed the next generation of space lighting. This type of lighting uses **light-emitting diodes**, or LEDs, as light sources. An LED changes electricity into light by using the properties of metals to produce light **photons**. Traditional light bulbs use electricity to heat a metal **filament**, or wire, inside a glass bulb. As the filament heats up, it begins to glow. Most of the energy produced is heat energy. LED lights are more energy efficient. They use much less electricity to produce light and produce much less heat than other types of light bulbs.

In the past, **incandescent** and **fluorescent** lights were used on the International Space Station, or ISS. LED technology makes it possible to replace these lights with **Solid State Lighting Modules**, known as SSLMs. The new lighting modules are more durable, reliable, and longer lasting. The old type of lighting on the ISS had to be changed every 12 months. SSLMs last about 10 years.

Incandescent light.
Image credit:
freefoto.com

Compact fluorescent light.
Image credit: Joe Colburn

Solid State Lighting Module.
Image credit:
NASA Kennedy Space Center

Figure 1. Types of lights.

These lights require less maintenance and make less trash for landfills. SSLMs could also be used in future spacecraft for long missions. SSLMs have another advantage over other kinds of lighting. The light from these modules can be adjusted to simulate natural light. The light we see is called **visible light**. Visible light is only a small part of the **electromagnetic spectrum**. Visible light, or white light, can be separated into individual colors of light. Each color has a unique **wavelength**.

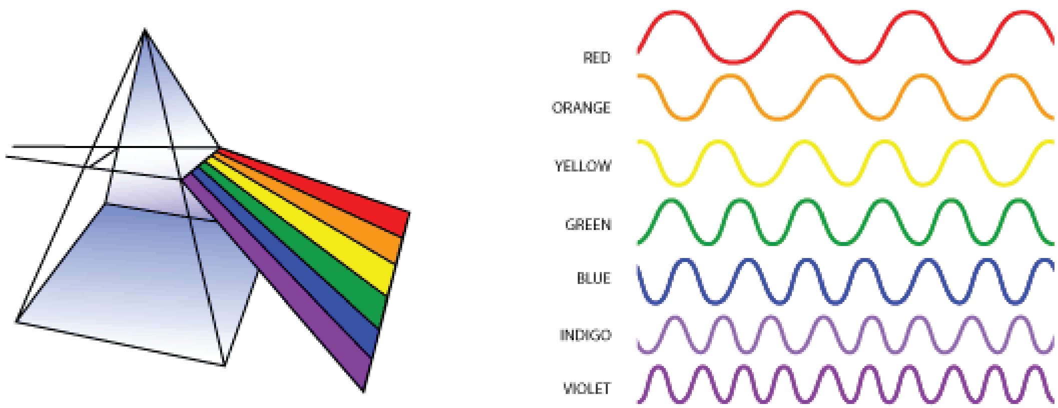

Figure 2. Visible Light. Image credit: NASA

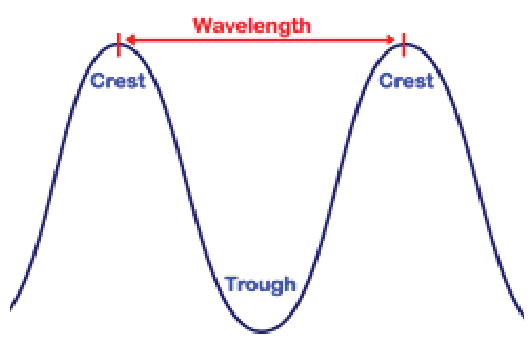

Figure 3. Wavelength. Image credit: NASA

Blue LED lights emit or give off blue wavelengths of light missing from incandescent light bulbs. Blue wavelengths can have a positive effect on moods. LED lights can also be adjusted at different times of the day so people are more alert during work periods. Changing light colors in the evening would allow a person to wind down before sleeping. This benefit is important to astronauts because their natural sleep and work patterns are disrupted by space travel.

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NASA is also studying the effect of LED lighting on the healthy growth of cells. Exposing cells to specific wavelengths of light have unique effects on a cell's **organelles.** An organelle is a tiny part of the cell that has a special function. Organelles carry out all life processes. Different wavelengths have different effects on the cells. Near-infrared light has a wavelength that is just outside the visible range. Biologists have found that when cells are exposed to near-infrared light from LEDs, the cells grow 150 to 200 percent faster than those cells not exposed to the same kind of light. Specific wavelengths may speed up the healing process or help prevent bone loss on long space flights.

LED lighting is being used to study plant growth in microgravity as well. Certain LEDs produce the exact light wavelengths that plants can use for **photosynthesis**. **Chlorophyll** in plants use mostly blue and red wavelengths. Red LEDs were used in the Astroculture3 plant growth chamber on several space shuttle missions. Because LED lights emit only narrow wavelengths, it is relatively easy to build a bank of lights with only the wavelengths needed by the plant. Different colors can even be hooked up to timers. Eliminating some of the wavelengths found in white light saves energy and makes the LED lights less expensive to use. LEDs also last longer than other types of light bulbs.

Figure 4. Astroculture 3 Growth Chamber. Image credit: NASA

Resources

The Electromagnetic Spectrum

http://science.hq.nasa.gov/kids/imagers/ems/index.html

Growing Plants in Space

https://www.nasa.gov/content/growing-plants-in-space

Leafy Green Astronauts

http://science.nasa.gov/science-news/science-at-nasa/2001/ast09apr_1/

Vocabulary

chlorophyll – Chlorophyll is a green chemical in plant cells that allows plants to use light energy to make food.

electromagnetic spectrum – The electromagnetic spectrum is the entire range of visible and invisible energy waves organized according to wavelengths. Visible light is a small part of the electromagnetic spectrum, which includes radio waves, ultraviolet waves, infrared waves, and microwaves. The shorter wavelengths have the highest energy. See Figure 5.

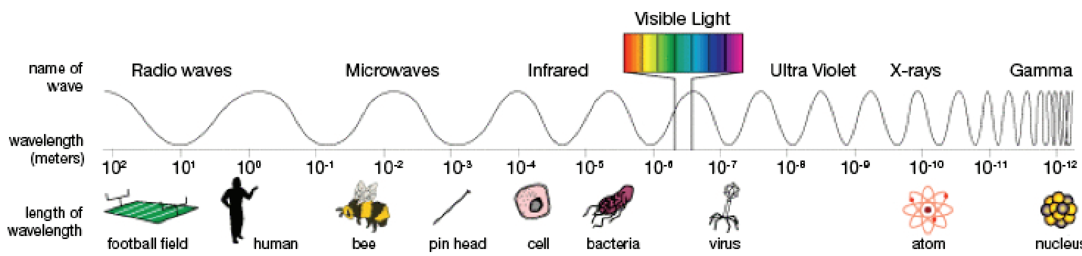

Figure 5. Diagram of the electromagnetic spectrum. Note: the unit of measurement for wavelength in the diagram is meters (m). Image credit: NASA

emit – To emit is to give off. LEDs give off, or emit, light. Colored LEDs emit very specific wavelengths of light.

filament – A filament is a small thin wire inside an incandescent light bulb that is heated until it glows.

fluorescent light – A fluorescent light uses an electric current to heat gas particles inside a specially coated glass tube. When the particles hit the sides of the tube, a glowing light is produced.

incandescent light – An incandescent light produces light when a metal wire inside a glass bulb is heated and gets hot enough to glow. The glass bulb contains an inert gas that does not react with the filament

light bank – A light bank is a group of lights that are connected. A Solid State Lighting Module, or SSLM, is a light bank made up of rows of light-emitting diodes.

light-emitting diode – A light-emitting diode, or LED, is a semi-conductor light source that emits visible light or invisible infrared radiation. Semi-conductors are made from materials that are poor electrical conductors that have impurities added to them. When electrons flow through the semi-conductor, they lose energy. This energy is lost, or emitted in the form of light. The color of the LED depends on the materials used to make the semi-conductor.

mean – The mean is one measure of central tendency. The mean is calculated by taking the sum of a set of data and then dividing that sum by the number of data points. For example, the mean of the numbers 2 and 8 is 5 (10/2).

measure of central tendency – A measure of central tendency is a single value that can be used to summarize data. The mean, median, and mode are all measures of central tendency.

median – The median is one measure of central tendency. The median is determined by organizing the data sequentially, and then identifying the middle value in that set of data. For example, 7 is the median of the numbers 2, 5, 7, 15, and 23.

mode – The mode is one measure of central tendency. The mode is the most common data value (the value that shows up most often). For example, 3 is the mode of 2, 3, 3, and 4. A set of data can have more than one mode. In the set of numbers 1, 2, 3, 3, 4, 5, 5, 6, 7, 8 there are two modes, 3 and 5.

organelles - Organelles are tiny parts of the cell that have unique forms and structures to carry out life processes. Mitochondria are organelles that produce energy. Vacuoles are organelles that contain and remove waste. Chloroplasts are organelles that produce food.

photons – Photons are energy packets and units of electromagnetic radiation. A photon contains a very specific amount of energy. Each wavelength in the electromagnetic spectrum in Figure 5 consists of photons with specific amounts, or quanta, of energy.

photosynthesis – Photosynthesis is the food-making process of green plants. Chlorophyll pigments in choroplasts use light energy, water and carbon dioxide to produce oxygen and sugar.

range – The range is the difference between the highest and lowest values in a set of data. For example, the range of the numbers 1, 3, 5, and 500 is 499 (500-1).

Solid State Lighting Module – A Solid State Lighting Module, or SSLM, is a light source made up of rows of light-emitting diodes.

variable – A variable is something that changes. In the case of experiments, only the condition being studied should be varied. All other conditions need to remain constant. The condition intentionally changed is referred to as the independent variable. The result measured in the experiment is referred to as the dependent variable.

visible light – Visible light is an electromagnetic wave that can be seen by the human eye (see Figure 5). The waves in the visible spectrum are perceived as different colors.

wavelength – A wavelength is the distance between two crests or two troughs of a wave. Different colors of light have different wavelengths. Figure 5 shows that radio waves are much longer than gamma waves.

EXPLORE - Experiment: How do different colors of light affect a plant's growth?

1. You and your team need the following materials:
   - 4 bean seeds
   - 4 250 mL foam or plastic cups
   - 400 mL potting soil (100 mL/cup)
   - 8-12 small rocks or pieces of gravel (2-3/cup)
   - 1 milk jug full of water (leave open to allow chlorine to escape)
   - 1 100 mL or 250 mL beaker
   - 1 100 mL graduated cylinder (a small size cylinder may be substituted)
   - 1 30 cm x 45 cm piece of plastic wrap or cellophane in each of four colors: red, blue, green, and clear
   - 4 wooden dowels to help support the cellophane/plastic wrap tents
   - 1 metric ruler
   - 1 computer with spreadsheet program or graphing calculator
   - 1 digital camera (optional)
2. As a class, discuss the need for consistency in the way that you set up and follow this experiment so that you can compare and share data.
3. In Table 1, make a list of all of the experimental conditions you and your team must keep constant so that you will be able to share your data with your class.
4. As a team, make a hypothesis about how different colored light will affect the plant's growth. Record the hypothesis in Table 1. Be sure to include reasons for the hypothesis.
5. Follow these steps to prepare your plant experiment.
   a. Place two or three small rocks or pieces of gravel in the bottom of the labeled plastic cups. This will help the soil drain.

b. Use the beaker to measure and fill each of the cups with about 100 mL potting soil. Pour 45 mL of water over the dry soil and let it absorb overnight.
c. Soak bean seeds in a beaker of water labeled with your team number for 24 hours.
d. In your groups, discuss ways to set up the four colored plastic sheets so that once your plants are positioned near the window or designated light source they will receive equal light through only the appropriate sheet which acts as a light filter. Present your solutions to the class and vote on the method that is both secure and allows for the efficient watering and measuring of the plants.
e. Plant one seed 3 cm deep in each cup.
f. Lightly cover the seeds with soil. Don't compact the soil.
g. Use the graduated cylinder to provide 15 mL (1 tablespoon) of water into each cup. Pour off any excess water.
h. Place the cups near a window or other designated light source. Arrange the cups so that each receives the same amount of light.
i. Set up the plastic sheets as decided in step d.
j. Planting day is Day 0. Water plants with 15 mL of water every other day (or every Monday, Wednesday, and Friday) for the next 20 days. If the plants appear to be too wet or too dry, discuss and agree to changes to the amount of water as a team. Share your changes and reasons with the class. Discuss what to do about long weekends.
k. Record plant observations in Table 2. Check daily to be sure to note the date the seeds first sprout. Once the plants have germinated, measure heights with a metric ruler with a flat "foot" made by folding a narrow piece of index paper and taping it closed around the bottom of the ruler. This will prevent the ruler from sinking into the soil. Measure plant height to the nearest tenth of a centimeter.

Table 1: Constants and Hypothesis for Plant Growth

Problem Record the question you're investigating.	
Constants List all of the experimental conditions that need to be kept constant.	
Hypothesis Record your team's hypothesis for this experiment (a prediction of the answer to the problem question).	
Reasons for your hypothesis.	

Table 2: Plant Heights and Other Observations

Planting Date (Day 0) ________ Germination Date ____________________

	Plant height (cm)			
Day	Condition A Blue Filter	Condition B Red Filter	Condition C Green Filter	Condition D Clear Filter
0	0	0	0	0
*				

*The second table entry for each plant should be the day the plant germinates.
Take a measurement and briefly describe what you see. Make additional measurements and observations two days per week.

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EXPLAIN

1. Construct a graph to represent the data collected over the 20 days. This graph will show change in plant height observed over time. "Time" (days) should be on the x-axis and "Plant height (cm)" should be on the y-axis. Plot the data for all four plants on one graph. Use a different color for each plant growth filter (color of light). Be sure to label your axes and include a key/legend explaining what each color represents.
2. Compare the final height of the plants in the four containers. Based on your data, what color of light filter resulted in the tallest plants?

3. Compare the amount of foliage on the plants. Based on your data, which color of light filter resulted in the plants with the most foliage?

4. First, find the measures of central tendency (mean, mode, median) for the sample data below. Then, obtain and analyze the class data for the plant setup you observed. For example, if you observed plant A, you will analyze class data for plant A.
   Sample data for seven plants grown for 20 days under red light:
   22 cm 20 cm 20 cm 22 cm 5 cm 19 cm 22 cm

   a. What is the range for this data? To find the range, organize the data sequentially and then calculate the difference between the highest and lowest values.

   b. Calculate the mean for this data. Mean is calculated by adding all plant heights and then dividing this sum by the number of data points.

STUDENT GUIDE

c. Calculate the mode for this data. The mode is the most common data value.

d. Calculate the median for this data. The median is the middle value once you have organized the data sequentially.

5. Which measure of central tendency best describes the typical growth of the plant? Give reasons for your choice.

6. Based upon the class data, which color of light do you think is best for plant growth? Support your answer with data and observations from the experiment.

7. Based upon what you've learned doing this experiment, what else would you like to know about plant growth and light or other environmental conditions? Phrase your answer as a question/problem to investigate. Write a short procedure (5 to 10 steps) that outlines how you might find the answer to your new problem. If there is time or you need a science fair project or extra credit, perform your experiment.

CAREER CLIP

Dr. Jack Fishman: Atmospheric Chemist NASA Langley Research Center

My training…

Bachelor's degree in math with a minor in chemistry; Master's and Ph.D. in meteorology

Best part of my job …

"I am excited to come to work every day. I have the freedom to pursue my own original ideas and be recognized by my peers for the solid research I have done."

My advice to students …

"Get a strong background in math! Even though I floundered in college, the math enabled me to pursue research in all of the physical sciences."

1. Throughout this lesson, you have been thinking and acting like a scientist and an engineer. Read this Career Clip to find out more about Dr. Jack Fishman, an atmospheric chemist at NASA Langley Research Center. Dr. Fishman studies chemical reactions that occur in the atmosphere

a. How is the work that you have been doing during this lesson similar to the work Dr. Fishman does every day?

b. What can you do today that may help you prepare you for a future career as a scientist or engineer?

Watch these **Ask SME: Close-up with a NASA Subject Matter Expert** videos to learn about other NASA careers related to agriculture.
https://nasaeclips.arc.nasa.gov/careerconnection

- Ask SME: Dr. Inbal Becker-Reshef, Program Director for NASA Harvest
- Ask SME: Dr. Hannah Kerner, NASA, NASA Harvest, Artificial Intelligence, AI Lead
- Ask SME: Dr. Catherine Nakalembe, Remote Sensing Scientist for NASA Harvest
- Ask SME: Dr. Jacob Torres, Technical & Horticultural Scientist NASA's Kennedy Space Center

ANSWER KEY

Table 1: Constants and Hypothesis for Plant Growth

Problem Record the question you're investigating.	
Constants List all of the experimental conditions that need to be kept constant.	*Answers may vary but should include:* • *one seed per cup* • *depth seed is planted, 3 cm deep* • *watering each seed with the same amount of water* • *setting all plants in the sun positioned to receive the same amount of light* • *maintaining the same temperature* • *soil composition* • *distance between light and top of plant* • *proximity to sources of heat or cold/drying (air vents, doorways, window sills) [This will have different effects depending on outdoor climate and school climate control (whether heat or AC is left on or off at night and on weekends)-e.g. Alaska in the winter or Arizona in August]*
Hypothesis Record your team's hypothesis for this experiment (a prediction of the answer to the problem question).	Answers may vary but may include: • The bean seed will grow tallest under the clear light. • Beans will be shortest growing under the red plastic. *NOTE: Students shouldn't add discussions or partial thoughts about things that aren't being experimented on into hypotheses. These ideas are appropriate in discussions of results, in which students should be encouraged to combine the results of research on the work of others with their own experimental data and any new ideas the students may have. This discussion and analysis process is doing what scientists do! This is the stage where students can suggest "why" something may have happened the way it did and propose new experiments to test these "new hypotheses."
Reasons for your hypothesis.	

Table 2: Plant Heights and Other Observations

Actual plant height data may vary significantly, but the following trends in data should be observed: The tallest plants grow under red light, the next tallest plants grow under white light, the next tallest plants grow under blue light and the shortest plants grow under green light. NOTE: Height isn't always a measure of health. It sometimes indicates stress, e.g., plants growing in the shade may grow tall and spindly, and have pale leaves.

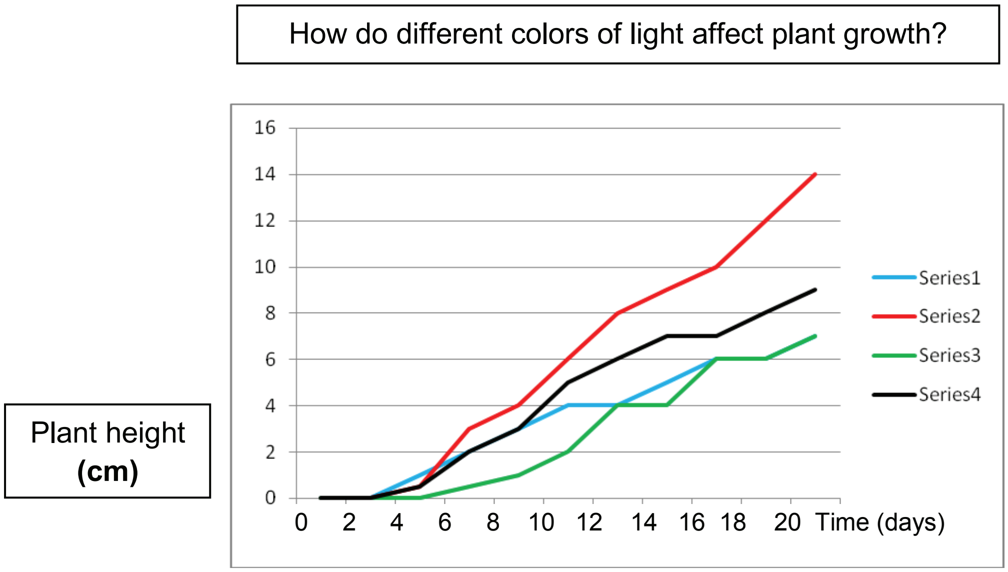
ANSWER KEY

Planting Date = Day 0 ________Germination Date _________

	Plant height (cm)			
Day	Condition A Blue Filter	Condition B Red Filter	Condition C Green Filter	Condition D Clear Filter
0	0	0	0	0
2	0	0	0	0
4	0.5 cm pale green	0.5 cm pale green	0 pale green	0.5 cm pale green
6	2 cm green, 1 small leaf	3 cm green, 2 small leaves	0.5 cm pale green	2 cm 1 small leaf
8	3 cm 2 small leaves	4 cm 3 small leaves	1 cm pale green	3 cm 2 small leaves
10	4 cm 3 small leaves	6 cm 4 small leaves	2 cm 2 small leaves	5 cm 4 small leaves
12	4 cm 3 small leaves	8 cm 4 larger leaves	4 cm 3 small leaves	6 cm 5 larger leaves
14	5 cm 4 small leaves	8 cm 4 larger leaves	4 cm 3 small leaves	6 cm 5 larger leaves
16	6 cm 5 larger leaves	10 cm 4 larger leaves and 1 small leaf	6 cm 4 larger leaves	7 cm 5 larger leaves
18	6 cm 5 larger leaves	12 cm 5 leaves various green colors	6 cm 4 larger leaves	8 cm 5 larger leaves
20	7 cm 5 larger leaves	14 cm 5 leaves various green	7 cm 4 larger leaves	9 cm 5 larger leaves

EXPLAIN

1. Construct a graph to represent the data collected over the 20 days. This graph will show change in plant height observed over time. “Days” should be on the x-axis and “plant height” should be on the y-axis. Plot the data for all four containers on one graph. Use a different color for each container. Be sure to label your axes and include a key.
   Answers will vary but should resemble this example.



2. Compare the final height of the plants in the four containers. Based on your data, what color of light filter resulted in the tallest plants?
   Red light should produce the tallest plants however the students should report exactly what their data show.
3. Compare the amount of foliage on the plants. Based on your data, which color filter resulted in the plants with the most foliage?
   Blue light should produce the most foliage.
4. First, find the measures of central tendency (mean, mode, median) for the sample data below. Then, obtain and analyze the class data for the plant setup you observed. For example, if you observed plant A, you will analyze class data for plant A.
   Sample data for seven plants grown for 20 days under red light.
   5 cm 19 cm 20 cm 20 cm 22 cm 22 cm 22 cm
   a. What is the range for this data? To find the range, organize the data sequentially and then calculate the difference between the highest and lowest values.
      The range for this sample data is 22 - 5 = 17 cm.
   b. Calculate the mean for this data. Mean is calculated by adding all plant heights and then dividing this sum by the number of data points.
      The mean for the sample data is 18.5 cm.
   c. Calculate the mode for this data. The mode is the most common data point.
      The mode for the data is 22 cm.

   d. Calculate the median for this data. The median is the middle value once you have organized the data sequentially.
      The median for the data is 20 cm.

5. Which measure of central tendency best describes the typical growth of the plant? Give reasons for your choice.
   The range is 17 cm.
   The mean is 18.5 cm.
   The median is 20 cm.
   The mode is 22 cm.
   The range is wide because one data point is an outlier. The median and mode are more representative of the typical plant growth. There are more data points shorter than the 3 most common measurements of 22 cm, so it's a toss up whether the median or the mode is the most representative measurement for the sample data. Keep in mind that a variety of plant heights can be expected if there is much genetic variability (if the seeds have different genes) in the plants.
6. Based upon the class data, which color of light do you think is best for plant growth? Support your answer with data and observations from the experiment.
   Answers may vary, but plants under red light should grow the tallest. The plant uses blue wavelengths to create food for leaf production. Red lights encourage flowers to grow. The most effective kind of light for photosynthesis is red and blue wavelengths.
7. Based upon what you've learned doing this experiment, what else would you like to know about plant growth and light or other environmental condition? Phrase your answer as a question. Write a short procedure (5 to 10 steps) to try to find the answer to your new problem. If there is time or you need a science fair project, perform your experiment.
   Answers will vary. If there is time, let students discuss their ideas. Is one so good, the whole class wants to try it (or all of them)? If there is time, let them. This activity is a true example of science as inquiry.

1. Throughout this lesson, you have been thinking and acting like a scientist and an engineer. Read this Career Clip to find out more about Dr. Jack Fishman, an atmospheric chemist at NASA Langley Research Center. Dr. Fishman studies chemical reactions that occur in the atmosphere.

a. How is the work that you have been doing during this lesson similar to the work Dr. Fishman does every day?

Answers may vary, but may include: designing and performing a plant experiment allows me to test my own ideas, just like Dr. Fishman talks about "having freedom to pursue original ideas." While studying atmospheric science, Dr. Fishman is also studying light. The math skills I used are also used by Dr. Fishman.

b. What can you do today that may help you prepare you for a future career as a scientist or engineer?

Answers may vary, but may include: learning how to observe, record, and analyze the plant data is something scientists do in their work. This lesson let me design a plant experiment. I used the engineering design process to design a plant chamber, the same process engineers use when they design new products. Learning more math will help prepare me for a job in one of these areas.