GPS Technology

Material from Teach Engineering Navigating at the Speed of Satellites lesson (http://www.teachengineering.org/view_lesson.php?url=http://www.teachengineering.com/collection/cub_/lessons/cub_navigation/cub_navigation_lesson08.xml)
and State Your Position activity
(http://www.teachengineering.org/view_activity.php?url=http://www.teachengineering.com/collection/cub_/activities/cub_navigation/cub_navigation_lesson08_activity1.xml)
Integrated Teaching and Learning Program, Boulder, CO 80309-0522

Introduction:

For thousands of years, navigators have looked to the sky for direction. Today, celestial navigation has simply switched from using natural objects to human-created satellites. A constellation of satellites, called the Global Positioning System, and hand-held receivers allow for very accurate navigation. In this lesson, students investigate the fundamental concepts of GPS technology — trilateration and using the speed of light to calculate distances.

Materials:
(Materials in bold are provided by SMILE)
1 paper clip
1 piece of string (~ 30cm or 12 inches long)
1 ruler (with cm)
3 GPS Worksheets (one for each group member)
3 GPS States Maps
Scotch tape (to tape the maps in place)
3 pencils (one per student)

Background:

Ask the students why satellites are a good tool for navigation. (Answer: They are "visible" for thousands of miles. Their orbits, and therefore positions, can be tracked to a high degree of accuracy. They can send information as well as simple location data in their signals.)

The idea of using satellites for navigation began with the launch of Sputnik 1 on October 4, 1957. Scientists at Johns Hopkins University's Applied Physics Laboratory monitored the satellite. They noticed that when the transmitted radio frequency was plotted on a graph, a characteristic curve of a Doppler shift appeared. By studying the change in radio frequency as the satellite passed overhead, they were able to figure out the orbit of Sputnik. It turns out that you can use this same concept in reverse. If the satellite orbit is known, measurements of frequency shift can be used to find a location on the earth. Knowing the orbits of four satellites, as well as their distances away, a Global Positioning System — or GPS — receiver can trilaterate (to determine a position using intersecting distances) a location.

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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. GPS satellite signals are free and available for anyone to use. GPS receivers are decreasing in cost every year and can be found in sporting good stores, are embedded in cell phones and even in watches.

How does a GPS receiver know how far away the satellites are? Early on, scientists recognized the principle that, 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. In order to do this calculation, a precise, synchronized time of departure and measured time of arrival of the radio signal must be obtained. By synchronizing the signal transmission time to two precise clocks, one in a satellite and one at a ground-based receiver, the transit time could be measured and then multiplied by the exact speed of light to obtain the distance between the two positions.

GPS - The Global Positioning System

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), so we are able to calculate the distance (Velocity x Time = Distance).

GPA as a Navigational Tool

To navigate, you must know roughly where you stand relative to your designation, so you can head in the right direction. In locations where landmarks are not available to help navigate (in deserts, on seas), objects in the sky are the only reference points. While celestial objects move fairly predictably, and rough longitude is not too difficult to find, it is not a simple matter to determine latitude and precise positions. In this activity, students investigate the uses and advantages of modern GPS for navigation.

If you were sailing to a harbor and saw a lighthouse, it would help guide you safely into that harbor. What type of navigation is this called and why is it important? (Answer: Landmark navigation, and it is important because sometimes it is the only method of navigation that is available.) A navigator's dream is a lighthouse that could be seen from anywhere in the world. It took a Cold War and a Space Race to lay the foundation, but this dream is now finally a reality. By the mid-1960s, it was possible to put our own precise points of reference in the sky via the U.S. Navy's NAVigation SATellite System or NAVSAT (also known as TRANSIT). The best part of this early system was that no human measurement of the objects was needed — the system would tell us their positions. This first system was accurate to about 200 meters (much better than celestial navigation) but consisted of only 6 satellites and did not provide coverage 24 hours a day.

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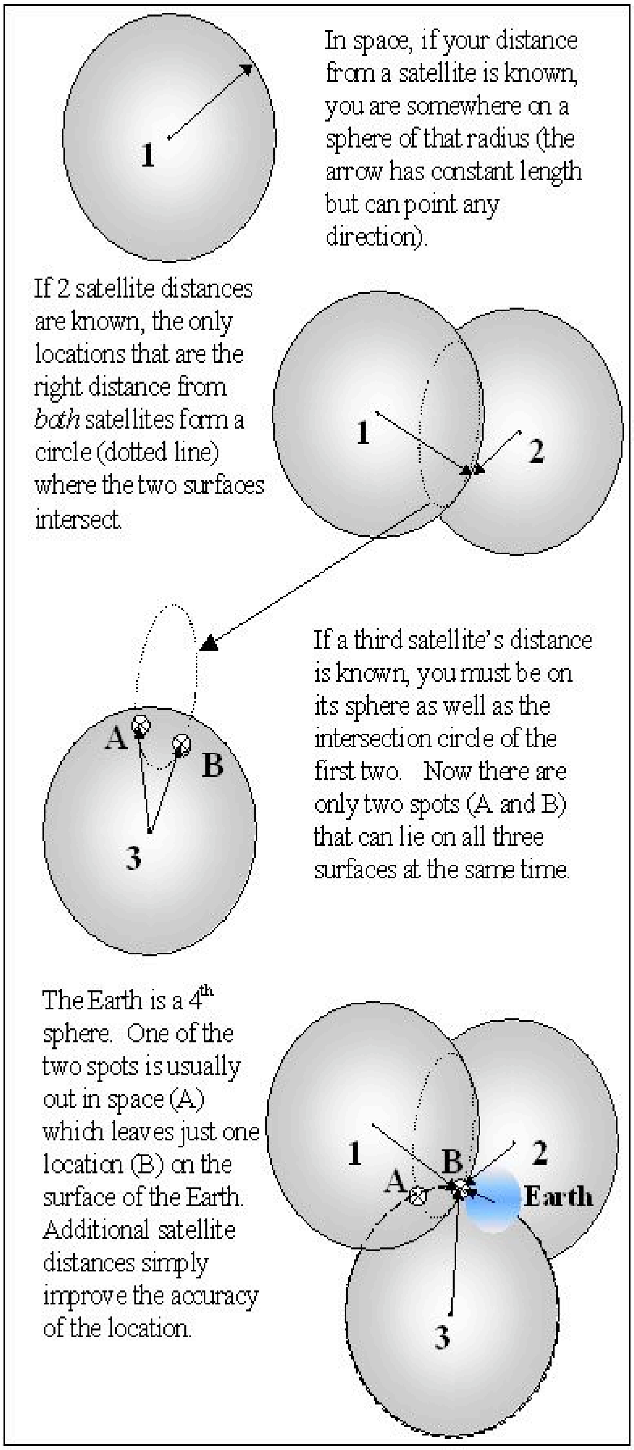
Due to the obvious military advantages to knowing precise locations, the U.S. Department of Defense made improvements to the first satellite system for obvious reasons: knowing more is better than knowing less. The development of the Global Positioning System (GPS) in 1989 was a $12 billion investment consisting of 24 satellites orbiting the earth about 11,000 miles away from Earth with 12-hour orbits.

GPS is based on satellite ranging. Our position on earth is calculated by measuring our distance from a group of satellites in space. This calculation is done by timing how long it takes a radio signal to reach us from a particular satellite. The radio signal travels at the speed of light (186,000 miles per second), so we are able to easily calculate the distance using: 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.

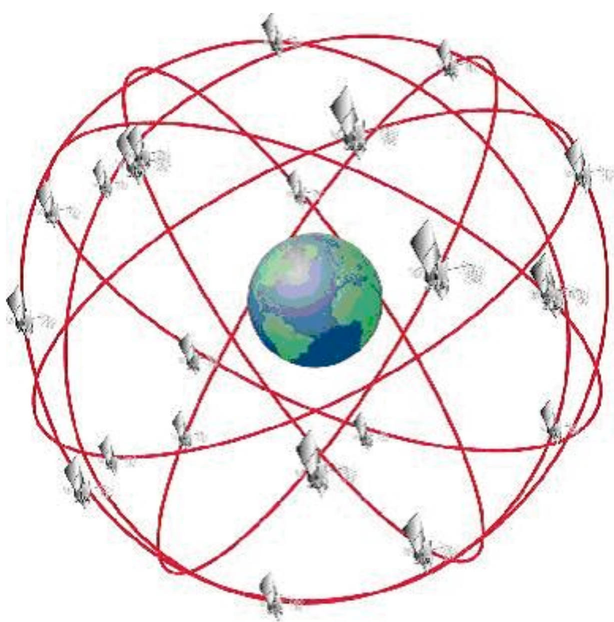
If it has extra information, a

receiver can figure out its position with fewer satellites. For example, if you know that you are on the ocean surface, you can use this piece of information and only three satellites to find your latitude, longitude, and timing. In this case, height is not needed because you already know it.

So, how do we know where the satellites are? 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, and 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. This helps to locate the satellite precisely.

Vocabulary/Definitions

GPS:	Global Positioning System.
Satellite:	An object launched specifically to orbit the Earth.
Receiver:	A device that accepts (receives) incoming signals and converts them to a usable form.
Orbit:	The path an object in space follows as it circles the Earth.
Trilateration:	Position determined by intersecting distances.
Triangulation:	The location of an unknown point by the formation of a triangle.



GPS satellite ranging allows a receiver to calculate its current 3-dimensional position — latitude, longitude, and height. Because the ranging measurements are based on timing, the times in the satellite transmitter and the user's receiver have to be coordinated. A GPS receiver measures the range to 4 satellites to determine latitude, longitude, height and this timing correction.

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. (See Figure 2 for a visual of this explanation.)

If it has extra information, a receiver can figure out its position with fewer satellites. For example, if you know that you are on the ocean surface, you can use this piece of information and only three satellites to find your latitude, longitude, and timing. In this case, height is not needed because you already know it, sea level.

So, how do we know where the satellites are? 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, and 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. This helps to locate the satellite precisely.

Activity: State Your Position

Ask students: Is it smart to go on a hike with only a GPS unit to guide you? (Answer: No, GPS should never be the only navigation tool used.) What would you do if your GPS unit malfunctioned or stopped working? (Answer: You should always have a paper map and a compass to rely on. Also, you should be familiar with using the sun, moon, and stars as a basic guide to direction.)

Hand out the string and paper clips to each group. Have them tie one end of the string to the paper clip.

Give each student a GPS Worksheet and have them read the introduction and arc instructions.

Hand out a GPS States Map to each group and have the students follow the instructions on the worksheet and answer the questions. Each student should fill in answers on their own worksheet.

When a group finishes, direct them to find some of the "friends" on the back of the worksheet (if time permits).

Follow-up questions:

- How many distances do you need to triangulate a position on a map? (Answer: 3).
- What does GPS stand for? (Answer: Global Positioning System)
- If you know you are 1 Earth radius away from the center of the Earth, where are you? (Answer: Anywhere on the surface of the Earth.)
- If you know you are 4 Earth radii away from the center of the Earth, where are you? (Answer: In space, possibly riding a GPS satellite.)
- Would you rather have 3 or 4 satellites locked when using GPS and why? (Answer: Four because the more satellites engaged gives you a more accurate position.)
- If you were traveling 100 years into the future, would you take a sextant or a GPS receiver? Discuss. (Answer: Open question. Possible reasons for not taking a GPS

receiver would be: GPS system was not kept up or fails in the future; a new better system has been put in place, and the old receiver is not compatible; if the GPS receiver breaks, the system is useless. Reasons to take a sextant: no batteries required, sun moon and stars will always be there, much easier to fix if something on it breaks.)