Activity Four: Networks

Educator Notes

Learning Objectives

Students will

- Solve a variety of network problems using minimum spanning trees.
- Determine the shortest route to visit each destination in a network.

Challenge Overview

Many networks link our society together, such as telephone networks, computer networks, and transportation networks, in addition to NASA's Deep Space Network (DSN). In this activity, students will find the most efficient way of getting from one place in a network to another.

Suggested Pacing

45 to 60 minutes

National STEM Standards

Science and Engineering (NGSS)	
• MS-ETS1-2: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. *Disciplinary Core Ideas* • ETS1.C: Optimizing the Design Solution	*Science and Engineering Practices* • Asking Questions and Defining Problems • Developing and Using Models • Using Mathematics and Computational Thinking • Crosscutting Concepts • Influence of Science, Engineering, and Technology on Society and the Natural World
Technology (ISTE)	
Knowledge Constructor • 3d: Students build knowledge by actively exploring real-world issues and problems, developing ideas and theories, and pursuing answers and solutions. *Computational Thinker* • 5a: Students formulate problem definitions suited for technology-assisted methods such as data analysis, abstract models, and algorithmic thinking in exploring and finding solutions. • 5d: Students understand how automation works and use algorithmic thinking to develop a sequence of steps to create and test automated solutions.	*Innovative Designer* • 4a: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts, or solving authentic problems. *Creative Communicator* • 6c: Students communicate complex ideas clearly and effectively by creating or using a variety of digital objects such as visualizations, models, or simulations.
Computer Science (CSTA)	
Standards for Students • 1B-NI-04: Model how information is broken down into smaller pieces, transmitted as packets through multiple devices over networks and the internet, and reassembled at the destination.	*Standards for Students (continued)* • 2-NI-04: Model the role of protocols in transmitting data across networks and the Internet. • 2AP-10: Use flowcharts and/or pseudocode to address complex problems as algorithms.
Mathematics (CCSS)	
Mathematical Practices • CCSS.MATH.CONTENT.6.EE.B.6: Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or depending on the purpose at hand, any number in a specified set.	

Challenge Preparation

The educator should

- Read the introduction and background material, particularly the information about NASA's Deep Space Network.
- Read the Educator Notes and Student Handouts to become familiar with the activity.
- Prepare the materials listed below.

Materials

Each student/group will need

☐ Student Handout: Scavenger Hunt
☐ Student Handout: Deep Space Neighbors

- ☐ Dry-erase board and colored dry-erase markers in black, red, and blue
- ☐ Colored pencils or markers
- ☐ 50 cotton swabs or toothpicks
- ☐ 10 buttons or pennies

Safety

- There are no safety concerns with this activity.

Introduce the Challenge

Engage

- Remind students that there are many kinds of networks in their lives, such as telephone networks, computer networks, transportation networks, and even networks of friends. NASA's DSN may be much more technically complex than a friend network, but relaying a message from Mars to Earth via satellites has a lot in common with passing a note to a friend via a few other friends. One of the most fundamental problems is figuring out which friend will pass the note most efficiently.
- Pass out Student Handout Challenge 1: Scavenger Hunt. Explain that the scavenger hunt activity is a simplified explanation for how computers design complicated networks by finding ways to efficiently connect each object in the network.

Facilitate the Challenge

Explore

- Read the scavenger hunt directions with students.
- Allow students to work individually on the scavenger hunt and then come back together as a whole group. To scaffold instruction within this activity, consider simplifying the scavenger hunt to only a few objects to introduce the idea of networks.

Explain

- Discuss with the group the solutions they found for the scavenger hunt challenge. Have students explain what strategies they used.
- On the board, write the following words and discuss with the group their ideas for the words' definitions. As the activity progresses, add the definitions from the lesson to the board.
  - Graph
  - Abstraction
  - Algorithm
  - Minimum spanning tree
- Give students the following directions:
  - To begin the scavenger hunt, pick one item on the scavenger hunt map. That is the starting point. The next task is to connect that location to another on the map, using the shortest path possible, and then color in the path.
  - Continue working through the scavenger hunt by connecting more items, using as few steps as possible. Items that are already linked through another path **do not** need to be connected. Sometimes it may be better to go back to a location that has already been visited in order to connect to other items, and it may be shorter to use a new path than to backtrack. Two example paths are shown here in red:

Share With Students

Brain Booster

TV and movies tend to make communication in space look easy. Astronauts communicate with family and friends with crystal-clear clarity and no delay. In actuality, space communication is a challenging task, and NASA is up for the job!

Artist's rendering of tracking and data relay satellites alongside the International Space Station and the Hubble Space Telescope. (NASA)

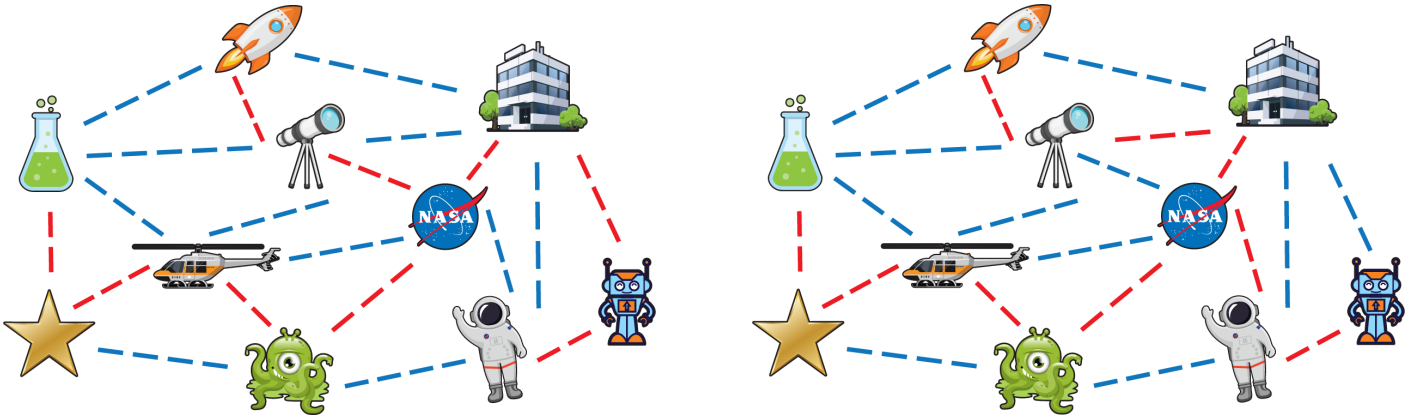
Learn more:
https://www.nasa.gov/feature/goddard/2020/space-communications-7-things-you-need-to-know

On Location

Virtually visit NASA's three Deep Space Network (DSN) antenna complexes across the world in the engaging video "Where in the World is the DSN?"

Artist's concept of Deep Space Station 23, a new antenna dish being constructed at the Goldstone, California, DSN complex. (NASA)

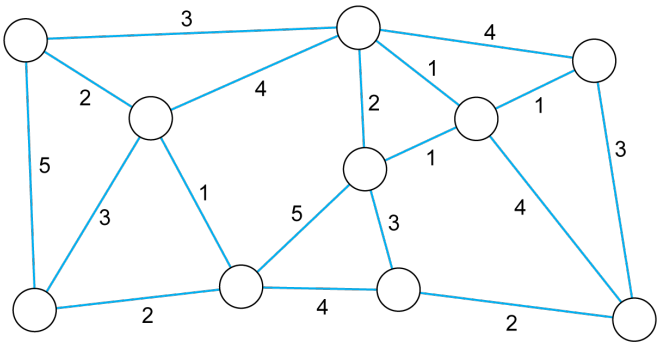
Learn more:
https://youtu.be/Plkmm8f_4DE



- Ask students where they would find networks of paths in real life. (Examples: Phone, computer, class schedules, bus routes, navigating a grocery store)

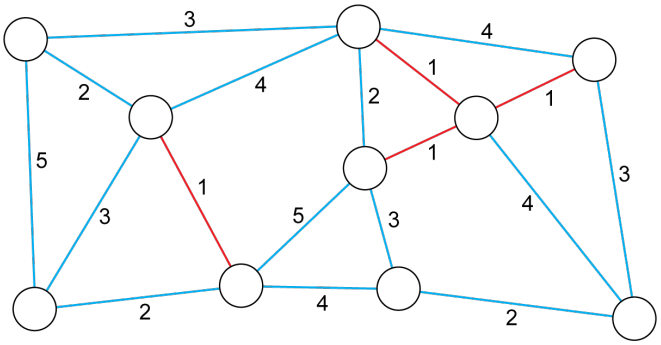
Elaborate

- It can be very time consuming to draw items and create detailed maps like the one in the scavenger hunt activity. A quicker way to generate new maps is to use circles and lines with numbers representing the length of each path. As a first example of this type of a simple network map, draw or project the diagram below on the board. Another option is to create a digital version that students can interact with on computers—for example, in a presentation.



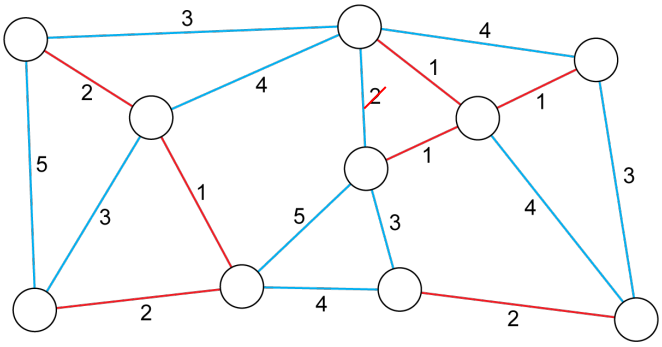
The formal name for this simpler type of map is a network *graph***.** There are many kinds of graphs; students may be more familiar with bar graphs, scatter plots, or histographs. All graphs represent data in a simpler fashion by highlighting some data and ignoring other data. This is called an *abstraction***,** and in this case, we are highlighting the distances and ignoring the object itself. The steps that are taken and repeated to solve a problem are called an *algorithm*. The algorithm demonstrated with the scavenger hunt is called a *minimum spanning tree***.** As a reminder, this algorithm focuses on always using the shortest distance available. With the scavenger hunt activity, the focus is on traveling the shortest route in order to visit all the locations on the map. However, for real-life networks, such as the DSN, a message just needs to find the shortest path to its destination; it may not need to travel along the entire network. In this way, a minimum spanning tree can be even more efficient for finding the shortest length of path from anywhere, not just from a single location. Explain to students that the next example will focus on this new, more efficient minimum spanning tree algorithm.

- In the graph above, shade in all the paths with a length of 1, because those are the shortest lengths to choose from. The completed shading is shown in red in the example that follows here:

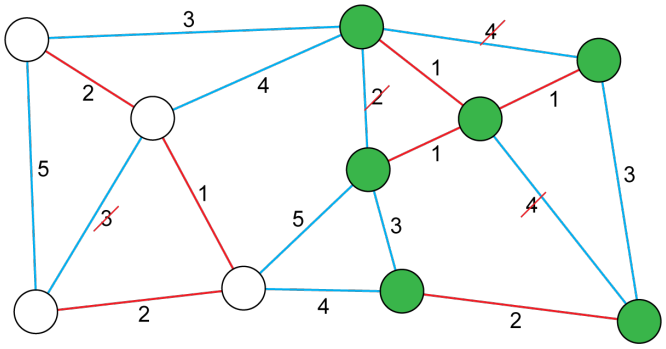


- Next, shade in the lengths of 2, *unless* the two circles have already been attached to the network through the lengths of 1.

  Note: Students may be confused to see that you are not starting in one place and drawing a connected path. Explain that since you already know the entire graph, a more effective decision can be made by selecting all the shortest lengths of paths. Also, notice that one length of 2 has been crossed through in the graph below. It is not needed because the two circles are already connected through the lengths of 1.



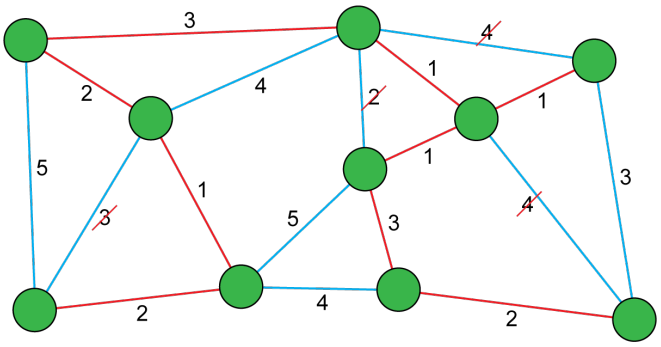
- Each circle now has at least one path leading to it. It is important to ensure that all the circles are connected to the entire network.
  - To ensure that all circles are connected, pick a circle at random to start with and fill it in (shown in the figure below with green circles).
  - Fill in every circle that can be reached directly from the starting circle using the shaded paths from the earlier exercise. For example, if starting with the circle to the top right, the circle that is one length away will be shaded in next.
  - In some cases, the circles will not be directly connected, but they will be connected in another way through the same network. That is okay! The goal is to lessen the number of steps in the minimum spanning tree.
  - If two items are connected in two different ways, eliminate the greater length by crossing it out. In this example, the length of 4 at the top of the graph is crossed out because there is another way (the length of 1) to get to the circle on the other end of that path. After connecting two more circles, another path of length 4 can be crossed out because the length of 3 is smaller.



- Ask students if all the items are connected. As seen in the figure above, all the filled circles are connected in the network, but there is no completed path to the four remaining items. Make sure students understand that there are six items that are connected, and the other four items are connected to each other. Once students have connected those four to the entire network, they have

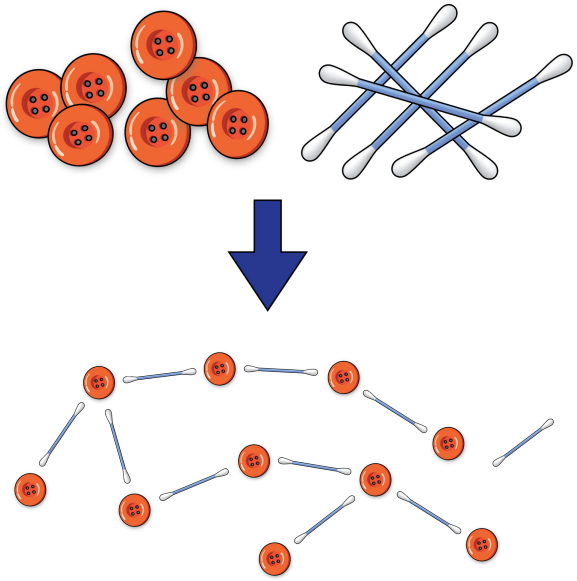
completed the graph. Ask students which path they would choose. There are four ways to connect them, but it is important to choose the shortest length of path possible. Students should choose the length of 3 at the top of the graph.

- Ask students what would happen if there were two lowest length paths.
  - Answer: We could choose either of them.
- The final solution is below. Each item can now be reached in the minimal number of steps. It is a minimal solution because for *n* items (10 in this example), *n* – 1 paths (i.e., 9) are needed. Adding extra paths would be redundant and would add unnecessary steps, because only one path is needed to connect each item.



Evaluate

- Now that students are familiar with minimum spanning trees, pass out Student Handout Challenge 2: Deep Space Neighbors.
- Instruct students to create a minimum spanning tree connecting all the satellites and antennas in the DSN.
- As a hands-on activity to this exercise and an evaluation of students' understanding, split up students into groups of two. Have each pair of students construct a connected graph using buttons or pennies and the cotton swabs or toothpicks, allowing students to choose what they prefer to work with. Have each group swap graphs with another group and try to find the minimum spanning tree of the other group's student-created graph.



Resources

Where in the World Is the DSN? A Virtual Tour of NASA's Deep Space Communications Network (Video). https://youtu.be/PIkmm8f_4DE

Basics of Radio Astronomy. https://www2.jpl.nasa.gov/radioastronomy/radioastronomy_all.pdf

Activity Four: Networks With NASA's Deep Space Network

Student Handout

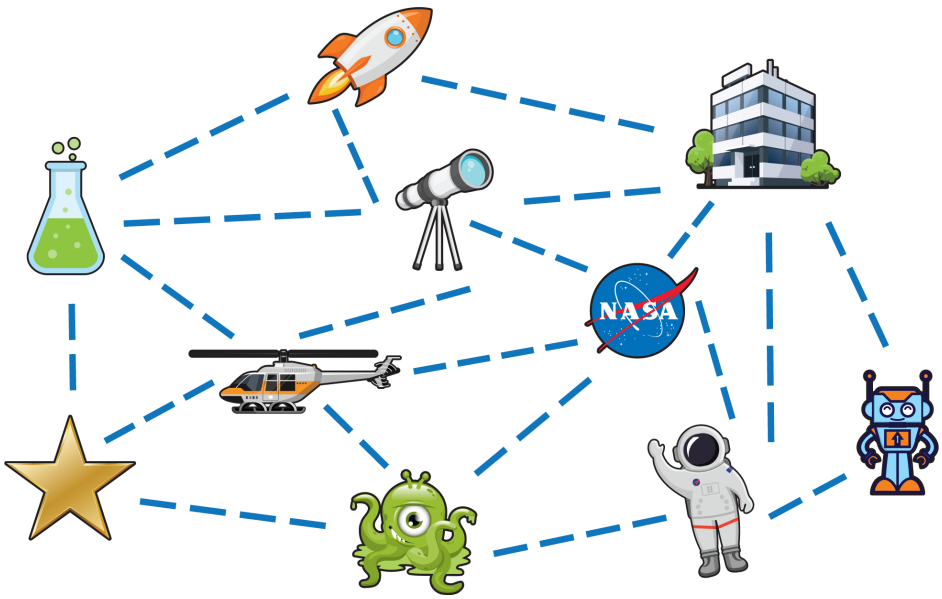
Challenge 1: Scavenger Hunt

You have been invited to a NASA center and you have been challenged to a scavenger hunt. The scavenger hunt contains a list of items you need to find quickly. In this exercise, it is also important to take as few steps as possible when locating all 10 items. In the diagram below, you can see a map of the items and dashes connecting each item. Each dash represents a total of **20 steps**.

The scavenger hunt has two conditions:

1. You must connect all the scavenger hunt items together with the paths that you choose.
2. You must take the least number of steps possible. Remember that each dash is equal to 20 steps.

Shade in the most efficient (fewest steps) route to find all the items in the scavenger hunt.



Fun Fact

Learn more about the Deep Space Network (DSN) with DSN Uplink–Downlink, an interactive game where you will use big antennas to send and receive information from NASA's robotic explorers in the solar system. An antenna "uplinks" instruction to the spacecraft and "downlinks" the spacecraft's images and data.

Learn more:
https://spaceplace.nasa.gov/dsn-game/en/

Career Corner

Eberhardt Rechtin is known as the "Father of the Deep Space Network." A pioneer in deep space research, he served as director of NASA's Deep Space Instrumentation Facility, the forerunner of the Deep Space Network. Prior to his career at NASA, he served in the U.S. Navy and received his doctorate in electrical engineering.

Eberhardt Rechtin directed the Deep Space Instrumentation Facility at NASA's Jet Propulsion Laboratory.

Learn more:
https://history.nasa.gov/SP-4210/pages/Ch_5.htm

Challenge 2: Deep Space Neighbors

NASA's Deep Space Network (DSN) is an important link in a network that communicates with all our satellites and spacecraft. Without this important network, we would lose contact with deep space satellites, like Voyager, or Mars rovers, like Perseverance and Curiosity. If we lost communication, we would not be able to send commands to our spacecraft or receive the amazing images and information that are sent back about our neighborhood, the solar system. In this activity, you will need to connect all the satellites to the giant DSN antennas in the most efficient way possible.

There are two conditions:

1. All satellites must be linked within the network
2. The network should be the most efficient. The numbers next to the paths between satellites represent distances. The farther the distance, or the bigger the number, the more degraded the message becomes, and the longer it takes to receive the message. After you complete your network, total up the distances. How does your total compare with other students' totals?

On the map below, shade in all the paths you plan on using: