SIEMENS STEM DAY | Science Technology Engineering Math

SATELLITE TELEMETRY

Level of Difficulty: 4
Grade Range: 9-12
Activity Time: 45-60 min
Business Category: IT
Topic: Information and Communication

OVERVIEW

Information and Communication

In this lesson, students will explore how satellites send images from telescopes in space, which we can access on Earth via the Internet. They will examine how data is transferred by radio waves, as well as decode images from real satellites using a series of ones and zeros. As an extension, students will research how maps of damage derived from satellite data impact how scientists think about future quakes and earthquake hazards.

STEM LESSON FOCUS

Engineering Design Cycle	21st Century Skills
• Communicating Results	• Critical Thinking

OBJECTIVES

Students will be able to:

- **Describe** how satellite data is transmitted from space to Earth,
- **Explain** how technological devices store and interpret this data from satellites, and
- **Synthesize and apply** this new information by decoding images from real satellites using a series of ones and zeros.

MATERIALS

For this lesson, students will need:

- A computer with access to the internet
- Satellite images and pixel maps (see links below)
- Graphic paper

SATELLITE TELEMETRY

- ***Summary Questions Student Worksheet***
- Black markers and pencils

HAVE YOU EVER WONDERED…

How satellites relay messages to ground receivers or how digital information is encoded/decoded in radio waves?

MAKE CONNECTIONS!

How does this connect to students?	How does this connect to careers?	How does this connect to our world?
Satellites have many applications and uses in our everyday life. Some of these satellite applications include internet and radio, GPS, astronomy, and weather.	**Geospatial intelligence specialists** are responsible for analyzing imagery from a variety of sources such as satellites and remotely piloted vehicles. Their intelligence activities support the mission of the US Air Force. **Satellite engineers** work with satellite systems and develop software that direct orbiting satellites, monitor satellites for problems, and conduct testing of communication systems. They are primarily employed by aerospace companies and defense contractors. **Electrical and computer systems engineers** work in a diverse engineering and analysis team to monitor satellite computer hardware/software for potential performance problems.	Over 2,000 Earth-orbiting satellites transmit signals carrying data, voice, and video to and from many locations throughout the world. In many developing countries, satellite-supported, smart phone technology provides the only means of telephone communication and internet access for much of the population, as little land-line infrastructure exists.

If you want students to further explore career opportunities connected to this topic, please allow for more classroom time.

SATELLITE TELEMETRY

BLUEPRINT FOR DISCOVERY

Follow the instructions below to complete the activity.

1. Divide Project the binary code image on the board or make half-sheet copies of an enlarged image. Ask students to decode the message by shading in or highlighting each number one. The message reads STEM.

```
00000000000000000000000000000000000000
00000111100011 1110001111001100 110000 0
00000100000 0001000001000001 01 0110000 0
000001111000000 100000111100 10 11010000 0
000000001000000 10000010000010000 10000 0
000001111000000 10000011110010000 10000 0
00000000000000000000000000000000000000
```

2. Explain to students that binary code (a series of zeros and ones) is used to transmit images, such as those from the Hubble Space Telescope, back to Earth via satellite using a process called telemetry. The word telemetry is derived from two Greek roots: *tele* = remote and *metron* = measure. Have students write down the following general definition of telemetry:

   Telemetry is the automated measurement and wireless transmission of data from remote sources by radio, cellular or other means.

   Show images from the Hubble Space Telescope using the following link (or, if students have one-to-one access to internet-connected devices, they can bring up the images themselves and review them for a few minutes independently while the teacher provides the overview): https://www.nasa.gov/mission_pages/hubble/multimedia/index.html

   Tell students that, according to NASA, the Hubble Space Telescope has made more than 1.3 million observations since its mission first began in 1990, and it has beamed hundreds of thousands of images back to Earth.

   The language that scientists and engineers use to communicate with these machines is binary code. The breathtaking and colorful pictures from space started out as signals sent to Earth via satellites in the form of binary code. Computers then decode and process these signals into magnificent images.

SATELLITE TELEMETRY

3. Review the following background information before beginning the main activity:

   - Satellites communicate by using radio waves to transmit signals to antennas on Earth. Radio waves are electromagnetic waves that range in frequency between 3 kilohertz (or three-thousand hertz) and 300 gigahertz (or three-hundred billion hertz) and have corresponding wavelengths from 1 millimeter to 100 kilometers. A radio wave is generated by a transmitter which is subsequently detected by a huge receiver. Antennas capture those radio electromagnetic waves and process the data coming from them. The data conveys information such as pictures the satellite took, the location of the satellite, and the operation/health of the satellite.

   - Pose the following questions to the class:
     Can someone tell me the two types of radio waves?
     How do these two types of radio waves differ?

     There are two ways to put information in a radio wave: A.M. or amplitude modulation and F.M. or frequency modulation. The amplitude is the height of a wave. The frequency is the number of crests of a wave that pass a given point, per unit of time. A common measure of frequency is hertz (Hz), which corresponds to one crest per second. To send binary code through amplitude modulation, there need to be two different levels of amplitude represented by 0's and 1's at a constant frequency. For instance, zero could represent lower amplitude (shorter wave) and 1 could represent higher amplitude (taller wave). In the frequency modulation (F.M.) method, the amplitude is held constant whereas the frequency is varied (0 could mean high frequency, and 1 could mean low frequency).

   - Now that we know how data is transmitted using binary code, let's discuss how that data is displayed. Ask students:
     Who can tell me what the word "pixel" means?
     In what context have you heard this term used?

     Computer screens are divided into a grid of small dots called pixels or **pic**ture **el**ements. Digital images are recorded/transferred as pixels and higher resolution is achieved with the use of a greater number of pixels which requires more memory. In a black and white image, each pixel is either black or white.

     Therefore, when a computer stores a picture, it stores which dots are black and which are white. Thus, a picture can be represented as a grid of numbers where 0 indicates white and 1 indicates black. Numbers along each row will represent the sequence of white and black pixels as shown below:

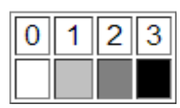
The sequence 0, 1, 1, 1, 1 can be represented pictorially as:

- To produce colored images, a number is used to represent the color (e.g. 0 = black, 1 = red, 2 = green, 3 = blue, etc.). Two numbers can then be used to represent a run of pixels (the first giving the length of the run and the second giving the color), thus compressing the overall length of the code.

- Pause for questions and to correct misconceptions before moving on to the activity.

4. Begin the decoding activity.[1] Divide students into four or eight NASA imaging teams. (For larger class sizes, eight teams can create two complete images.) Task each team with decoding one data set, each of which will be combined with others to reveal an actual satellite image of a celestial body.

    - Each team needs one of four pixel maps, available here: https://btc.montana.edu/ceres/html/Pixel/pixelfour.htm , a sheet of graph paper, a black marker, and a pencil. Direct students to carefully read across rows, one row at a time to ensure accuracy, shading each square on their graph paper according to the legend provided on the pixel map



NOTE: The marker should be used for "black" and the pencil to shade in the two gradients of gray.

- Challenge students to use their creativity to come up with ways to speed up the process, while still maintaining accuracy.

- When all teams have finished, line up the teams' images (as shown below) with no gaps in the data.

[1] Decoding activity adapted from the NASA/MSU-Bozeman Center for Educational Resources (CERES) Project's *Digital Images: From Satellites to Internet* online educational resource: https://btc.montana.edu/ceres/html/Pixel/pixel1.html

SATELLITE TELEMETRY

Image TWO	Image ONE
Image THREE	Image FOUR

The combined images will yield an actual image of our Sun that was captured by a telescope on board the NASA and Japanese Yohkoh satellite. The black spots illustrate energetic and active regions where sunspots are often observed. Interestingly, when these charged particles emanating from the Sun strike atoms in the Earth's atmosphere, the electrons in those atoms get excited and release energy in the form of light as they drop back down to their lowest energy state. This process creates the beautiful Aurora Borealis, or Northern Lights.

5. Instruct students to get back into their NASA imaging teams to answer the ***Summary Questions Student Worksheet*** collaboratively. After the teams answer all of the questions, assign each team one question to report out to the class. Have representatives from each team share their answers and explain how they reached their conclusions.

   The questions and suggested answers are shown below:

   - How does the class image compare to the latest images taken by the Yohkoh satellite, seen here: https://umbra.nascom.nasa.gov/images/latest.html . Identify at least three comparisons.

     Answers will vary, but students should notice that both their images and the ones on the NASA website depict contrasting elements such as black sunspots. However, the images posted on the NASA website have color. This is a good opportunity to tell students that producing these color images is a much more complicated process than the one undertaken in class. Scientists must use "false color" techniques to visually represent data from electromagnetic waves that span outside the visible region. The colors in the online images represent different properties (intensity, energy, temperature) of the radiation and these, in turn, highlight various properties of the astronomical body being examined.

   - Unlike most images from the Internet, which are 256 x 256 pixels, many satellite images are 512 x 512 pixels. How many total pixels are in a satellite image of that size? How long would it take to relay that many pixels verbally, assuming it takes one second per pixel?

There are 512 x 512 = 262,144 pixels. Assuming it takes one second per pixel, it would take 262,144 seconds which is equal to more than three days (assuming 24-hour non-stop work).

- Due to the length of time required to read a huge amount of data points, scientists must come up with strategies to expedite the process through data compression. How did your imaging team speed up the process of decoding the image while maintaining accuracy?

  Answers will vary but it's important to note that scientists must work in big teams to break down the work into more manageable chunks and make the process more efficient. It is important for students to realize that although computers are used extensively to decode satellite images, scientists and programmers must work diligently in quality control measures to validate that the computers are producing technically correct images. One mistake can lead to inaccurate results, which is why scientists are so careful in checking all of the data.

- These images are of the sun, but satellite telemetry is also used to view Earth from space. What are specific real-world applications of this kind of satellite telemetry? Think of at least three possibilities.

  Possible examples include the following:
  - **Forecasting weather**
  - **Monitoring agriculture**
  - **Making topographic maps**
  - **Studying and tracking animal migration**
  - **Surveying areas after natural disasters**
  - **Observing changes over time in population density/land development**

TAKE ACTION!

Research how damage maps derived from satellite data impact how scientists think about future quakes and earthquake hazards. The following resources provide useful information on the topic:
https://www.nasa.gov/feature/jpl/nasa-damage-maps-may-help-in-future-quakes
https://www.nasa.gov/feature/jpl/study-of-complex-2016-quake-may-alter-hazard-models
https://pubs.usgs.gov/fs/2003/fs017-03/

SATELLITE TELEMETRY

NATIONAL STANDARDS

Next Generation Science Standards	HS-PS4-5. Communicate technical information about how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
Standards for Technological Literacy	Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies. M. Information and communication systems allow information to be transferred from human to human, human to machine, machine to human, and machine to machine. P. There are many ways to communicate information, such as graphic and electronic means.

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GRAPHING PAPER

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SUMMARY QUESTIONS WORKSHEET

1. How does the class image compare to the latest images taken by the Yohkoh satellite, seen here: https://umbra.nascom.nasa.gov/images/latest.html . Identify at least three comparisons.

2. Unlike most images from the Internet, which are 256 x 256 pixels, many satellite images are 512 x 512 pixels. How many total pixels are in a satellite image of that size? How long would it take to relay that many pixels verbally, assuming it takes one second per pixel?

3. Due to the length of time required to read a huge amount of data points, scientists must come up with strategies to expedite the process through data compression. How did your imaging team speed up the process of decoding the image while maintaining accuracy?

4. These images are of the sun, but satellite telemetry is also used to view Earth from space. What are specific real-world applications of this kind of satellite telemetry? Think of at least three possibilities.