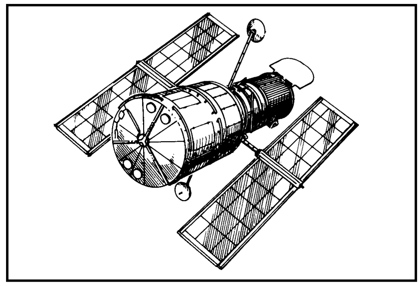


UNIT 4
DOWN TO EARTH

Introduction

Although astronomers who work with ground-based telescopes have to deal with bad weather and atmospheric filtering, they do have one advantage over astronomers working with instruments in space. The ground-based astronomers can work directly with their instruments. That means that they can constantly check and adjust their instruments first-hand. Astronomers working with satellite-based instruments must do everything remotely. With the exception of telescopes mounted in the Space Shuttle's payload bay, astronomers can only interact with their instruments via radio transmissions. That means that the instruments have to be mounted on a satellite that provides radio receivers and transmitters, electric power, pointing control, data storage, and a variety of computer-run subsystems.

Data collection, transmission, and analysis are of primary importance to astronomers. The development of photomultiplier tubes and charged coupled devices (CCDs) provides astronomers with an efficient means of collecting data in a digital form, transmitting it via radio, and analyzing it by computer processing. CCDs, for example, convert photons falling on their light sensitive elements into electric signals that are assigned numeric values representing their strength. Spacecraft subsystems convert numeric values into a data stream of binary numbers that are transmitted to Earth. Once received, computers reconvert the data stream to the original numbers that can be processed into images or spectra.

If the satellite is geostationary, these data may be transmitted continuously to ground receiving stations consisting of one or more radio antennas and support equipment. Geostationary satellites orbit in an easterly direction over Earth's equator at an elevation of approximately 40,000 kilometers. They orbit Earth in one day, the same time it takes Earth to rotate, so the satellite remains over the same location on Earth at all times.

Satellites at other altitudes and orbital paths do not stay above one point on Earth. As a result, they remain visible to a particular ground station for a short time and then move out of range. This requires many widely spaced ground stations to collect the satellite's data. In spite of this, the satellite still spends much of its time over parts of Earth where no stations exist (oceans, polar regions, etc.). For this reason, one of the subsystems on astronomical satellites are tape recorders that store data until they can transmit it to ground stations.

In the mid-1980's, NASA began deploying the Tracking and Data Relay Satellite System (TDRSS) into geostationary orbit. The purpose of this system is to relay data to ground stations. Because of their high orbits and their widely spaced station points over Earth's equator, the TDRSS satellites serve as relay points for lower satellites and the Space Shuttle. The system provides nearly continuous contact with spacecraft as they orbit Earth. TDRSS satellites relay data to a receiver at White Sands, New Mexico. From there, the data travel via telephone lines, fiber optic cable, or commercial communications satellites to its destination. Most astrophysics data travels from White Sands to the NASA Goddard Space Flight Center in Maryland for distribution to scientists.

Unit Goal

- To demonstrate how astronomical satellites use technology to collect optical data, transmit that data to Earth, and reassemble it into images.

Approach

The activities in this unit demonstrate the imaging process of astronomical satellites such as the Hubble Space Telescope. Use the Magic Wand and Persistence of Vision activities together or as alternates. The Magic Wand activity shows how images can be divided and reassembled. The Color activity shows how astronomy satellites collect color data and how that data can be reassembled on the ground. The Binary Number and Paint by the Numbers activities familiarize students with the process of data transmission to Earth and its re-assembly into images.

ACTIVITY: Magic Wand

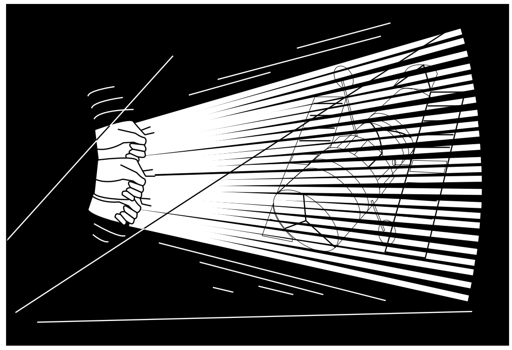
Description:
A recognizable image from a slide projector appears while a white rod moves rapidly across the projector's beam.

Objective:
To demonstrate how an image falling on a CCD array is divided into individual pieces.

National Education Standards:
Science
Evidence, models, & explanation
Motions & forces
Understandings about science & technology
Technology
Understand relationships & connections among technologies & other fields
Understand, select, & use information & communication technologies

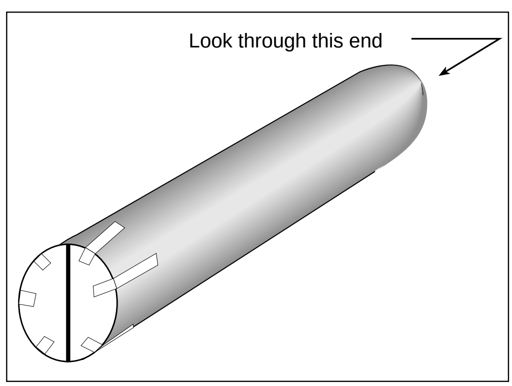
Materials:
Slide projector
Color slide of clearly defined object such as Saturn, a building, etc.
1/2-inch dowel, 3 feet long
Sheet of white paper
White paint (flat finish)
Dark room

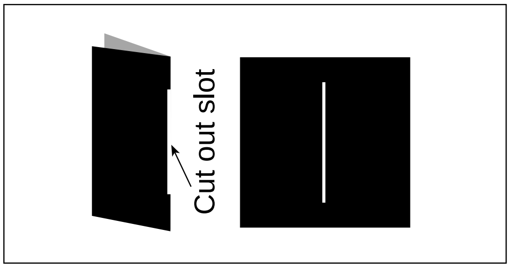
Procedure:
1. Paint the dowel white and permit it to dry. (A piece of 3/4-inch PVC water pipe from a hardware store can substitute for the dowel and white paint, and so can a painted meter stick.)
2. Set up the slide projector in the back of the classroom and focus the image of the slide at a distance of about 4 meters away from the projector. Hold the sheet of paper in the beam at the proper distance for easy focusing. Be sure the focus point you select is in the middle of the room and not near a wall.
3. Arrange the students between the focus point and the projector. Darken the room. Hold the dowel in one hand and slowly move it up and down through the projector beam at the focal point. Ask the students to try to identify the image that appears on the dowel.



4. Gradually, increase the speed of the dowel's movement.
5. When the dowel moves very fast, the image becomes clear.

Background:
Because astronomy spacecraft operate in space for many years, the data they collect cannot be recorded on camera film. There is simply no easy way to deliver the film to Earth for processing and to resupply the spacecraft with fresh film. Rather, the satellite instruments collect light from objects and divide it into discrete bits of information and radio them to Earth as a series of binary numbers. This activity demonstrates how images can be divided into many parts and then reassembled into a recognizable picture. By slowly moving the dowel across the slide projector's beam, small fragments of the image are captured and reflected ("radioed") towards the students. Because more and more fragments are sent as the dowel is moved, the image quickly becomes confused in the student's minds. However, as the rod is moved more rap-





idly, an important property of the eye and brain connection comes into play; light images are momentarily retained. This property is called persistence of vision. As the dowel's movement increases, single lines of the image remain just long enough to combine with the others to form a recognizable image. In this manner, the rapidly moving rod simulates the CCD and the eye/brain interaction simulates the final imaging computer that receives the radioed data and reassembles it for use.

Management and Tips:

By setting up the projector so that its projected image is focused in the middle of the room, the light from the image that falls on the far wall will be out of focus. This will make it more difficult for students to recognize the image until the dowel is passed through the light beam. Be sure to point out that the rod sends ("radios") a fragment of the entire image. When the rod is moved, another image fragment is received. Challenge your students to memorize each fragment as they receive it. The fragments will be quickly forgotten as new fragments are added. It is only when the rod is moved very fast that they will be able to recognize the image. However, if the fragments were received by a computer in a digital form, each fragment would be recorded and an image would be built up at any speed. Relate this activity to the Paint by the Numbers activity on pages 00-00.

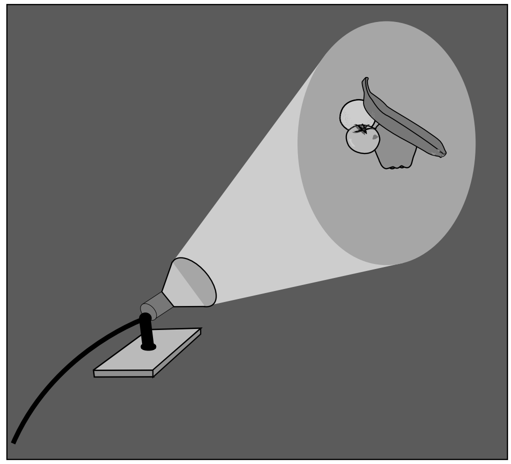
Assessment:

Ask students to explain the imaging process as it is demonstrated here and use examples of images in other applications where the images consist of small parts that combine to make a whole.

Extensions:

- How do television studios create and transmit pictures to home receivers?
- How does a CCD work?
- Project some slides. Magnify them as much as possible on a projection screen to see how the complete image consists of many discrete parts.
- Construct a persistence of vision tube. Close off the end of a cardboard tube except for a narrow slit. While looking through the open end of the tube, wave the tube back and forth. A recognizable image will form at the other end of the tube. Use the tube to examine fluorescent lights. Why do slightly darker bands appear across the lights? **Hint:** Fluorescent lights do not remain on continuously. The light turns on and off with the cycling of AC current. Will using the tube to view an incandescent light have the same effect? Use the tube to examine the picture on a television screen. Why is the TV picture reduced to lines? **Hint:** Television pictures consist of scan lines.
- A simpler version of the persistence of vision tube can be made with a 10 by 10-centimeter square of black construction paper. Fold the paper in half. Using scissors, cut a narrow slit from the middle of the fold. Open the square up and quickly pass the slit across one eye while looking at some distant objects.

ACTIVITY: Colors



Description:

Students identify the actual colors of objects bathed in monochromatic light and learn how three colors of light can be combined to produce colors ranging from black to white.

Objectives:

- To identify the actual colors of objects bathed in monochromatic light.
- To demonstrate how three colored lights can be combined to produce a wide range of secondary colors.
- To show how space observatories make use of monochromatic filters to collect data on the color of objects in space.

National Education Standards:

Science
    Evidence, models, & explanation
    Change, constancy, & measurement
Abilities necessary to do scientific inquiry
    Properties & changes of properties in matter
    Transfer of energy
    Understandings about science & technology
Technology
    Understand relationships & connections among technologies & other fields
    Understand troubleshooting, R & D, invention, innovation, & experimentation
    Understand, select, & use information & communication technologies

Materials:

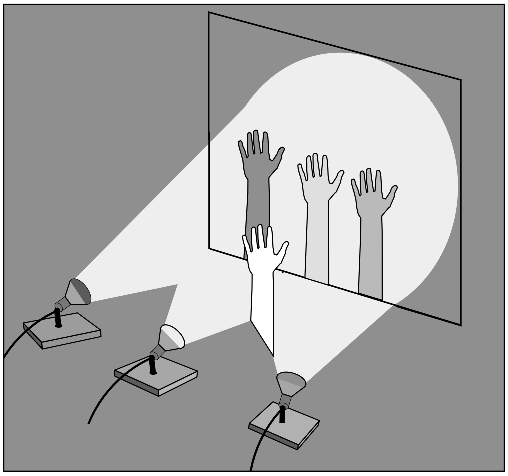
Indoor/outdoor floodlights (red, green, and blue)
Adjustable fixtures to hold the lights
Projection screen
Various colored objects (apple, banana, grapes, print fabrics, etc.)
Dark room

Procedure Part 1 - Color Recognition:

1. Prior to class, set up the three floodlights in a row at a distance of about 4 meters from the projection screen so that they each point to the center of the screen. The lights should be spaced about 1 meter apart. When properly aimed, the three lights should blend to produce a nearly white light falling on the screen. Move one or more lights closer to or farther away from the screen to achieve a proper balance.
2. Darken the classroom and turn on the red lamp.
3. Hold up the colored objects one at a time. Ask students to make notes on the Color Table as to how bright or dark the objects appear in the red light.
4. Turn off the red light and turn on the green light and repeat with the same objects. Repeat again, but this time use the blue light.
5. Turn on the room lights and show the students the actual colors of the objects.
6. Challenge the students to identify the colors of new objects. Show them the unknown objects in the red, green, and then blue lights. By using their notes, the students should be able to determine the actual colors of the objects.
7. Hold up a Granny Smith or Golden Delicious apple to see if the students can correctly judge its actual color or will instead jump to an erroneous conclusion based on shape.

Procedure Part 2 - Color Shadows:

1. Using the same light and screen setup, darken the room and turn all the floodlights on, hold up your hand between the lights and the screen. Three colored shadows appear—yellow, cyan, and magenta.
3. Move your hand closer to the screen. The shadows will overlap and produce additional colors—red, blue, and green. When all the

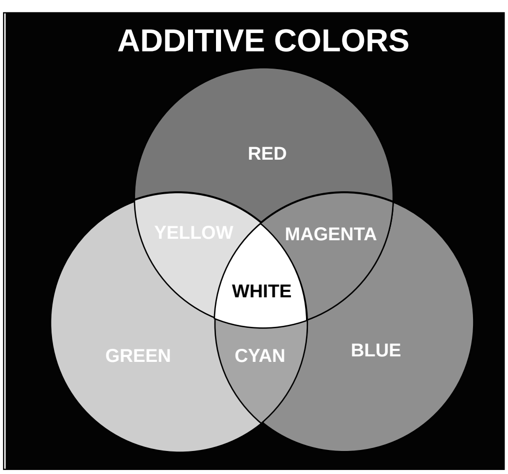


shadows overlap, there is no color (light) left and the shadow on the screen becomes black.

4. Invite your students to try their "hand" at making shadows.

Background:

Astronomical spacecraft, working in the visible region of the electromagnetic spectrum, collect images of stars and galaxies in various colors. Color filters rotate into the light path so that the detector sees one color at a time. The image in each of these colors is transmitted to Earth as a series of binary numbers. Image processing computers on Earth take each of the images, color them, and combine all the images to reconstruct a multi-colored image representing the true colors of the object. To enhance details in the images, astronomers will use artificial colors or boost the color in one or more wavelengths.



Part 1 of this activity demonstrates the data collection part of the color imaging process. By examining various objects in red, green, and then blue light, the students note that the brightness varies with the illuminating. Using colored lights is equivalent to observing the objects through colored filters. The way each object appears relates to its "real" colors as seen in normal light. By noting subtle differences in brightness in each of the three colored lights, the actual colors of the objects can be identified.

Part 2 of this activity demonstrates how a few basic colors can produce a wide range of colors and hues. When the three lamps are set up properly, the screen appears whitish. When all shadows overlap, they become black; black is the absence of light. In between white and black are red, green, blue, cyan, yellow, and magenta. By moving the floodlights forward and back, a wide range of hues appears.

Management and Tips:

It is difficult to get a pure white screen with indoor/outdoor floodlights. The colors produced by them are not entirely monochromatic. Using much more expensive lamps produces a better white but the whiteness is not significantly enhanced. An alternative to the colored lamps is to obtain red, green, and blue theatrical gels (filters) and place them (one each) on the stage of three overhead projectors. Aiming each of the three projectors to the same place on the screen produces the same effect as the lamps, but the colors are more uniform across the screen and the white is purer.

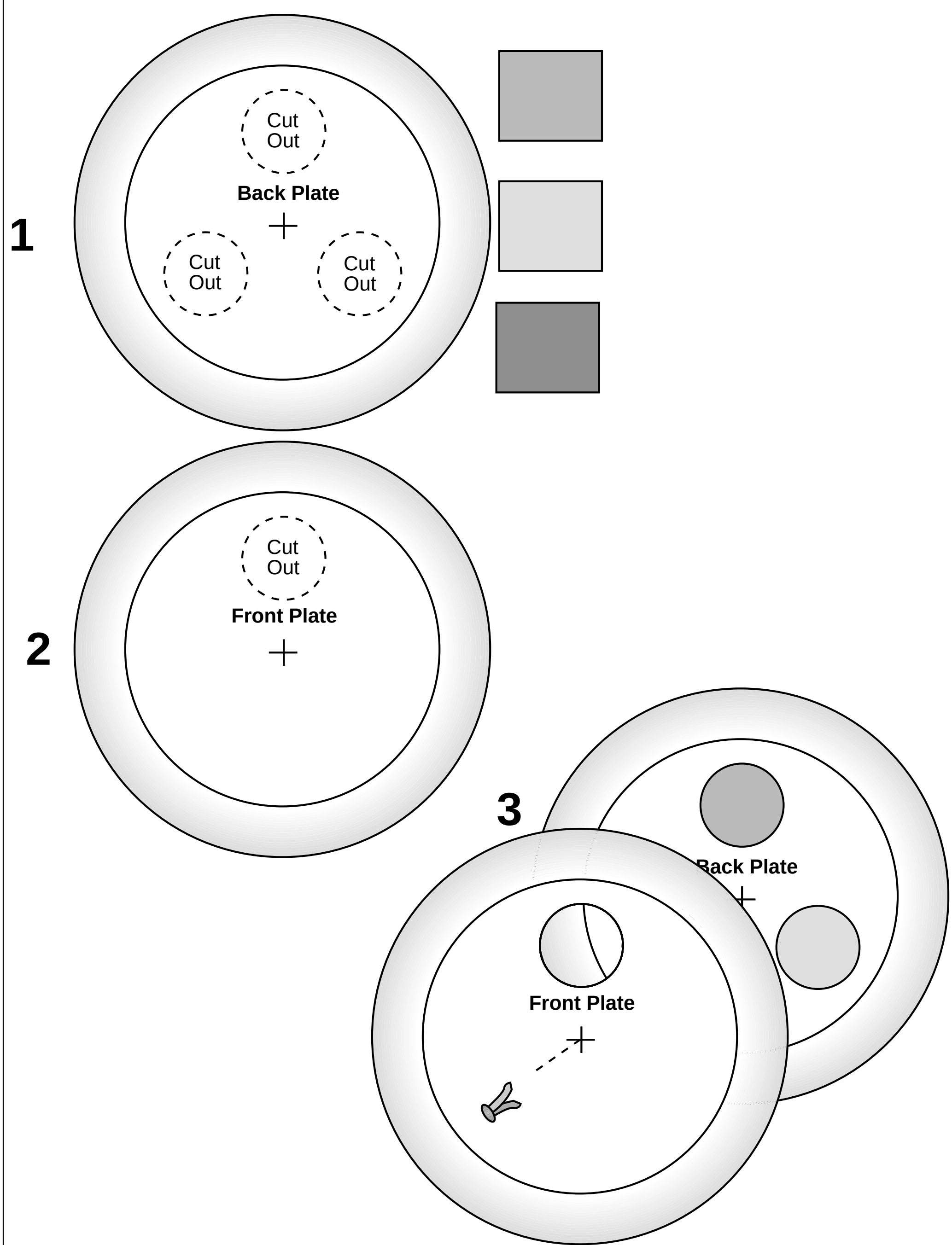
Assessment:

Collect the color tables of the students. Hold up colored objects in different monochromatic lights and have the students try to identify their white light colors.

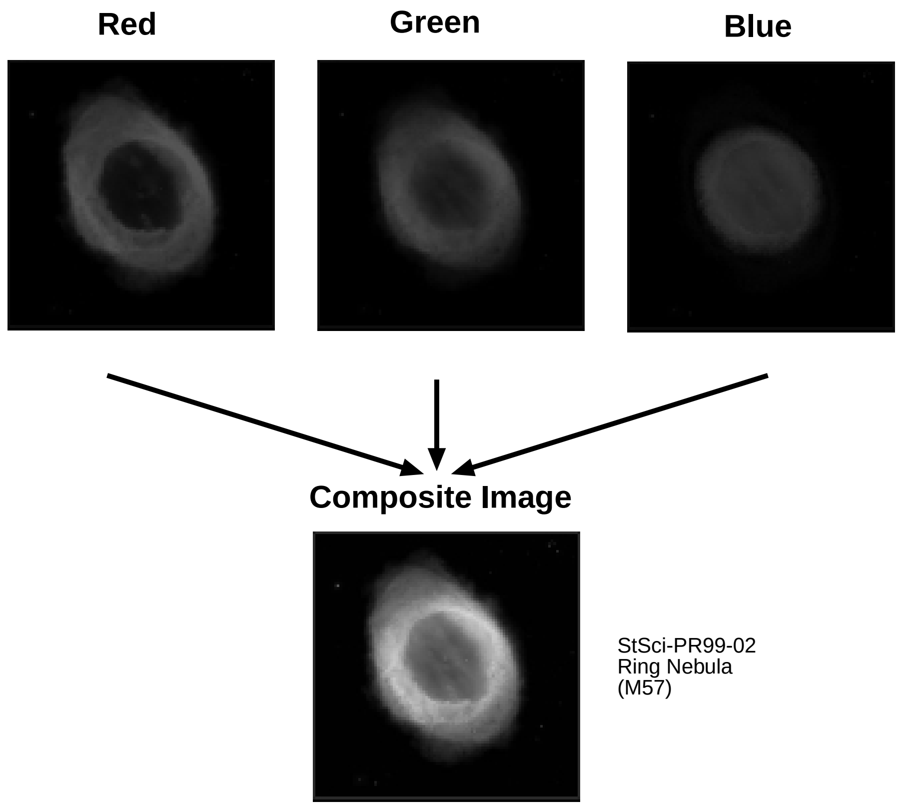
Extensions:

- Look at color magazine pictures. How many colors do you see? Examine the pictures with a magnifying glass. How many colors do you see? Also examine the picture on a color television screen.
- What common devices use red, green, and blue to produce colored pictures?

Color Filter Wheel



Color Image Process



This simulation of the imaging process of the Hubble Space Telescope required three separate images, each taken through a different filter. The M57 Ring Nebula looks very different in each of the exposures. To create the color composite image, each image is colored in red, green, or blue and combined.

- Is there any difference in the results of mixing colored lights and colored paints?
- Punch a 2-centimeter hole in an opaque piece of paper. Adjusting the distance of the paper to the screen may help students investigate the color additive process.
- This activity also works using colored acetate filters taped over small windows cut into file cards. Sheets of red, green, and blue acetate can be purchased at art supply stores. Students can make their own filter cards and take them home to look through the windows at a variety of objects. Better quality filters, that transmit "purer" colors, can be obtained from theatrical supply stores at a cost comparable to acetate filters. If your school has a theater department, you may be able to obtain filters (gels) from them.
- The following reference describes further activities with the filters:

Sneider, C., Gould, A., & Hawthorne, C., "Color Analyzers Teacher's Guide," *Great Explorations in Math and Science (GEMS),* Lawrence Hall of Science, University of California at Berkeley, 1991. (Available from the museum or the National Science Teacher's Association.)

Student Work Sheet

Color Table

Name ______________________________

Known Colors

Object	Red	Green	Blue	True Color

Unknown Colors

Object	Red	Green	Blue	True Color ?
1				
2				
3				
4				
5				

ACTIVITY: Binary Numbers

Description:

Two flashlights are used to demonstrate how astronomy spacecraft transmit images and other scientific data to Earth.

Objective:

To use the binary number system to transmit messages.

National Education Standards:

Mathematics
- Number & operation
- Patterns, function, & algebra
- Measurement
- Data analysis, statistics, & probability
- Communication
- Connections
- Representations

Science
- Evidence, models, & explanation
- Change, constancy, & measurement
- Understandings about science & technology

Technology
- Understand relationships & connections among technologies & other fields
- Understand cultural, social, economic, & political effects of technology
- Understand, select, & use:
  - Medical technologies
  - Agricultural technologies & biotechnologies
  - Energy & power technologies
  - Information & communication technologies
  - Transportation technologies
  - Manufacturing technologies
  - Construction technologies

Materials:

Two flashlights with pushbutton switches
Binary code and data sheets

Procedure:

1. Explain how astronomical spacecraft use the binary system to transmit, via radio waves, images and other scientific data from spacecraft to Earth. Refer to the background section for details on how the system works.
2. Distribute the data sheet and substitution code page to every student. Tap out a six number sequence of the push buttons on the two flashlights. Your right hand flashlight will represent a 1 and your left hand flashlight will represent a 0. As the lights flash, each student should check off the appropriate box in the practice column. To make sense later, the students must check off the boxes representing right or left flashes in the exact sequence of the flashing lights. Refer to the sample on the next page to see how to make the checks.
3. For the practice columns, total up the numbers each sequential flash represents. For example, if all flashes are with the left flashlight, the value is 0+0+0+0+0+0 = 0. If six flashes are all with the right flashlight, the value of the binary number is 63. The first right flash represents a 1, the second is 2, the third is 4, the fourth is 8, the fifth is 16, and the sixth is 32 (1+2+4+8+16+32=63). The following sequence of flashes is 37: Right, Left, Right, Left, Left, Right. After the boxes are filled in, the students total the numbers in the two columns. The answer will give students the total value of the number that was transmitted. (In this activity, the number will represent a letter in a message. With the Hubble Space Telescope, the number will represent the brightness of a particular point on an image.)
4. After the students become familiar with the method, transmit a message to the them. Create the message by referring to the substitution code in the following pages. Replace each word in your message with the corresponding code number. For example, "Hello!" would convert to 7, 4, 11, 11, 24, 38. Next, convert each code number into a binary number. Seven, for example, becomes Right, Right, Right, Left, Left, Left and 24 becomes Left, Left, Left, Right, Right, Left. As you will note in the substitution code, only the first 40 of the 64 possible numbers are used. The remaining numbers can be assigned to common words of your choosing such as "the" and "but," and to short sentences such as "How are you?" Transmit the message by flashing the lights in the proper sequence. Every six flashes represents a binary number

that can be converted into a letter or word through the code. Students receive the message by checking the flashes on the data sheet, determining the binary numbers they represent, and then changing the numbers into letters or words.

5. Discuss how a picture could be translated through binary code. (Refer to the activity Paint by the Numbers.)

Background:

Because astronomical spacecraft operate in orbit around Earth, the images they collect of objects in space have to be transmitted to the ground by radio signals. To make this possible, the light from these objects is concentrated on a light sensitive charged coupled device (CCD). The Hubble Space Telescope uses four CCDs arranged in a square. The surface of each CCD is a grid consisting of 800 vertical and 800 horizontal lines that create a total of 640,000 light sensitive squares called pixels for picture elements. With four CCDs, the total number of pixels in the Hubble Space Telescope CCD array is 2,560,000.

Photons of light fall on the CCD array and are converted into digital computer data. A numerical value is assigned to the number of photons received on each of the more than two million pixels. This number represents the brightness of the light falling on each pixel. The numbers range from 0 to 255. This range yields 256 shades of gray ranging from black (0) to white (255).

These numbers are translated into a binary computer code on board the spacecraft. A binary number is a simple numeric code consisting of a specific sequence of on and off radio signals. They are the same codes that are used in computers. A binary number radio transmission can be compared to a flashing light. When the light is on, the value of the signal is a specific number. When the light is off, the value is 0. (In this activity the right flashlight is the 1 and the left flashlight is the 0. Although the activity could be done with 1 flashlight, it would be difficult for students to determine how may 0's are being transmitted when the light is off. Computers precisely time the interval to determine how many 0's are in the sequence. Using a second flashlight for 0's makes it easy for students to determine the number of 0's.)

A binary number usually consists of 8 bits (1 byte). The first bit in the sequence represents a 1. The second bit represents a 2. The remaining 6 bits represent 4, 8, 16, 32, 64, and 128 respectively. If all bits are "on" the value of the binary number is the sum of each bit value—255. If all bits are "off," the value is 0. A sequence of on, off, on, on, off, off, on, and off represents the numbers 1+0+4+8+0+64+0, or 77. To save classroom time, the binary system has been simplified in this activity by using a 6-bit binary code. The total value of a 6-bit code is 64, or 1+2+4+8+16+32.

After the image of the space object is encoded, the binary bits are transmitted by radio waves to a receiving station on the ground. The photons of light that fall on each of the 2,560,000 pixels are now represented by a data set consisting of 20,480,000 binary bits. The computer will convert them to a black and white image of the space object. If a colored image is desired, at least two more images are collected, each one taken through a different colored filter. The data from the three images are combined by a computer into a composite image that shows the actual colors of the object being observed.

Because images collected by the HST and other astronomy spacecraft are digital, astronomers can use computers to manipulate images. This manipulation is roughly analogous to the manipulation of color, brightness, and contrast controls on a television set. The manipulation process is called enhancement and it provides astronomers with a powerful tool for analyzing the light from space objects.

To learn more about the imaging process, refer to the following activities in this guide: Paint by the Numbers and Colors.

Management and Tips:

Students may be confused by right and left flashlights when you face them. The right (1) and left (0) flashlights refer to the student's right and left.

Look at the columns of marks for each letter you transmit. If the mark is in the right-hand box and represents an on (1) signal, flash the right flashlight. Students will read this as a 0. If the mark is in the left-hand box and represents an off (0) signal, flash your left flashlight. Students will read this as a 1.

Students will sometimes lose track of the light sequence by concentrating on their paper. If you can dim the room lights a bit, which flashlight beam is turned on is easier to see out of the corner of the eye. Also, you can use the light fixtures used in the color activity for the code. Use the green lamp on for a 1 and the red lamp on for a 0.

Students may also become confused by using one number to represent another number. Make sure they understand the sequence of 1's and 0's is the code. The on-off (1-0) code is what is used in the process. However, other things could be used for the 1-0 such as the words "on-off" or even words like "pickle-pineapple." It is the sequence of the words or numbers used that is important.
If you have visually impaired students, you can substitute tapping two different surfaces to make two different sounds for them to listen to and interpret as 1's or 0's.

If you wish to use materials other than flashlights for transmitting data, you can make two cards with a large 1 on one card and a 0 on the other. Raise and lower the cards in sequence to represent a binary number.

Assessment:

Check the student sheets to see if they have correctly received the message.

Extensions:

- Have students code binary numbers with a binary coder consisting of several paper desert plates or shallow cups and markers such as jelly beans or breakfast cereal pieces. Arrange the plates in a row and number the first one "1". Mark the plate to the left "2" and the plate to the left of that one "4", etc. Place a small group of markers in the 1 plate. To code the markers into binary numbers, follow these rules: If a plate has two or more markers, remove two markers. Place one of the markers in a discard pile and place the other one in the plate immediately to the left. Continue removing markers from the 1 plate until there is only 1 or 0 left. If plate 2 has 2 or more markers, remove two. Discard one and place the other one in the plate to the left. Continue until all plates have only 1 or 0 markers in them. Starting on the left, write the binary number. Put down a 0 for a plate with no markers in it and a 1 for a plate with a marker in it. To check your work, add up the numbers on all the plates with markers. It should be the same as the number of markers you started with.
- Transmit binary numbers by having four students stand in a row in front of the class. Give each student a card with a 1 on one side and a 0 on the other. Quietly tell the students to transmit the number 7 to their classmates. The four students will have to determine between them who holds up a 0 and who holds up a 1. The binary sequence for 7 is 0111. The remainder of the students should try to decode the binary number. With more students in the row, higher numbers can be transmitted.
- Have students transmit other scientific data with binary numbers. For example, students can measure the temperature of a liquid or the mass of an object and transmit the results to another student.
- How are binary numbers used in computers?
- How high can you count with a binary number consisting of 10 bits? 12?

Student Work Sheet - 1

Data Sheet

Name: ______________________________

Sample

32	16	8	4	2	1
0	**1**	**0**	**1**	**1**	**0**

= **22** Total

(16 + 4 + 2 = 22)

Practice

32	16	8	4	2	1
0	**0**	**1**	**1**	**0**	**1**

= ____ Total

Practice

32	16	8	4	2	1
1	**1**	**0**	**1**	**1**	**0**

= ____ Total

(Practice answers at bottom of page)

Start

Work down

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

Go to top

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

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32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

Go to top

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

= ____ Total

32	16	8	4	2	1

Finish

= ____ Total

Practice Answers: 13 and 54

ACTIVITY: Paint by the Numbers

Description:

A pencil and paper activity demonstrates how astronomical spacecraft and computers create images of objects in space.

Objective:

To simulate how light collected from a space object converts into binary data and reconverts into an image of the object.

National Education Standards:

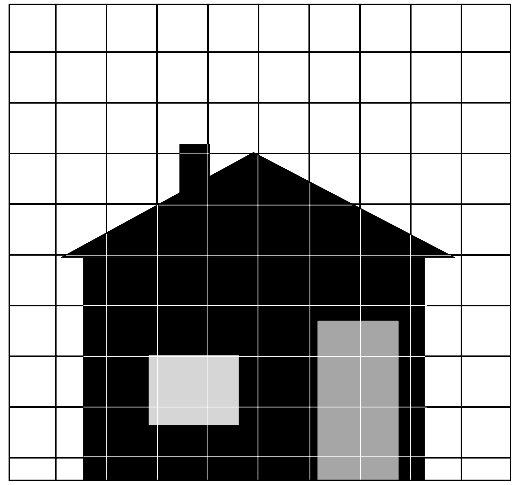
Mathematics
- Number & operation
- Patterns, function, & algebra
- Measurement
- Data analysis, statistics, & probability
- Communication
- Connections
- Representations

Science
- Evidence, models, & explanation
- Change, constancy, & measurement
- Earth in the solar system
- Abilities of technological design

Technology
- Understand cultural, social, economic, & political effects of technology
- Ability to use & maintain technological products & systems
- Understand, select, & use:
  - Medical technologies
  - Agricultural technologies & biotechnologies
  - Energy & power technologies
  - Information & communication technologies
  - Transportation technologies
  - Manufacturing technologies
  - Construction technologies

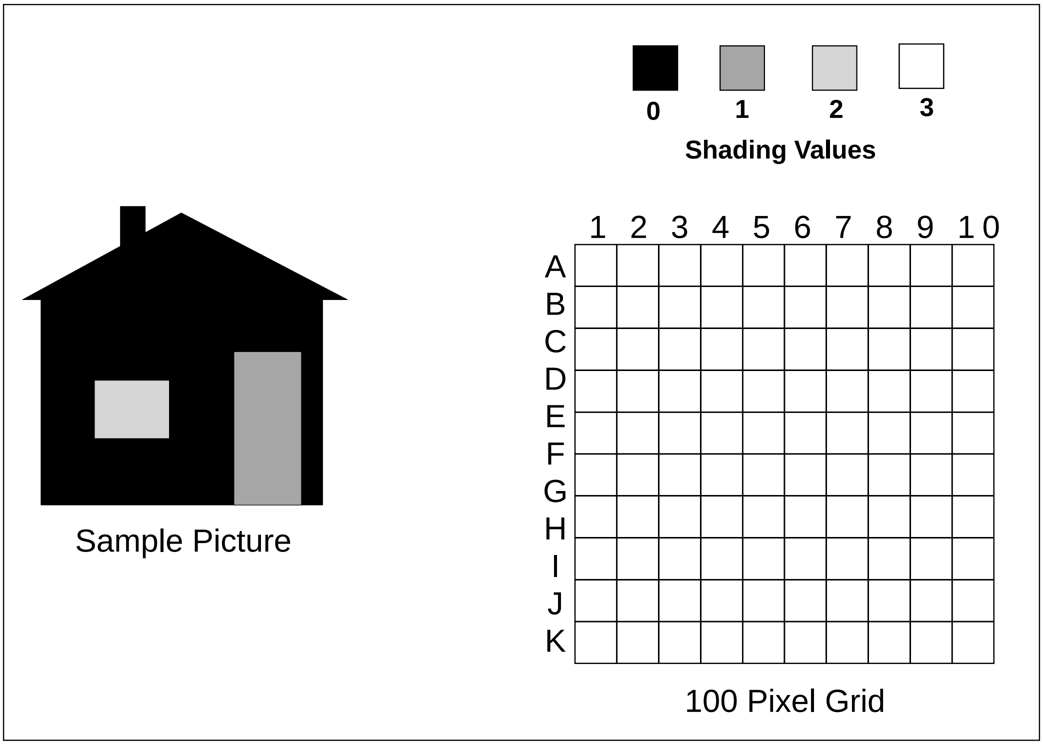
Materials: (per group of two students)

Transparent grid
Paper grid
Picture of house
Pencil



Procedure:

1. Divide students into pairs.
2. Give one student (A) in each pair the paper copy of the blank grid on the next page. Give the other student (B) in each pair the picture of the house on the next page. Instruct student B not to reveal the picture to student A. Also give student B a copy of the transparent grid. (See notes about making student copies of the picture and grids on the next page.)
3. Explain that the picture is an object being observed at a great distance. It will be scanned by an optical device like those found on some astronomical satellites and an image will be created on the paper.
4. Have student B place the grid over the picture. Student B should look at the brightness of each square defined by the grid lines and assign it a number according to the chart above the picture. Student B will then call out the number to student A. If a particular square covers an area of the picture that is both light and dark, student B should estimate its average brightness and assign an intermediate value to the square such as a 1 or a 2. Note: The letters and numbers on two sides of the grid can assist the receiving student in finding the location of each square to be shaded.
5. After receiving a number from student B, student A will shade the corresponding square on the grid. If the number is 0, the square should be shaded black. If it is 3, the square should be left as it is.



6. Compare the original picture with the image sketched on the paper.

Background:

This activity simulates the process by which an astronomy spacecraft such as the Hubble Space Telescope collects light from an astronomical object and converts the light into a digital form that can be displayed on Earth as an image of the object. The student with the transparent grid represents the spacecraft. The picture is the object the spacecraft is trying to collect from. The student with the paper grid represents the radio receiver on the ground and the image-processing computer that will assemble the image of the object.

The image created with this activity is a crude representation of the original picture. The reason for this is that the initial grid contains only 64 squares (8 x 8). If there were many more squares, each square would be smaller and the image would show finer detail. You may wish to repeat this activity with a grid consisting of 256 squares (16 x 16). However, increasing the number of squares will require more class time. If you wish to do so, you can select a single student to represent the spacecraft and transmit the data to the rest of the class.

With the HST, the grid consists of more than 2.5 million pixels and they are shaded in 256 steps from black to white instead of just the 4 shades used here. Color images of an object are created by the HST with color filters. The spacecraft observes the object through a red filter, a blue filter, and then a green one. Each filter creates a separate image, containing different information. These images are then colored and combined in a process similar to color separations used for printing colored magazine pictures.

Management and Tips:

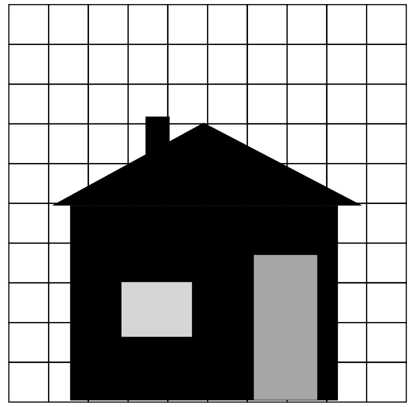
Students can provide their own pictures for this activity. It is important for the pictures to show strong contrast. The smaller the grid squares, the more detail that will appear in the image. However, simply going from a grid of 10 x 10 to a grid of 20 x 20 will quadruple the length of time it takes to complete the image. Refer to the Color Recognition and Colored Shadows activities for more details on how color filters work and how to combine colors.

Assessment:

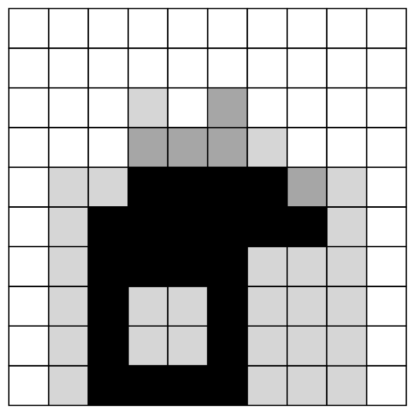
Collect the pictures of the house drawn by the student receivers. Compare the original drawing with the student images. Discuss with your students possible strategies for improving the detail of the images.

Extensions:

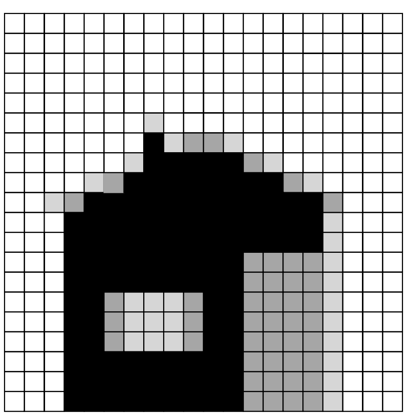
- Transmit and reconstruct the image of Saturn shown on the next page. This more advanced picture uses six shades and smaller grid squares.
- Examine printed copies of drawings made with a computer art program. Notice how the pictures are constructed of individual points. Also notice how the size of the points contributes to the fineness of detail in the picture.
- Examine pictures drawn on a computer. Use the magnifying tool to move to the maximum magnification possible. Compare the two views.
- Obtain Hubble Space Telescope images from the Internet sites given in Unit 5. Examine them closely for the pixel structure. Alternately enlarge and reduce the image size on your computer screen to see the effect on the fineness of detail.



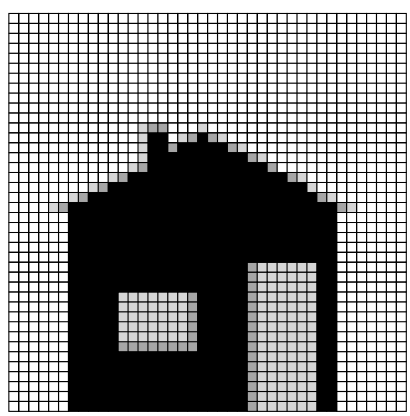
100 Pixel Grid Over House



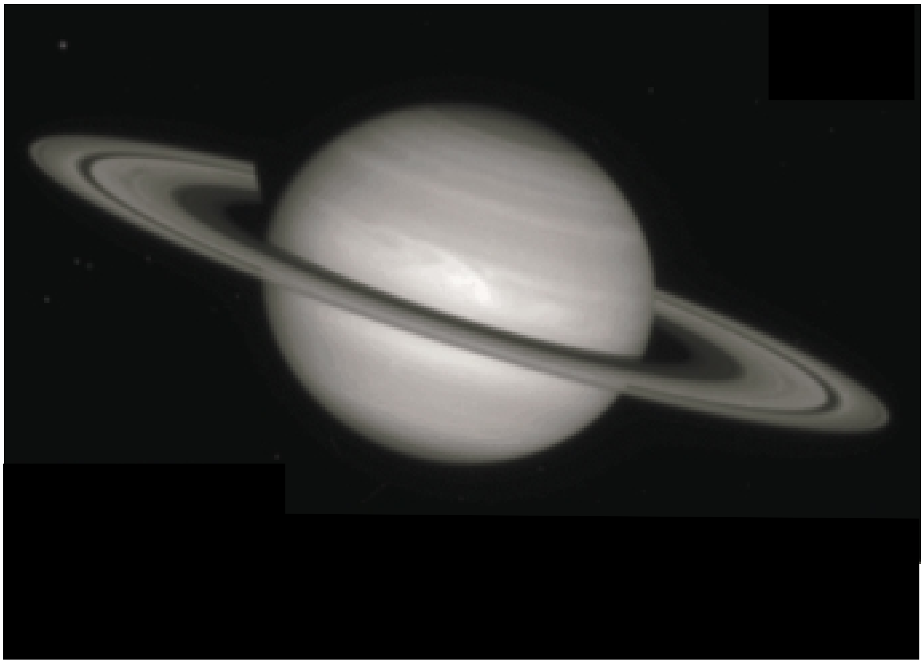
100 Pixel Grid

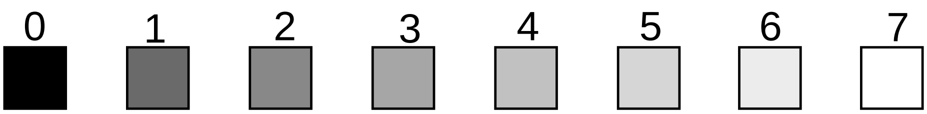


400 Pixel Grid



1,600 Pixel Grid

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