



## Summary

How do we know where we are? What happens if you are completely lost in the middle of nowhere? Does technology provide tools for people lost in their travels? A person cannot usually determine an accurate position just by looking out a window in the middle of the ocean or vast area of land, particularly if it has not been charted before. In this lesson, students explore the concept of triangulation that is used in navigation satellites and global positioning systems designed by engineers. Also, students learn how these technologies can help people determine their position or the location of someone else.

## Engineering Connection

Satellites have been in existence for years for various purposes, including scientific research, weather, communications, navigation and, simply, for observing the Earth. Engineers are involved with designing these satellites, getting them into orbit and analyzing the information relayed by them. Satellites for navigation purposes were developed in the late 1950s as a direct result of maritime ships needing to know exactly where they were at any given moment. As people explore more and more remote regions and as communication needs for those living in more distant locations increase, navigation and pinpointing exact locations becomes an even more important challenge for engineers.

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**Grade Level:** 4 (3-5)

**Lesson #:** 6 of 6

**Time Required:** 15 minutes

**Lesson Dependency :**None

**Keywords:** navigation, orbit, satellite, location, GPS, triangulation, lost, position

## Related Curriculum

subject areas Earth and Space  
Physical Science

## Science and Technology

curricular units Rockets

activities Find It!

Educational Standards

- Colorado Math
- 1. recognize shapes and their relationships (for example, symmetry, congruence) using a variety of materials (for example, pasta, boxes, pattern blocks); (Grades 0 - 4) [2005]
- 2. identify, describe, draw, compare classify, and build physical models of geometric figures; (Grades 0 - 4) [2005]
- 4. solve problems using geometric relationships and spatial reasoning (for example, using rectangular coordinates to locate objects, constructing models of three-dimensional objects); and (Grades 0 - 4) [2005]
- 1. know, use, describe, and estimate measures of length, perimeter, capacity, weight, time, and temperature; (Grades 0 - 4) [2005]
- 3. demonstrate the process of measuring and explain the concepts related to units of measurement; (Grades 0 - 4) [2005]
- Colorado Science
- Standard 5:  
Students know and understand interrelationships among science, technology, and human activity and how they can affect the world. (Grades 0 - 12) [1995]
- 4.4 Students know the structure of the solar system, composition and interactions of objects in the universe, and how space is explored. (Grades 0 - 12) [1995]

Learning Objectives ([Return to Contents](#))

After this lesson, students should be able to:

- Explain how triangulation is used to find a location.
- Define Global Positioning Systems (GPS) and explain why they are useful.
- List several different ways engineers help locate people on Earth.

Introduction/Motivation ([Return to Contents](#))

Spacewoman Tess is now in space. Having deployed her satellites, she is now happily exploring outer space. Their daughter, Maya, has been paddling her canoe north into Canada for just over a week now. Spaceman Rohan is, of course, excited and worried about both of them. Maya has carried a Global Positioning System unit with her so that she can determine where she is at all times and, in fact, call her father, Spaceman Rohan, on her satellite phone if she needs anything.

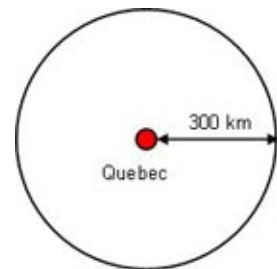


Figure 1. The concept of triangulation, using one data point.

But, what exactly is a Global Positioning System (GPS), and how does it work? In order to better understand this, we should take a step back. GPS uses a concept called *triangulation*. What do you think triangulation might mean? It sounds like the word triangle. Well, it is kind of similar. Triangulation is finding a location of point by measuring the distance from two or more other known points.

Let's say that Maya does not have her GPS unit or her satellite phone, and is totally lost in Canada. Maya has just met a talking beaver out building a dam where she stopped for the night. She asks him where he thought they might be. He replies, "I just walked and swam from Quebec, and it took me 10 hours at 30 kilometers per hour." How far did the beaver travel? (Answer: 10 times 30 = 300 kilometers) What does this tell Maya? Think about it like this (draw Figure 1 on the board): if Quebec is the center of a circle, and Maya is 300 km from Quebec, then she could be anywhere on the circle (but not inside the circle). So now Maya has one piece of information, she is somewhere on the outside of this 300 km radius circle around Quebec.

Now what? It just so happens that Maya has also met a talking bird, a Blue Heron to be specific. She asks the bird where they are, and the bird says that he has just flown from New Brunswick. It took 10 hours flying really fast at 50 km per hour. How far did she fly? (Answer: 10 times 50 = 500 kilometers) So now, what other piece of information does Maya know? She now knows that she is also 500 kilometers from New Brunswick. If the Blue Heron's information is combined with the beaver's information, we have two circles combined (draw Figure 2 on the board). So if Maya is 300 km from Quebec AND 500 km from New Brunswick then there are only two points that she can be at. Can you point out these two points on the drawing?

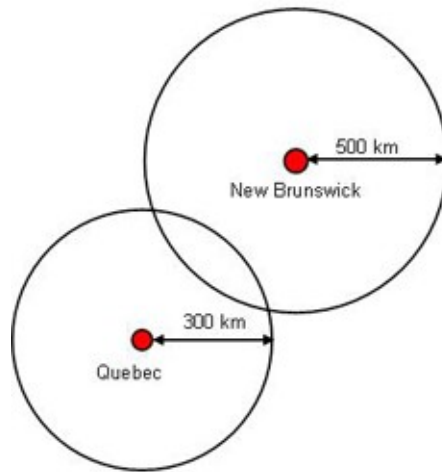


Figure 2. The concept of triangulation, using two data points.

Okay, do we need one more piece of information? Yes! We need to know on which of those two points we are actually located. Well, Maya has actually just run into a talking fish who has recently swam all the way down from Sept-Les. Wow! The talking fish told her that she had swam at 20 kilometers per hour, and it took her 20 hours to get to where Maya was. How far did she swim? (Answer: 20 times 20 = 400 kilometers) So now Maya knows that she is also 400 kilometers from Sept-Les. If the fish's information is combined with the Blue Heron's and beaver's information, then we have three circles (draw Figure 3 one on the board).

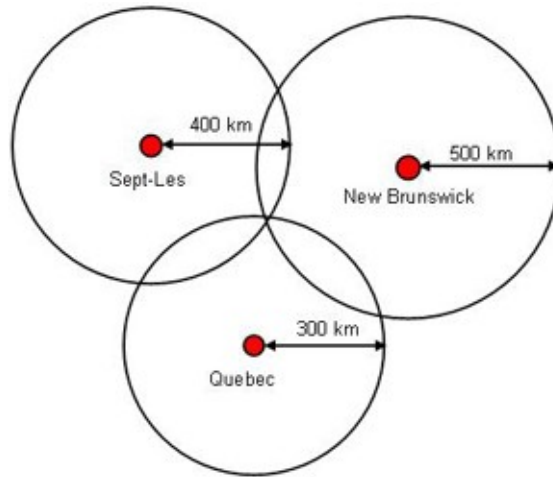


Figure 3. Diagram of 2-D Triangulation.

Maya now knows that she is 400 km from Sept-Les, 500 km from New Brunswick, and 300 km from Quebec. There is only one point she can be at. Now, where on the drawing must Maya be? (Answer: The only point where all of the three circles intersect - the only point that is on all of the three circles exactly the radius of each circle away from its center.)

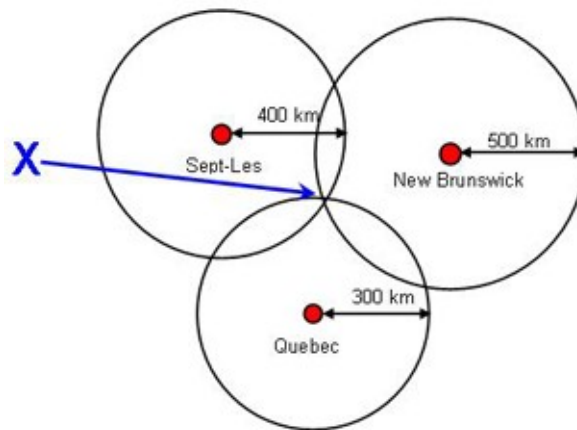


Figure 4. X marks the spot.

This geometrical concept is called *triangulation* and can be used on a larger and 3-dimensional scale with satellites to pinpoint exactly where on Earth you are. This short exercise that we just did gave Maya her position which can then be converted into a coordinate on the Earth using longitude and latitude.

But is the Earth a circle? What is the 3-dimensional equivalent of a circle? (Note: If this question is not readily answered, ask students: What does a flat basketball look like? A circle. What does a full basketball look like? A sphere!) So with our 2-dimensional drawing, we needed three circles to pinpoint our location. What are the three dimensions? Well, we already had two of them: *longitude* and *latitude*. What is the other one? What about how far away from the Earth's surface we are? Might a mountain climber like to know how far she is from the summit? Possibly. The other dimension then is *altitude*. Exact locations are determined by using longitudinal, latitudinal, and altitudinal information from navigation satellites that orbit the Earth.

Usually, we will not run into talking beavers, talking Blue Herons, or talking fish out in the middle of nowhere, so if we need to know exactly where we are, we might have to rely on some other form of technology. Global positioning satellites (GPS) will work in remote areas. GPS uses a concept similar to triangulation, combined with orbiting satellites in space, to pinpoint specific locations on the Earth.

Global Positioning System (GPS)

Navigation satellites are like orbiting landmarks. Rather than seeing these landmarks with our eyes, we "hear" them using radio signals. The Global Positioning System is a constellation (or set) of at least 24 satellites that continuously transmit faint radio signals toward the Earth. These radio signals carry information about the location of the satellite and special codes that allow someone with a GPS receiver to measure distance to the satellite. Combining the distances and satellite locations, the receiver can find its latitude, longitude, and height (altitude).

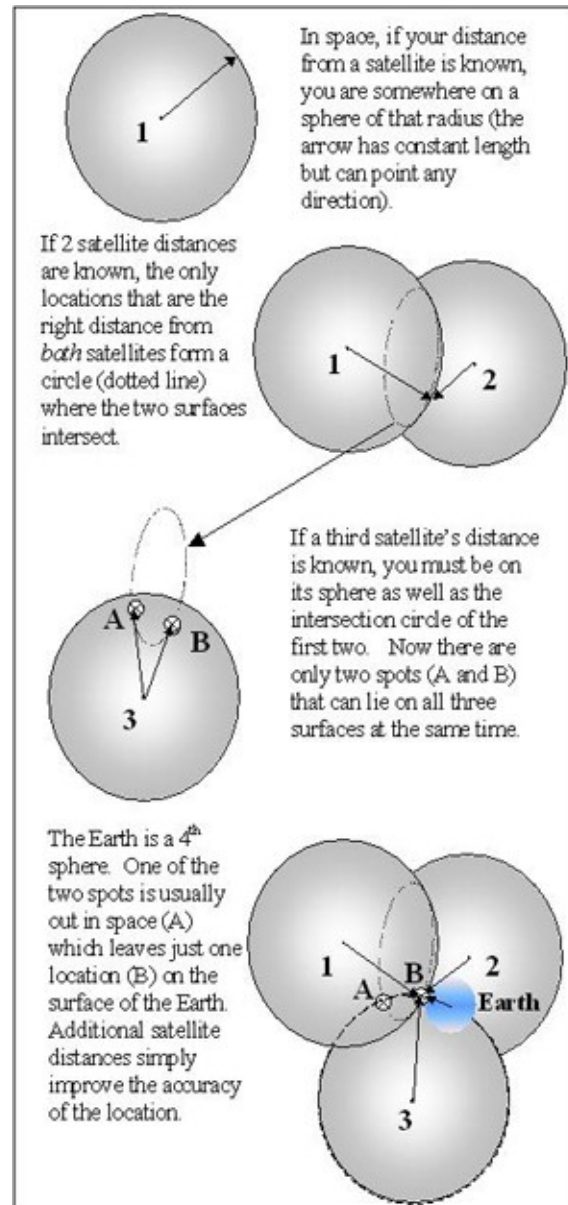


Figure 5. How GPS Works

How does a GPS receiver know how far away the satellites are? Given velocity and the time required for a radio signal to be transmitted between two points, the distance between the two points can be computed; the transit time can be measured and is then multiplied by the exact speed of light to obtain the distance between the two positions.

GPS is based on satellite *ranging*. Our position on Earth is calculated by measuring our distance from a group of satellites in space. This is done by timing how long it takes a radio signal to reach us from a satellite. The signal travels at the speed of light (186,000 miles per second), allowing us to calculate the distance (Velocity x Time = Distance).

GPS satellite ranging allows a receiver to determine its 3-dimensional position: latitude, longitude and height. Because the ranging measurements are based on timing, both the time in the satellite transmitter and the user's receiver have to be coordinated. A GPS receiver measures range to four satellites to determine latitude, longitude, height and this timing correction.

Let's take this one step at a time. For now, assume that the satellite and receiver clocks are already coordinated, and the positions of the satellites are known. If we measure distance to one satellite, we know that we are located on a sphere of that radius, centered on the satellite. With two satellite range measurements, our location is limited to a circle and with three satellites to one of two points. A fourth satellite can be used to find the correct point and to take care of the time coordination.

So, how do we know where the satellites are located? All satellites are constantly monitored. They have a 12-hour orbit, and the U.S. Department of Defense is able to monitor the satellites from ground stations around the world. The satellites are checked for errors in their position, height and speed. These minor errors are caused by gravitational pulls from the moon, sun or even pressure from solar radiation on the satellite. The satellites transmit special codes for timing purposes, and these codes carry a data message about their exact location. These codes help to precisely locate the satellite.

Vocabulary/Definitions ([Return to Contents](#))

- Satellite:* An object that travels around another object or any object in orbit about some body capable of exerting a gravitational force.
- Longitude:* Imaginary lines that cross the surface of the Earth, running from north to south, measuring how far east or west of the prime meridian a place is located.
- Latitude:* Imaginary lines that cross the surface of the Earth parallel to the Equator, measuring how far north or south of the Equator a place is located.
- Altitude:* The elevation (height) of an object from a known level.
- Triangulation:* A method of surveying so that the location of an object may be calculated from the known locations of two other objects.
- Orbit:* The path of a celestial body or an artificial satellite as it revolves around another body.
- Navigation:* The science and technology of finding the position and directing the course of vessels and aircraft.

Associated Activities

- [Find It!](#) - In this activity, students learn how triangulation and Global Positioning Systems (GPS) work.

Lesson Closure

In this lesson, we learned that we can determine a person's location through the process of triangulation. What word does triangulation sound like? Yes, a triangle! And, how many sides does a triangle have? Three. So, how many points do we need to find a location? That's right: three (the point where you are located and two other points at a distance away). How many satellites do we need to find a person using GPS? Yes, also three. In two dimensions, and using the distances between specific places, a person's coordinates on the Earth (latitude and longitude) can be figured out by triangulating with two known points. In three dimensions, using navigation satellites and global positioning systems, a person's coordinates (latitude, longitude *and* altitude) can be determined using satellites and the data on their

respective distances from Earth.

Assessment ([Return to Contents](#))

### Pre-Lesson Assessment

**Brainstorming:** As a class, have the students engage in open discussion. Remind students that in brainstorming, no idea or suggestion is "silly." All ideas should be respectfully heard. Take an uncritical position, encourage wild ideas and discourage criticism of ideas. Have them raise their hands to respond. Write their ideas on the board.

- Ask students to individually think about how they can know where they are, describe to other people where they are, or know where other people are. (Answers may include: ask people, use a compass, identify landmarks, read a map, etc.)

**Question/Answer:** Ask students to answer the following questions. Students should work in groups of 2 to 3 and share ideas. Discuss their answers as a class.

- Ben is on the outside of a circle and Shali is in the center of the circle. They are 5 meters away from each other. What is the radius of the circle? (Answer: 5 meters) What is the diameter of the circle? (Answer: 10 meters)
- Ben is on the outside of a circle and Shali is in the center. Again, they are 5 meters away from each other. To walk to Shali, it takes Ben one whole hour. How fast can Ben walk? (Answer: 5 meters every hour, so 5 meters per hour) If Ben walks this fast all the time, how far can Ben walk in three hours? (Answer: Five multiplied by three, so 15 meters, or  $5 \times 3 = 15$  meters)
- Now the circle is much bigger, and Ben is lost in space very very far away from Earth, perhaps near Jupiter. He is sending a signal to Shali, who is still on Earth. The signal travels 300,000 kilometers per second and the signal takes 2 seconds to reach Shali. How far away is Ben? (Answer: 600,000 kilometers)

### Post-Introduction Assessment

**Where Am I?** Put students in groups of four. Tell them that Student 1 is lost. Her three friends (Students 2, 3 and 4) know how far away from Student 1 they are, though none of them can see each other. Their distances from each other are as follows:

- Student 2 is 5 meters from Student 1
- Student 3 is 10 meters from Student 1
- Student 4 is 2 meters from Student 1

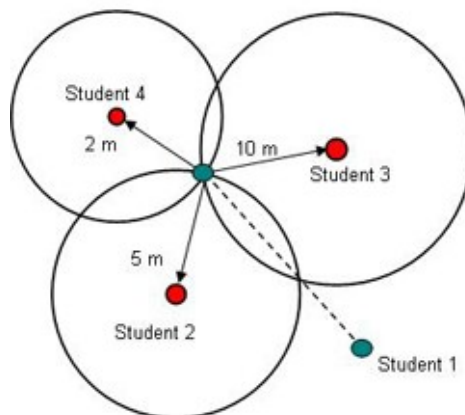


Figure 6. Triangulation Assessment - Possible Answers

Ask the students to do three tasks:

1. Discuss with their group how they might solve the problem.
2. Sketch a drawing of the students in relation to one another.
3. Point out on the drawing where each student is.
4. Could this information also be used to find out how far Student 2 is from Student 3? How? What about Student 2 from Student 4? And Student 4 from Student 3?

(There is an alternative solution to this problem, as shown in Figure 7. Student 1 could be in the center of all of the circles. If none of the students come up with this solution tell them that there is another solution and challenge them to find it. Finally, draw figure 7 on the board.)

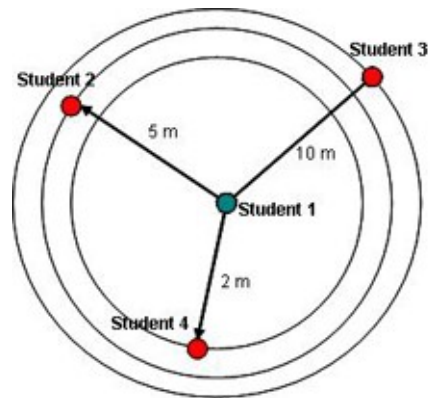
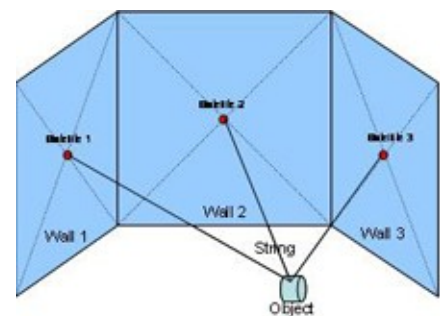


Figure 7. Triangulation Post-Introduction Assessment - Alternate Answer

### Post-Lesson Assessment

*Navigation Engineers:* Before this assessment begins, hide an object in the classroom (somewhere on the floor) and measure its distance from each of the centers of three walls. Break the class up into six groups and tell the students that you have hidden something on the floor of the classroom, and the students have to work together to find out where the object is. See Figure 8 for an illustration of the following group tasks.



- Group 1: This group is Satellite 1 located on Wall 1, directly in the center of the wall. Group 1's job is to locate exactly where on the wall Satellite 1 is (i.e., find the center of the wall). They should tape a piece of paper to the wall representing their satellite.
- Group 2: This group is Satellite 2, located on Wall 2, directly in the center of the wall. Group 2's job is to locate exactly where on the wall Satellite 2 is (i.e., find the center of the wall). They should tape a piece of paper to the wall representing their satellite.

- Group 3: This group is Satellite 3, located on Wall 3, directly in the center of the wall. Group 3's job is to locate exactly where on the wall Satellite 3 is (i.e., find the center of the wall). They should tape a piece of paper to the wall representing their satellite.
- Group 4: This group is Satellite 1's distance from the object which is XX meters (this needs to be measured ahead of time). Group 4's job is to measure and cut a string this length.
- Group 5: This group is Satellite 2's distance from the object which is XX meters (this needs to be measured ahead of time). Group 5's job is to measure and cut a string this length.
- Group 6: This group is Satellite 3's distance from the object which is XX meters (this needs to be measured ahead of time). Group 6's job is to measure and cut a string this length

Ask students the following questions after they have found the hidden object:

- Let's imagine that these are actually satellites and they are moving in a circular orbit. If they move, does the length of the string change? (Answer: no, since the orbit is circular the satellite is always the same distance away from the center of the orbit)
- If Satellite 3 malfunctioned, would we have still been able to locate the object? (Answer: Maybe; we know the object was on the floor, so we could have searched the entire floor. Although it would have taken a while, it would be possible... But, if the floor and our classroom were super large, it would have been very difficult to find the object without all three of the satellites.)

*Triangulation Math Extension:* Have students work in pairs to come up with their own 2-D or 3-D triangulation problem. They can choose an object and measure the distance to it from three points. Have them write it down which three points they used and the distances from those points to the mystery object. Then they can give their problem to another pair of students to solve.

Point One: \_\_\_\_\_ Distance to object: \_\_\_\_\_

Point Two: \_\_\_\_\_ Distance to object: \_\_\_\_\_

Point Three: \_\_\_\_\_ Distance to object: \_\_\_\_\_

The object I am looking for is: \_\_\_\_\_

#### Lesson Extension Activities ([Return to Contents](#))

- For upper grades, have students in groups hide objects in the classroom and make up a list of information (measurements to the center of the walls) for another group to find the object.
- Have students come up two different ways of describing how to find a location and then have the students use their descriptions to find a location. Next, have the students discuss which parts of the descriptions worked better, worse, etc.
- Using the skills they learned in this unit, have students create a poster of the story of Spacewoman Tess, Spaceman Rohan and their daughter, Tess. Have them explain one engineering concept they learned. They can tell the story of Tess getting into space or Maya communicating with her parents.

#### References ([Return to Contents](#))

Section borrowed wholly from: White, J., Lippis, M. Axelrad P., Yowell, J., Zarske Schaefer, M. TeachEngineering digital library lesson, Navigating at the Speed of Satellites, Integrated Teaching and Learning Program, College of Engineering, University of Colorado at Boulder, 2004.  
[http://teachengineering.com/view\\_lesson.php?url=http://www.teachengineering.com/collection/cub /lessons/cub\\_navigation/ cub\\_navigation\\_lesson08.xml](http://teachengineering.com/view_lesson.php?url=http://www.teachengineering.com/collection/cub /lessons/cub_navigation/ cub_navigation_lesson08.xml) - accessed March 2006.

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Supporting Program ([Return to Contents](#))

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