BEAM Me There!

June Chang | Fall 2026

Field(s) of Interest: Physics, Space Science, Aerospace Engineering, Mathematics, and Navigation Science

Brief Overview:
Inspired by late-night food deliveries, mentees discover how a delivery driver's phone knows where to bring the pizza. They'll explore the main parts of a satellite, learn how signals carry information, and see how GPS uses trilateration to find a location from several satellites' signals.

Agenda:

- Introduction (5 min)
- Module 1: It's a Bird, It's a Plane...It's a Flying "Bus" (15 min)
- Module 2: Stop the Mixed Signals! (15 min)
- Module 3: WYA (Where You At?) (20 min)
- Conclusion (5 min)

Main Teaching Goals/Key Terms:

- ➔ Orbit
- ➔ Satellite
- ➔ Antenna
- ➔ Power Source
- ➔ Signal
- ➔ Transmitter
- ➔ Receiver
- ➔ GPS (Global Positioning System)
- ➔ Distance
- ➔ Trilateration

Background for Mentors

Module 1

- Orbit
- Satellite
- Antenna
- Power source
- **Atomic Clocks**

An **orbit** is a *regular, repeating path that one object in space takes around another.* An object (such as a satellite) stays in orbit because of a balance between two things: its forward motion (momentum) wants to carry it off in a straight line, while gravity keeps pulling it back toward Earth. Without gravity, the satellite would fly off into space in a straight line.

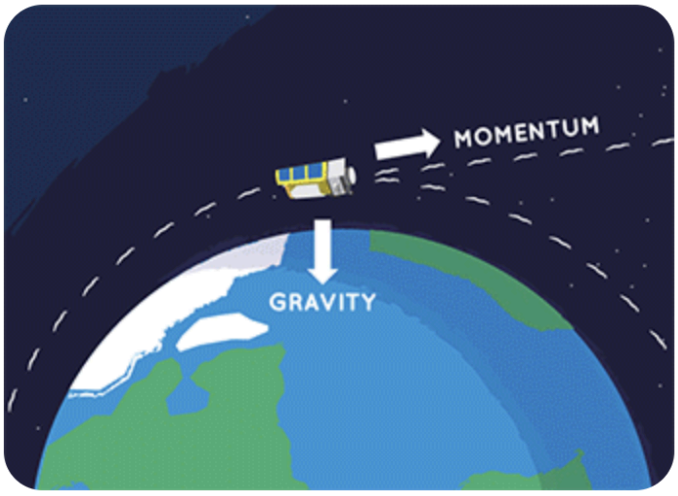


Figure 1: *Gravity pulls down, momentum pushes forward, and the result is an orbit.*

A **satellite** is *any object that orbits a larger body in space*. There are two types: natural satellites and artificial satellites. **Natural satellites** are *created by nature*, like the Moon orbiting Earth or the many moons orbiting Jupiter. Usually, though, when people say “satellite,” they mean **artificial satellites**, which *are human-made machines launched into space to orbit Earth or other bodies*. We use them for communication, navigation (like GPS!), tracking weather, and studying space.

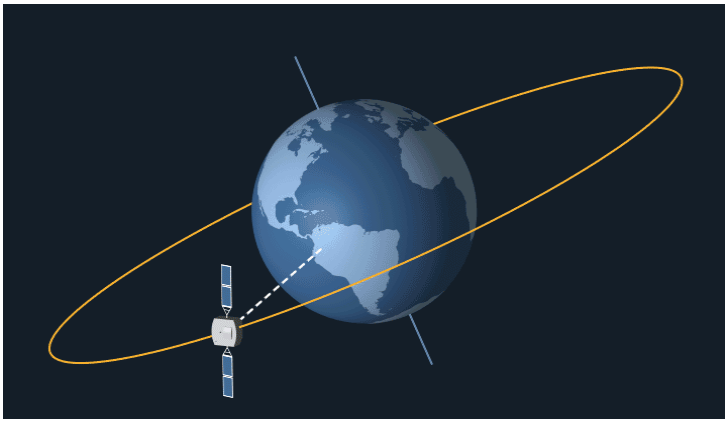


Figure 2: *An artificial satellite in orbit.*

Today, around **16,700** active artificial satellites orbit Earth. About **31** of them make up the U.S. GPS constellation, which lets anyone with a GPS receiver find their exact position, speed, and time anywhere in the world.

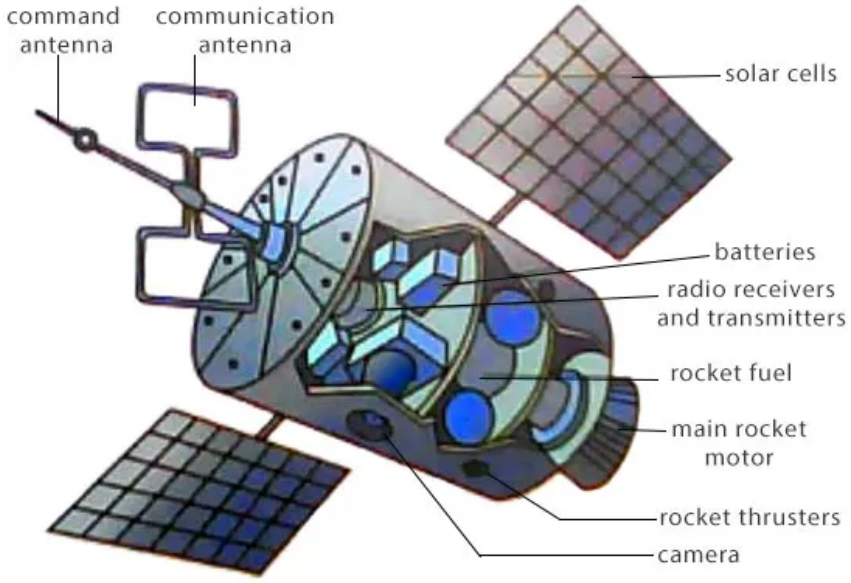


Figure 3: *Satellite components.*

A typical artificial satellite has several components that let it work in space for many years. The main ones we'll focus on are:

- **Body** (the satellite **"bus"**): the main frame that holds the computer, batteries, and clocks.
- **Antenna**: sends radio signals down to receivers on Earth.
- **Power source** (solar panels): turns sunlight into electricity so the satellite can run. Batteries take over when Earth blocks the Sun.
- **Atomic Clocks**: keep extremely precise time by counting how fast atoms (like cesium or rubidium) vibrate.
    - Each satellite uses this exact time in its signal, which basically says, "*I'm satellite #X, here's where I am, and this message left at exactly time T.*"

Module 2

- Signal
  - Encode
  - Decode
- Transmitter
- Receiver
- **Interference**
- **Types of waves**

Signals *carry information by changing in a pattern*. The **transmitter** *encodes a message* into a pattern, and the **receiver** *decodes it using a code* that both sides agreed on ahead of time (e.g., Morse code).

In GPS, each satellite is a transmitter. It constantly broadcasts a coded signal that says which satellite it is, where it is, and exactly when the signal was sent. Your phone is the receiver. It picks up signals from several satellites and decodes them to figure out where you are. The signal only travels one way, so your phone never sends anything back to the satellites. GPS also has ground stations, which keep track of the satellites and send them small corrections so their clocks and locations stay accurate.

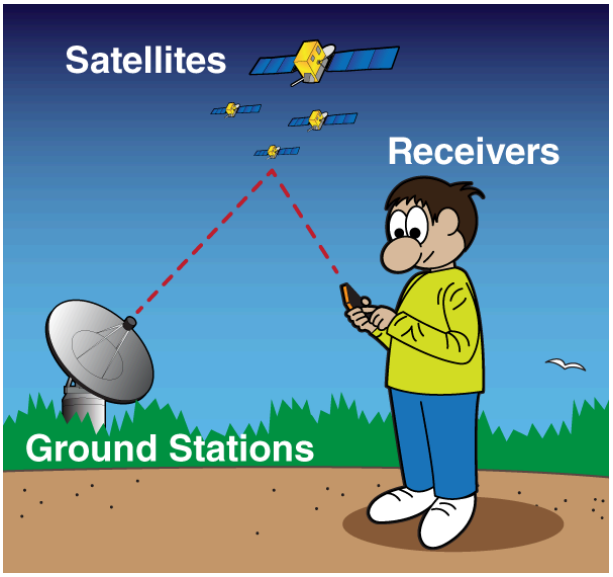


Figure 4: *The three parts of GPS – satellites, receivers, and ground stations.*

Signals can travel as different **types of waves**, such as *sound, light, and radio waves*. GPS satellites send radio signals (at roughly 1.2–1.6 GHz) for two reasons. Unlike sound, radio waves don't need air or anything else to travel through, so they can cross the vacuum of space. And unlike visible light, they pass easily through clouds, rain, and the atmosphere.

Interference is *any unwanted signal or obstacle that disturbs a useful signal*. It can cause errors or scramble the message completely. Engineers often measure this with the signal-to-noise ratio, which compares the strength of the signal to the strength of the noise. The stronger the signal compared to the noise, the easier it is to decode.

Module 3

- GPS
- Distance
- Trilateration
- **Navigation**
- **Radius**

GPS (Global Positioning System) is *a space-based radio navigation system*. It's made up of the satellites that orbit Earth, the ground stations that maintain them, and the receivers that process their signals. Examples of GPS receivers include phones, car navigation systems, and smartwatches. A receiver measures how long each signal took to arrive and turns that time into a distance using this formula:

distance *= speed of light × travel time*

GPS signals are radio waves, which travel at the speed of light (about 30 cm every nanosecond). That means a signal from 20,200 km away arrives in under a tenth of a second. Because the signals are so fast, tiny timing errors turn into big distance errors. Being off by just **1 microsecond means being off by about 300 m.**

A **radius** is *the distance from the center of a circle (or sphere) to its edge*. In GPS, each satellite is the center, and its distance to you is the radius. Every point that's exactly that far from the satellite forms a sphere around it, so one satellite alone can't tell you where you are.

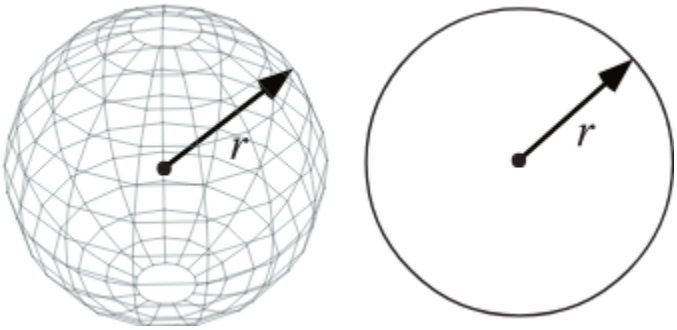


Figure 5: *Radius of a sphere and a circle.*

Knowing your distance from one satellite puts you somewhere on a sphere around it. On our flat map, that sphere becomes a circle whose radius is that distance. A second satellite narrows it down to where the two overlap, which is two points on the map. A third satellite narrows it to just one point. In real life (3D), three spheres still meet at two points, but one of them is usually far out in space, so it gets ignored. *Finding a location from distances is called* **trilateration**. Real GPS uses **3D trilateration**, while our map uses **2D trilateration** on a flat surface. Trilateration is often confused with triangulation, which finds a location using angles, not distances.

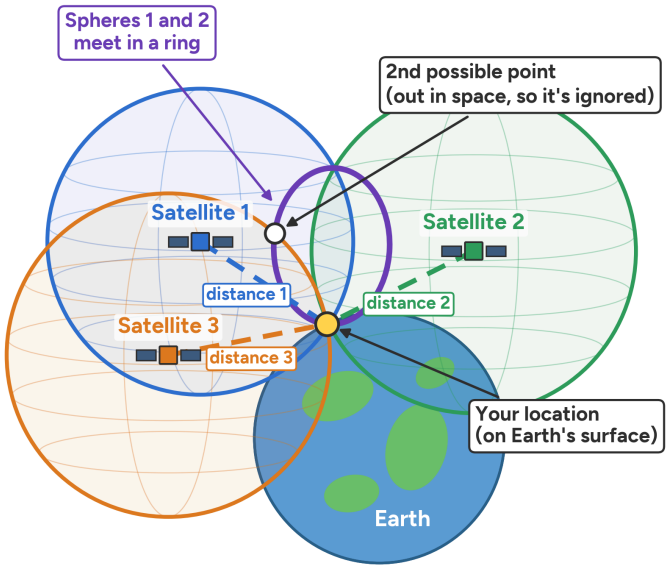


Figure 6: *3D trilateration. Each satellite's distance forms a sphere in 3D.*

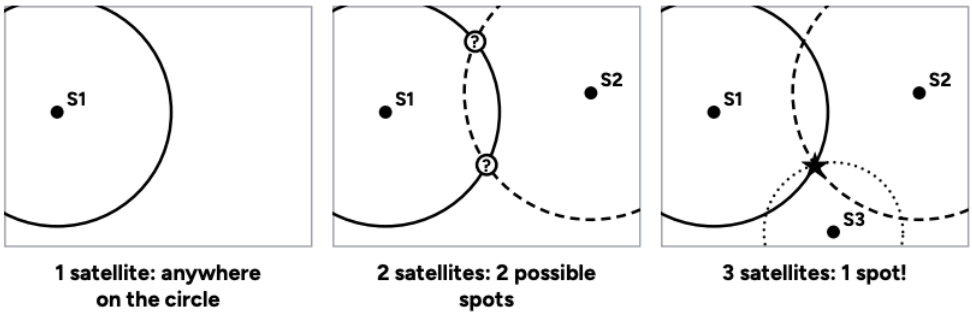


Figure 7: *2D trilateration. Each satellite's distance forms a circle in 2D. This is exactly what the string demo and treasure maps in Module 3 activity show.*

Finding your location once is called positioning. **Navigation** is *using your position to get somewhere*. To navigate, the receiver repeats this about once per second. Comparing positions over time gives speed and direction, which a maps app combines with road maps to plan a route and give turn-by-turn directions. That's exactly how a delivery driver finds your house! Real receivers need at least four satellites. A phone's clock is far less precise than an atomic clock, so the receiver solves for four unknowns: x, y, z, and its own clock error.

Trilateration can be confusing without a visual, so **please watch this video starting at the linked timestamp** to better explain the concept to mentees.

Introduction

GPS is everywhere! It powers everything from food delivery and rideshares to finding a lost phone (or a lost friend...), yet it's completely invisible! This lesson takes something we usually assume just happens like magic and turns it into a hands-on activity. Start with a question like, "How does your phone know where you are? Does it look up your address? But then how does it know you're at the park instead of at home? How does it find exactly where YOU are, right now?"

Concepts to Introduce

- **GPS in one sentence:** satellites in space constantly broadcast "Here I am, and here's the time!" and your phone listens to figure out where you are.
    - **Analogy:** Marco Polo. You find people by listening for where they are, not by looking.
- **One satellite isn't enough:** it only tells you that you're somewhere on a circle. Each extra satellite rules out more spots until only one is left, so more satellites mean a more accurate location.
- **Trilateration:** satellites send the signals, and the receiver (your phone) puts the clues together to find you.

Questions to Pique Interest

- How do your parents' phones know the way to school, the park, or a baseball game?
- Do you know how many artificial satellites are in space?
- Why don't satellites fall out of the sky?
- There are no outlets in space. How do satellites get electricity?
- How could you send a message to a friend across the room without talking?
- Does GPS need Wi-Fi?
- Why does your map app sometimes get confused in a tunnel or next to tall buildings?
- If I told you a hidden treasure is 10 steps away from you, do you know exactly where it is?

Scientists, Current and Past Events

- **Gladys West** is a mathematician whose precise computer models of Earth's shape became a foundation for GPS. She was inducted into the Air Force Space and Missile Pioneers Hall of Fame in 2018.
- **Bradford Parkinson** led the Air Force team that designed GPS in 1973 and is often called the "*father of GPS.*"
- **Physicists William Guier and George Weiffenbach** listened to the radio signal from Sputnik (launched in 1957), the first artificial satellite, and figured out exactly where it was just from its beeps. Then they reversed the idea, so satellites in known locations could find you. This led to the first satellite navigation system.

Careers and Applications

- **Everyday uses:** delivery and rideshare apps, maps, finding a lost phone, fitness watches that track your run, and more.
- **Aerospace engineer:** designs satellites.
- **Electrical engineer:** designs antennas and the radio systems that send and receive signals.
- **GIS analyst or cartographer:** makes maps from location data. (GIS stands for Geographic Information Systems.)
- **Software developer:** builds navigation and delivery apps.

Module 1: It's a Bird, It's a Plane...It's a Flying "Bus"

Each mentee assembles their own model GPS satellite from pre-cut pieces while mentors introduce its parts: the body, the solar panels (power source), and the antenna.

Teaching Goals

1. **Orbit:** the curved, repeating path an object in space takes around another body.
2. **Satellite:** an object that orbits a larger body, like the Moon orbiting Earth.
    a. **Natural satellite** vs. **artificial satellite**
3. **Antenna:** the part of a satellite that sends radio signals down to GPS receivers (like phones) on Earth.
4. **Power Source:** the solar panels that turn sunlight into electricity so the satellite can run.
5. **Atomic clocks:** super-precise clocks on each GPS satellite. The exact time is part of every signal it sends.

Materials

Per mentee:

- 1 toilet paper roll
- 1 dumbbell-shaped paper strip (rectangle at each end connected by thin band), 11 in long
- 1 paper circle, 4 in diameter, with a cut from edge to the center

Per site (shared):

- 2-3 rolls of tape
- 8-10 markers

Different Methods for Teaching

1. **Orbit:** Have mentees think about swinging a ball on a string in a circle. The string pulls the ball toward the center, like gravity, and the ball's speed keeps it moving around instead of falling in. That's how a satellite orbits Earth.
2. **Antenna:** Have mentees think about a walkie-talkie. Sends and catches signals!
3. **Power source:** Ask mentees if they've ever seen solar panels and where (like on roofs, calculators, or street signs). There are no outlets in space, but the Sun is always shining, so satellites use solar panels to power themselves.

Procedure

1. **Design the solar panels:** Have mentees draw grids on both ends of the strip. These are the solar panels! (*Do this before taping the strip to the roll.*)
2. Wrap the middle of the strip around the back of the roll and tape it on.
3. Fold the ends out where they leave the roll, so they stick out like wings.
4. **Build the antenna:** Slide one cut edge of the paper circle over the other to make a cone, like an ice cream cone. Tape it.

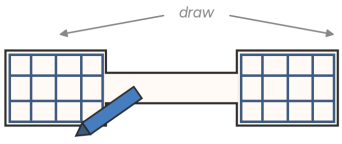


Figure 1: *Draw grids on both ends of the strip.*

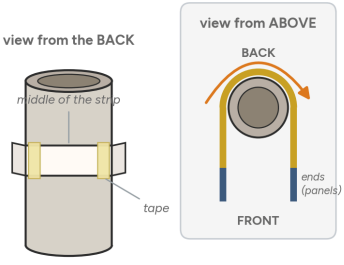


Figure 2: *Wrap the middle of the long strip*

5. Put the cone on top of the roll, pointy end down. Use about 3 pieces of tape around the rim so it stays in place.
6. **Name your satellite!**
7. Ask mentees which part sends the signal and which part powers the satellite.
8. Have mentees set their satellites aside for Module 3. After that, they can bring their models home.

around the back of the roll and tape it.

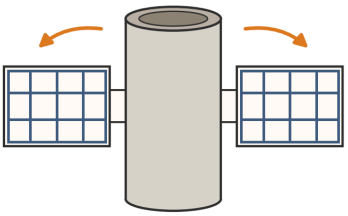


Figure 3: *Fold the ends outward like wings.*

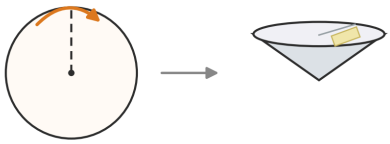


Figure 4: Slide one cut edge over the other to make a cone. Tape it.

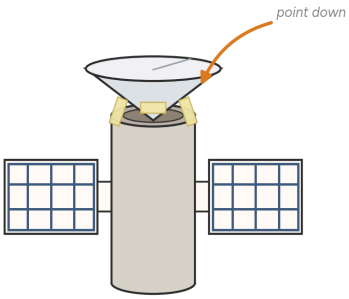


Figure 5: Put code on top pointing downwards. Tape around the rim.

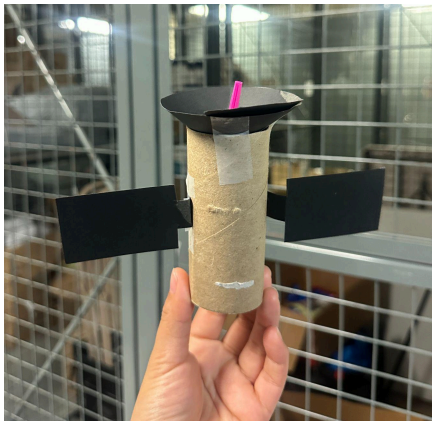


Figure 6: *Completed satellite model*

Classroom Notes

As mentees build, connect each part of the model to the teaching goals! Ignore the antenna tip in the picture, we do not need to add this.

Module 2: Stop the Mixed Signals!

Mentees play “Clap Says,” a Simon Says-style game where claps are the signal. One mentor is the transmitter and claps a coded message, every mentee is a receiver who decodes it and does the action. Decode it wrong and you sit down. The last mentee standing wins. In Round 2, mentors add noise so mentees experience interference firsthand.

Teaching Goals	**Materials**
1. **Signal:** a pattern that carries information from one place to another. 2. **Transmitter:** a device that creates and sends a signal. 3. **Receiver:** a device that picks up a signal and decodes what it means. 4. **Interference:** any unwanted signal or obstacle that disrupts, weakens, or changes a signal. 5. **Types of waves:** the different ways signals travel, such as sound, light, and radio waves. GPS uses radio waves because sound can’t travel through space.	*Per Pair of Mentees:* • 1 printed Clap Code sheets

Different Methods for Teaching

1. **Signal:** Have mentees think about a referee’s whistle or a traffic light. Each one sends a message without using words. That’s a signal!
2. **Encode & decode:** Have mentees think about texting a friend 🍕. Your friend knows you’re asking about pizza! You encoded a message into emojis, and they decoded it.
3. **Transmitter & receiver:** Have mentees think about talking on a walkie-talkie. One person talks (the transmitter), and the other listens (the receiver).
4. **Interference:** Have you ever tried to talk to a friend in a loud cafeteria? The noise makes it hard to hear. Tunnels and tall buildings do the same thing to GPS signals.
5. **Types of waves:** Have mentees think about why we can hear each other in the classroom, but astronauts need radios to talk in space. Sound needs air to travel, but radio waves can cross empty space.

Procedure

1. Hand out the Clap Code sheets so each pair of mentees can share one.
    a. **Younger sites:** use only rows 1–3. Younger mentees may not be able to read yet, so demonstrate each signal and say its action out loud instead.
    b. **Older sites:** use all 6 rows.
2. **Explain timing rule:** claps that belong to the same signal are *fast, with no pause*. Different signals are *separated by a clear pause (about 1 second)*.
    a. CLAP-CLAP (fast) = Turn around
    b. CLAP … CLAP (with a pause) = Step forward, then step forward again
3. **Practice (1 min):** A mentor (the transmitter) claps a few codes while mentees (the receivers) do the actions. No one gets out yet.
4. **Round 1 (3–5 min):** Now play for real. The transmitter can combine signals into a series. Anyone who does the wrong action, or reacts too slowly, sits down. No talking, mouthing, or pointing from the transmitter! The last one standing wins.
5. **Round 2 with interference (3–5 min):** Everyone stands up again. This time, other mentors tap desks or clap random patterns while the transmitter claps. The last one standing wins again.
6. **Older sites:** If time allows, play a few more rounds in smaller groups.
7. **Debrief (2 min):** Ask, "*Why was round 2 harder?*" Connect it to GPS: satellites are transmitters, phones are receivers, and buildings and tunnels cause interference.

#	Signal (clap pattern)	Action
1	CLAP	Take one step forward
2	CLAP CLAP	Turn around
3	CLAP CLAP CLAP	Jump once!
4	CLAP + SNAP	Raise both hands *older sites*
5	SNAP + TAP desk	Touch your head *older sites*
6	_____	Invent your own! _____ *older sites*

Figure 1: *Clap Code.*

Classroom Notes

Keep pause between signals clear and consistent so the game feels fair. Mentees have to listen to the timing, not just count claps, which is exactly how real codes like Morse code work.

Module 3: WYA (Where You At?)

Mentees see trilateration in action, then do it themselves. In Part 1, mentors run a stand-up string demo that shows one satellite narrowing the treasure to a circle, two narrowing it to two spots, and three pinpointing one spot. In Part 2, each mentee uses an I-spy treasure map and a paper compass to find their own hidden treasure. There are three map versions, so mentees find different treasures and compare.

Teaching Goals

1. **Global Positioning System (GPS):** a group of satellites and receivers (like phones) that work together to find locations on Earth.
2. **Distance:** how far apart two things are.
    a. A GPS receiver finds its distance from each satellite by timing how long the signal takes to arrive.
3. **Trilateration:** finding a location using distances from three or more known points.
    a. One satellite narrows it to a circle, two narrow it to two spots, and three narrow it to one spot.
4. **Navigation:** using a location to find your way somewhere.
5. **Radius:** the distance from the center of a circle (or sphere) to its edge.

Materials

Part 1 (per site):

- 3 strings: 1m, 1.25m, and 1.5m
- 3 Module 1 satellites (ask volunteers from mentees)
- 15 paper circles (5 each in 3 different colors)

Part 2 (per mentee):

- For older sites:
    - 1 treasure map (Map A, B, or C)
    - 1 paper compass
    - 1 pencil
- For younger sites:
    - 1 treasure map (beginner)
    - 1 pencil

Part 2 (per site):

- 1 map answer key

Different Methods for Teaching

1. **GPS:** Have mentees think about how a delivery driver finds your house. Their phone listens to satellites to figure out exactly where it is.
2. **Radius:** Have mentees imagine drawing a line from the center of a circle to its edge, or quickly draw one on the board.
3. **Trilateration:** Draw a diagram on board so that mentees can actually see the process.

Procedure

Part 1: String Trilateration Demo (6-8 min)

- **Setup (before mentees watch):** One mentor pinches the ends of all three strings together on the floor. This is the “treasure” spot.
- Three other mentors each hold a satellite model in one hand and take the free end of one string in the other. They walk out in different directions until their string is tight, spreading out like 12, 4, and 8 on a clock, and stay in place for the rest of the demo.
- The mentor at the center lets go of the strings.
- **Satellite 1:** The center mentor takes the free end of Satellite 1’s string and walks all the way around the satellite holder, keeping the string tight. Along the way, they drop 5 paper circles of the same color on the floor.
    - Ask: “*Where could the treasure be?*”
- **Satellite 2:** The center mentor repeats this with Satellite 2’s string, using a different color of paper circles.
    - Ask: “*Where do the two circles cross?*”
- **Satellite 3:** The center mentor repeats this with Satellite 3’s string, using a third color.
    - Ask: “*Where do all three circles meet?*”

Part 2: I-Spy Treasure Map (12-15 min)

- **Hand out maps** so neighbors get different versions. Older sites also get a paper compass strip, and younger sites get beginner maps with predrawn circles.
- **Older sites:**
    - Read the three satellite clues.
    - **Make your compass:** For each clue, find the number on the paper compass strip and poke a small hole on the line with a sharpened pencil tip.
    - **Draw the first circle:** Hold the paper compass’s black dot on the satellite's dot with fingertip. Put pencil tip through the hole at the clue’s number, and swing the pencil around to draw a circle.

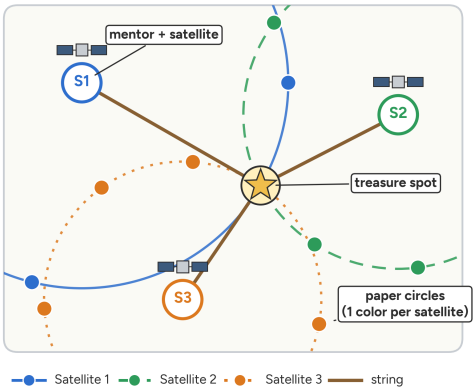


Figure 1: *String demo. Each string traces a circle; only one spot touches all three strings.*

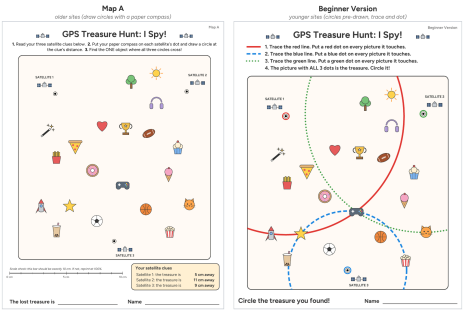


Figure 2: *Example Map for older sites (left; clues in the box under the map) and younger sites (right; pre-drawn, mentees find spot).*



Figure 3: *Poke a hole at each clue’s distance on the paper compass strip, so the pencil can go through it to draw the circle.*

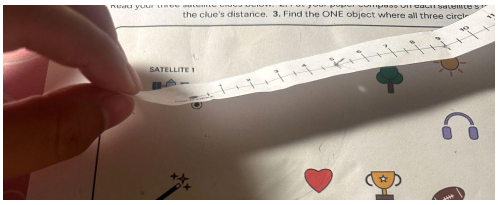


Figure 4: *The “HOLD HERE” dot on the paper compass needs to touch the dot next to the satellite you’re working on.*

- Draw the second and third circles around Satellite 2 and 3 the same way.
- Find the item where all three circles cross! Then write down the solution in the blank at the bottom of the paper.
- Check answers using the answer key and have mentees share what they found since they should have different versions of the map, thus different solutions!!!
- Hand out candy if available (real treasure to them).

- **Beginner sites:**
  - Trace the circle with a pencil, then draw a dot on every item Satellite 1 touches.
  - Repeat the same step for Satellite 2 and 3, but instead draw a different symbol for each satellite (star, heart-shape, etc.)
  - The item that has all 3 symbols next to it is the treasure (which is the controller here)!

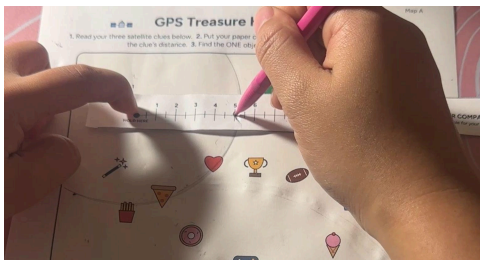


Figure 5: *With your fingertip holding the "HOLD HERE" dot in place, put a pencil through the hole and swing it around to draw the circle.*



Figure 6: *If swinging is too tricky, try the dot method instead. Keep holding the strip in place, mark a dot next to the desired distance, then turn the strip slightly and mark another.*



Figure 7: *Keep going until dots form a circle.*



Figure 8: *The spot where all three circles cross is the treasure, which is the pizza here!*

Classroom Notes

If the classroom is tight, mentors can demo on the whiteboard instead. Print maps at actual size.

Conclusion

Bring it back to the pizza! Ask mentees, "*Next time you're in a car with a map app open, what's sending the signals that make it work?*" (Satellites!) Then follow up with, "*And how many satellites does your phone need to find you*?" (At least three, and in real life, usually four or more!)

References

- *GPS: The Global Positioning System*, U.S. Government. https://www.gps.gov/
- *Space Segment*, GPS.gov. https://www.gps.gov/systems/gps/space/
- *GPS Accuracy*, GPS.gov. https://www.gps.gov/systems/gps/performance/accuracy/
- *What Is GPS?*, NASA Space Place. https://spaceplace.nasa.gov/gps/en/
- *How GPS Works*, BRIGHT SIDE, YouTube. https://www.youtube.com/watch?v=wCcARVbL_Dk

Printables

- Module 2 - Clap Code.pdf
- Module 3 Paper Compass Strips.pdf
- Module 3 Beginner GPS Treasure Maps.pdf
- Module 3 Advanced GPS Treasure Maps.pdf
- Module 3 Treasure Maps Answer Key.pdf

Summary Materials Table

Material	**Amount per Site**	**Expected $$**	**Vendor (or online link)**
Toilet paper rolls	1 per mentee	$25.99 per 180 ct ($77.97 for 3 pks)	Amazon
Tape	2-3 rolls per site	$17.99 per 18 rolls	Amazon
Circle-shaped paper (4-inch diameter)	1 per mentee (for module 1) 15 per site (for module 3)	$21.99 per 1,000	Amazon
Dumbbell-shaped paper strip (needs cutting)	1 per mentee	$0	
Markers	8-10 per site	$0	

Clap code sheet	2 per site	$0	Printing Required
Strings (1m, 1.25m, 1.5m)	1 of each per site	$0	
Paper compass	1 per mentee	$0	Printing Required
Treasure maps (A, B, C)	1 per mentee (evenly split between the diff. versions)	$0	Printing Required
Treasure map answer key	1 per site	$0	Printing Required