National Aeronautics and Space Administration

LASER MAZE

This activity explores the properties of light reflection and refraction through an engineering design process challenge. Currently, NASA missions rely primarily on radio waves for communications. But as science instruments advance and capture significant amounts of data, missions will need more advanced ways to send data back to Earth. NASA has developed a new communications method: lasers. Laser communications offers satellites higher data rates, meaning more data in a single link back to Earth. Laser terminals like NASA's Integrated LCRD Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T) will demonstrate this technology on the International Space Station, and potentially provide astronauts and experiments with enhanced data capabilities. However, using laser communications has its own challenges because the Earth's atmosphere and satellites in space can block or distort transmissions.

Objective

Students will investigate the properties of light reflection and refraction by using mirrors to send a laser beam through a maze to hit multiple targets. Students will use the Engineering Design Process to construct a mount for the laser and any mirrors used in maze navigation to meet predetermined criteria and communicate their solution (a message) with their peers.

NGS Standards[1]

Performance Expectations
MS-PS4-2, MS-ETS1-4

Science and Engineering Practices
- Planning and Carrying Out Investigations
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence
- Obtaining, Evaluating, and Communicating Information
- Developing and Using Models

Disciplinary Core Ideas
- Electromagnetic Radiation
- Developing Possible Solutions
- Optimizing the Design Solution

Crosscutting Concepts
- Patterns
- Cause and Effect: Mechanism and Prediction
- Systems and System Models

[1] A complete list of the NGS Standards can be found at https://ngss.nsta.org/AccessStandardsByTopic.aspx.

AGE:
11+

DURATION:
Two 1-hour sessions

MATERIALS
- Laser pointer, 1 per group
- Masking tape, as maze boundary
- Clothespins, a dozen per group
- Small square mirrors (approximately 2" x 2" or 3" x 3"), 1-2 per group
- Tape (packaging or cellophane)
- Cardboard
- Printed bullseyes
- A sheet of dark construction paper

OPTIONAL
- Recycled materials for student construction
- Section of clear plastic bag or clear plastic wrap, 1 per group
- Protractor
- A hot-glue stick cut into coin-like discs (or another translucent object that "lights up" when illuminated by the laser)
- A printed picture of the Earth and the International Space Station (see "Templates & Cut-outs" below)

BUILDING BACKGROUND KNOWLEDGE

TEACHERS WILL

- Demonstrate the law of reflection to their class using a laser pointer, mirror, and a hot glue stick target.
- Use household materials to build laser barrier courses around their classroom for their students to solve.

STUDENTS WILL

- Apply the Engineering Design Process to brainstorm a solution to their maze.
- Simulate transmitting data via laser communications by using the properties of light reflection and refraction to navigate around barriers.
- Practice teamwork and communication to implement and explain their maze solution.

Vocabulary

Absorb: take in light, sound, or heat waves with minimal or no reflection

Angle of Incidence: the angle that a line or ray perpendicular to a surface makes at the point of incidence

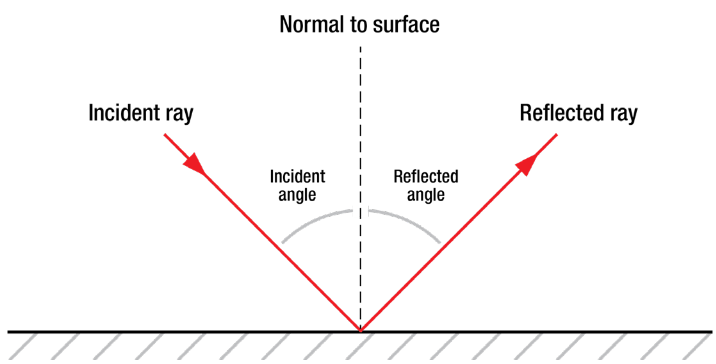
Angle of Reflection: the angle at which a reflected ray bounces off a surface

Normal Line: a line perpendicular to ('normal to') the surface of a surface at which the incident ray and the reflected ray can be divided into two equal angles

Point of Incidence: the point on a surface where the line or ray of light falls

Reflect: send back light, sound, or heat waves with minimal or no absorption

Transmit: broadcast or pass data from one place, person, or terminal to another



Expansion and Differentiation

Expansion

- Introduce students to core concepts of this activity within a virtual space in the NASA Science's Relay: A Laser-Based Space Communications Game.[2]

- Advanced students looking to challenge themselves further can add microdevices and coding opportunities to this activity. Consult the NASA Jet Propulsion Laboratory's Build a Relay Inspired by Space Communications[3] for guidance on how to expand the activity with more sophisticated lenses and light sensors.

Differentiation

- Students will work in flexible groupings of two to three for this learning experience.

- The challenge can be modified to include fewer or more light bounces as appropriate for student needs or abilities. The relay can be simplified by providing students with one target instead of two.

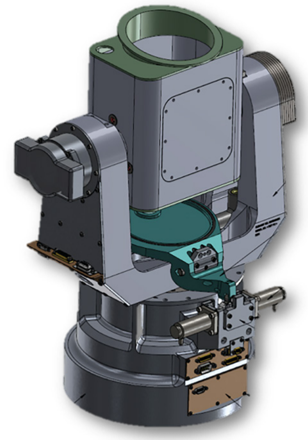
[2] https://spaceplace.nasa.gov/relay-laser-communications-game/en/
[3] https://www.jpl.nasa.gov/edu/teach/activity/build-a-relay-inspired-by-space-communications/

Engagement

1. Ask your learners: *What do you think engineers do?* There are many answers, but primarily engineers use technology to *solve problems*.

    a. **Laser communications is a form of problem solving!** For example, as spacecraft take higher quality pictures of more distant objects, NASA needs a way to send those pictures from space to Earth more efficiently while using less power. Laser relay terminals and satellites like ILLUMA-T, Orion Artemis II Optical Communications System (O2O), and more are smaller, lighter, and use less power than NASA's current radio frequency communications systems. The smaller size means there is more room on a spacecraft for science instruments. The lighter weight means it takes fewer resources—and less money—to launch. Less power means communication uses up less of the spacecraft's batteries. Plus, the use of tight infrared light waves, or lasers, means that satellites and ground stations can receive more data at once than they can from more spread-out radio waves.

    b. **Laser communications is a great solution, but it also introduces its own challenges.** Before we begin our exploration, can your class imagine any challenges introduced by communicating with lasers? Some issues include atmospheric distortions, or the *refraction* of light as it passes through our atmosphere, dense clouds blocking the laser's path, and the challenge of a much narrower laser beam point having to hit its target.

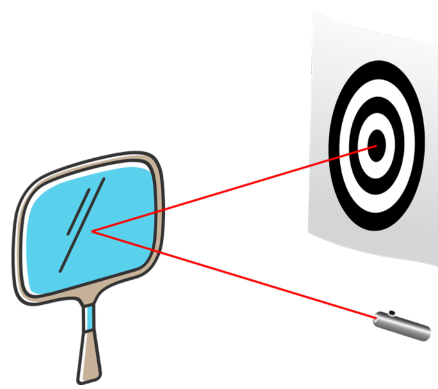


ILLUMA-T Artist Rendition

2. Use a laser pointer, a mirror, and a target to introduce your students to the *law of reflection* through a mini investigation.

    a. Place the mirror against the chalkboard or another surface facing *away* from your students and lay the protractor in front of the mirror. Draw or tape a bullseye to the dark piece of construction paper and hold it away from the mirror.

    b. Position the laser pointer so that the beam hits the mirror at the center or origin of the protractor. Adjust the angle so that beam's reflection hits the target.



In this demonstration, the laser pointer represents a ground station on Earth transmitting data. In order to communicate with its target, the International Space Station, the ground station needs help from a relay satellite — think of our mirror as LCRD!

Note that NASA's laser relays aren't quite the same as mirrors: at a real laser relay, the data encoded within the laser is received, processed, and retransmitted via telescope. However, the mirror and target are useful stand-ins when discussing the precision— and potential barriers —that must be accounted for in laser communications.

    c. Adjust the angle of the laser pointer and target to demonstrate how the **angle of incidence** is always equal to the **angle of reflection**.

Suggestion: For more visual excitement, you may want to replace the target with a disc cut from a hot glue stick. No matter what you choose, make sure your target is surrounded by something opaque to keep your students' eyes safe.

Suggestion: If you'd like to delve deeper, you can introduce a clear piece of glass or small sheet of plastic tape between the laser pointer and the mirror to demonstrate *atmospheric distortion*, where the beam *refracts* through the glass 'atmosphere.' Placing a dark piece of construction paper between the laser and its target can represent dense cloud coverage *absorbing* the beam before it can reach its destination.

This movement is also part of laser communications! NASA software needs to be able to maintain the laser beam's accuracy while the Earth rotates and the International Space Station moves along its orbital path.

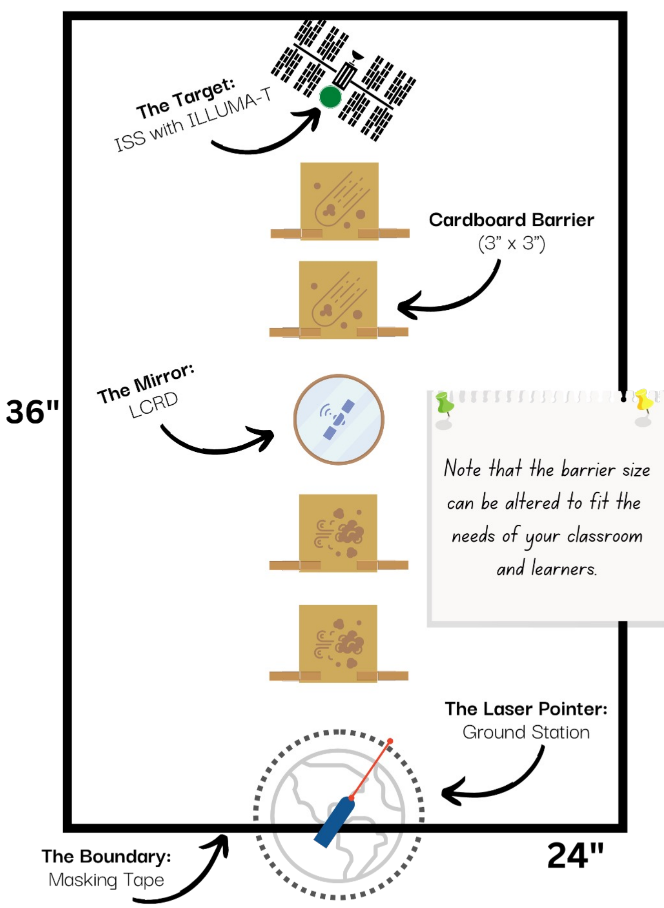
3. Show your students the Laser Communications Relay Demonstration (LCRD) video overview.[4] LCRD, together with ILLUMA-T and NASA ground stations, creates an end-to-end laser communications system.

    a. Allow your students to share their observations! Brainstorm why accuracy is so important to laser communications. Questions include:

    - *Why are lasers important in space communications?*
    - *Why is accuracy so important to space communications? What happens if a laser transmission is inaccurate?*
    - *What barriers does NASA have to consider when designing and implementing laser communications?*

Exploration

Be safe! Avoid using lasers at eye level and talk to your students about the dangers of prolonged eye contact with lasers. NO part of this activity should involve pointing your laser at yourself, another person, or any living creature.



Teacher Preparation

For this activity, you will be creating laser mazes for your students to solve. The **Example Mazes and Solutions** section demonstrates one simple way to organize the relay and barriers, but we encourage you to design your own barrier configuration. Depending on the size of the maze and the number of groups participating in the activity, you may need to clear some space.

1. Create a masking tape boundary for the activity. This boundary can be whatever size your class requires, but should have enough room for the target, at least two cardboard barriers, and the mirror(s) your students will use to direct their laser. Ensure that your cardboard pieces are tall enough to keep the laser beam from passing over the barrier. The solution(s) to your maze must be possible within the masking tape boundary.

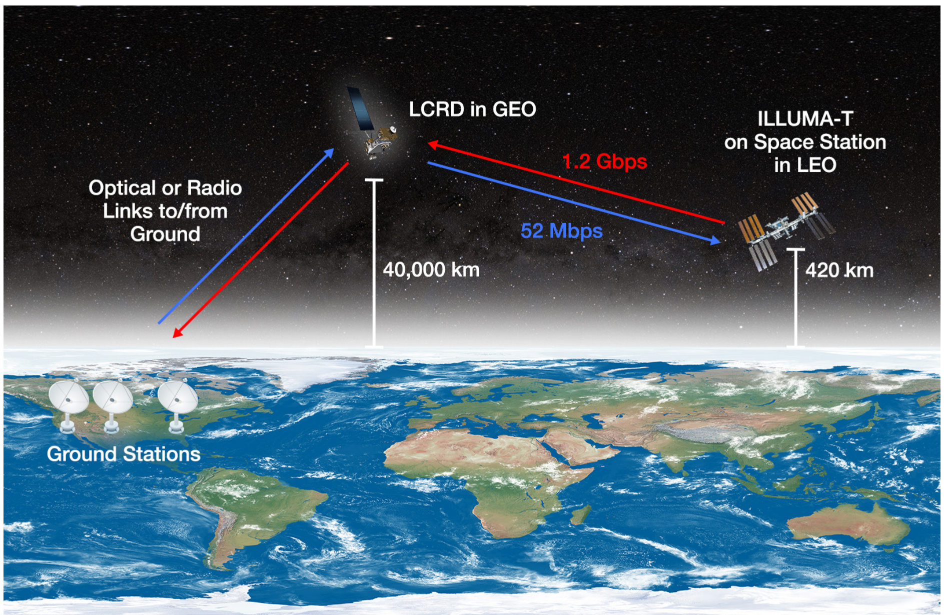
2. Place a circle marker at the edge of the boundary to represent an optical ground station on Earth. Our included Ground Station Printable is roughly situated in Table Mountain, California. Set the laser pointer on top of the circle marker. The laser pointer may be angled in any direction, but it

[4] https://www.youtube.com/watch?v=OAFkd5DdLZU

cannot leave "Earth."

3. Add your ILLUMA-T target within the boundary. The placement of the target can vary based on the difficulty of your laser maze. **Consult Example Mazes and Solutions** (page 8) for some possibilities. You may want to add a hot glue stick disc to the target to make the laser's impact more visible.

   The laser from our "ground station" must reach a laser relay terminal, a midpoint target represented by a mirror, which will then relay the information to ILLUMA-T on the International Space Station.



4. Cut the cardboard into small square or rectangular pieces. Place one or two clothespins at the bottom of each piece to serve as a stand for the cardboard barriers. At least two barriers made of cardboard and clothespins should be placed between each target to obstruct the beam's destination.

   These cardboard obstructions represent various real-world barriers faced by our engineers, such as planetary or lunar obstructions, asteroids, or even our own planet, as its rotation can point our ground station away from its target.

   For an even greater challenge, consider moving the target so that it is farther away from the starting point. Note how the mirror-as-relay needs to be adjusted to match the target's movement. While the relay is designed to be visible to the ground station *and* the International Space Station for a significant amount of time, the International Space Station's orbit means that it's not consistently visible to ground stations. The laser relay is so useful because it can adjust and track the International Space Station's movement in the way a ground station cannot. That is part of what makes laser relays so important!

Suggestion: While the schematic only demonstrates cardboard construction, interested classrooms may go deeper. A humidifier might represent cloud and dust formations. A nearby lamp could stand-in for the diffuse but powerful light and heat waves of the Sun. Transparent or translucent barriers, such as plastic wrap, could represent other environmental distortions.

Student Activity

1. Introduce your students to NASA's Engineering Design Process[5] with our three-minute video. Ask your students:

   a. Discuss and explain answers as a class. As engineers, your students will be asked to:

      Step 1: *Define the problem*
      Step 2: *Do background research*
      Step 3: *Specify requirements*
      Step 4: *Brainstorm and choose a solution*
      Step 5: *Develop a prototype*
      Step 6: *Test the solution*
      Step 7: *Communicate results*

Suggestion: Have your teams log their progress through the engineering design process.

2. Students are now ready to practice their own engineering design process by solving a laser maze of their own! State the goal of this exercise. **In this activity, students must successfully transmit a message from an Earth ground station (their laser pointer) to the International Space Station (the target). To do so, they will need to navigate the laser beam around obstructions (cardboard blockades) using no more than two relays (mirrors).** We suggest grouping students in teams of two or three. At the start of the activity, they can already:

   1. **Define the problem:** Barriers stand in the way of their laser reaching their target.
   2. **Do background research:** They have learned about laser communications, the laws of reflection and refraction, and how to approximate the angle of incidence. Remind students how the incident ray reflects at the same angle as the reflected ray when it hits a flat, reflective surface. This information should inform their engineering process.
   3. **Specify requirements:** They must have the laser reach their target without removing the laser pointer from the "ground station" or using more than two relay-mirrors.

Suggestion: You may make the mirror mounts yourself in advance of the activity, or challenge your students to make their own with various recycled materials. Additional 'cost restraint limits' might include limiting the number of recyclable materials each student/student group can use to reach their target. See the examples below.

3. Introduce your students to their project constraints. For instance:
   a. The laser pointer must stay within the circular area of our "Table Mountain ground station."
   b. Laser beam point must be fully within the receiver telescope target.
   c. All materials must stay within a defined boundary. Determine the acceptable amount of space your classroom allows, but also consider real NASA constraints. Mark this space with masking tape, as suggested above, or otherwise make this boundary clear. Relay-mirrors cannot touch obstructions and cannot be placed outside your boundary for both cost and feasibility reasons.
   d. Reflective material mounts must support the reflective surface without human interference.
   e. Limit students to two or three mirror-satellites at most, depending on maze difficulty.

[5] https://www.youtube.com/watch?v=wE-z_TJyzil&list=WL&index=4

f. If your learners find the engineering to be too easy, consider adding additional complications such as

    1. a time limit, representing the schedule constraints of operating budget and orbital windows,
    2. limiting supplies (mirrors, clothespins, tape, cardboard),
    3. assigning materials a dollar amount and providing a cost constraint,
    4. challenging learners to design a laser mount that holds the laser stably even when subjected to minor disturbances, or
    5. adding "orbital paths" in masking tape, representing the common orbits used by NASA. Restrict your mirror-relays to staying on those orbits.

4. Now it's time to work together to brainstorm a solution! Encourage students to begin by drawing a diagram or diagrams for their potential mirror placement. Note that this should happen *after* they have seen their maze. Some example scenarios and solutions can be found in the **Example Mazes and Solutions** section.
5. After working together to plan out their solution on paper, it is time to develop a prototype. Each team should recreate their diagrammed solution using their relay-mirrors to ensure the laser pointer's beam reaches its ILLUMA-T target.
6. Testing and evaluation is an iterative process; each team's solution should be tested repeatedly. If the first prototype misses its goal, encourage your students to continue testing. If their prototyped solution works, ensure that every member of the team can successfully relay their beam from "Earth" to "ILLUMA-T."

Explanation

How would their solutions change if they wanted their laser pointer to reach a target 250 miles away (the actual distance between the Earth and the International Space Station)?

Ask student groups to provide an explanation of their solution to their peers. Potential ideas for implementation:

- Have students participate in a gallery walk to communicate their solution.
- Swap planning documents to see if different student groups can recreate one another's success. Remember that step 6 of the engineering design process is testing your solution, and the strongest designs are tested repeatedly! This is an opportunity to emphasize the importance of *iteration*.
- Allow student teams to create brief videos explaining their design process and solution.

Challenge students to evaluate each other's work as engineering peers. Ask your learners to record questions and observations they have about their solution, and compare their work to their peer groups. Do they see opportunities to optimize their peers' solution? How many alternative solutions to the maze did the class uncover? Are there any additional challenges with trying to implement these solutions in the real world of NASA engineering?

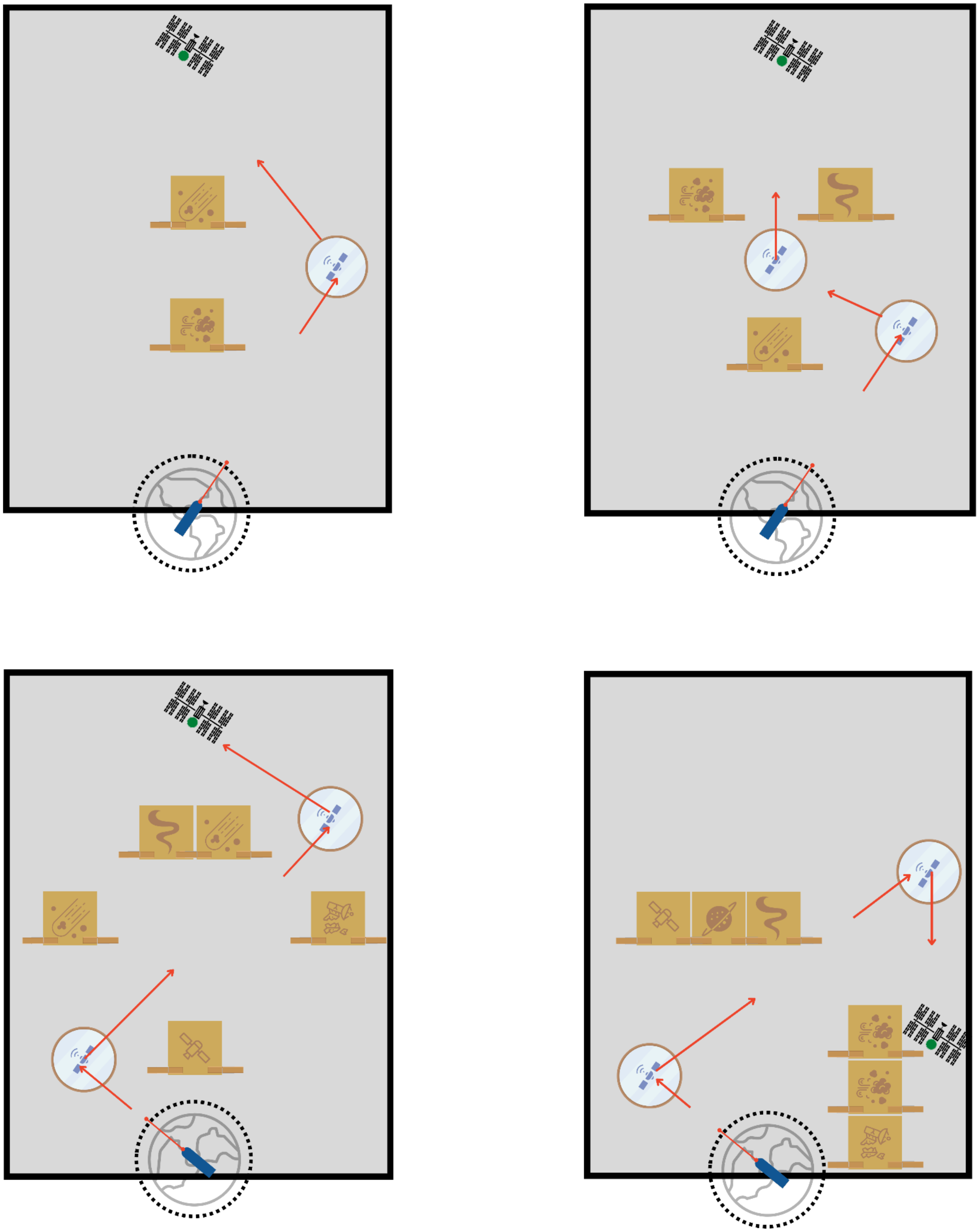
Evaluation

Encourage students to demonstrate their mastery of the key concepts introduced in this activity with the following extensions:

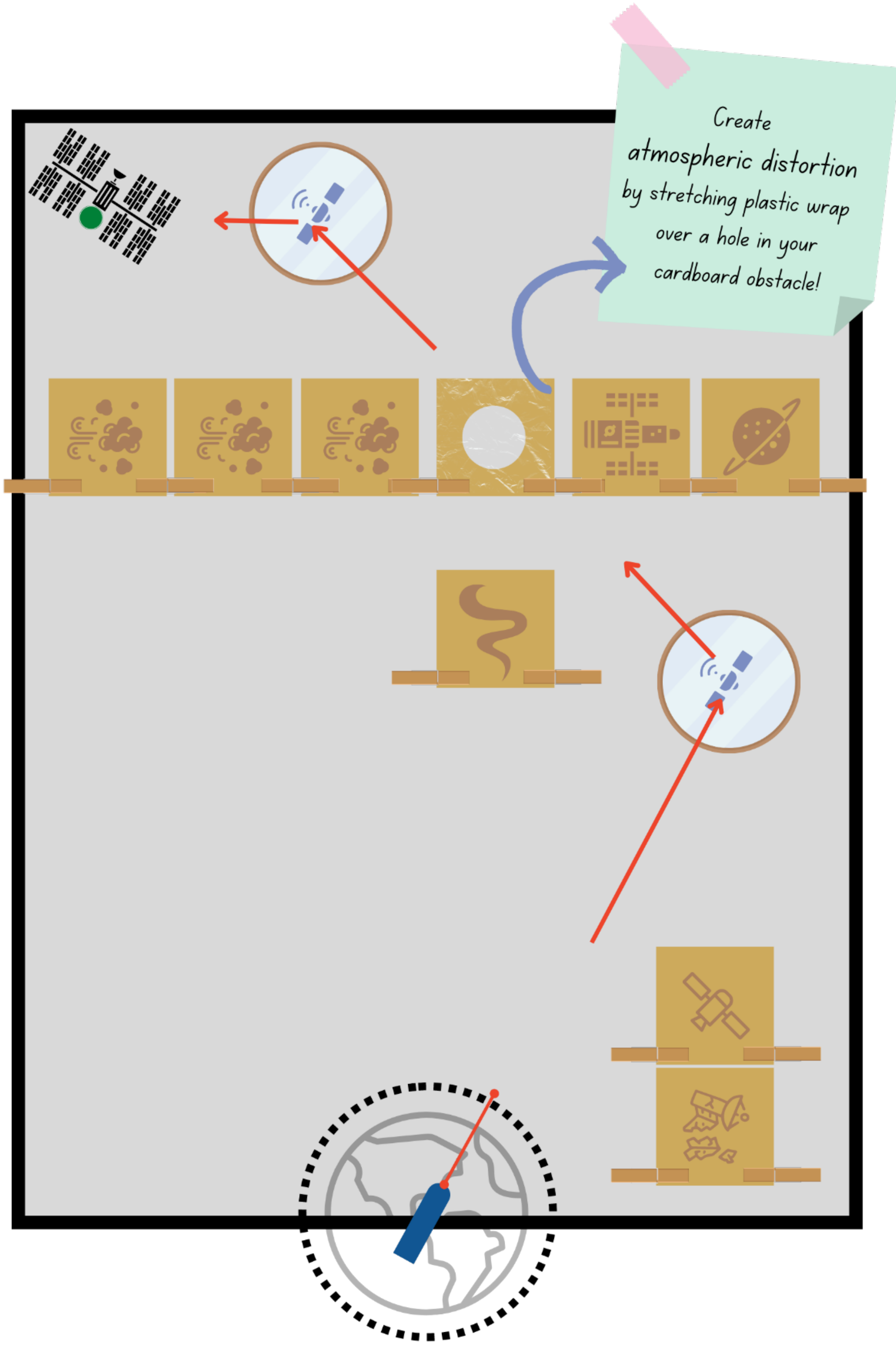
1. Challenge your learners to compete in NASA's Laser Communications Kahoot![6]
2. Ask students to create a presentation or poster about how they used the Engineering Design Process to solve their Laser Maze problem.
3. For those students who completed the activity in groups, ask them to consider how each member of the group played a role in their design solution. Engineering is easier and more efficient with teamwork. What did each engineer bring to the design process?

[6] https://play.kahoot.it/v2/?quizId=e7df4fb6-ddb1-436a-b27f-d9541eeacc19

EXAMPLE MAZES AND SOLUTIONS

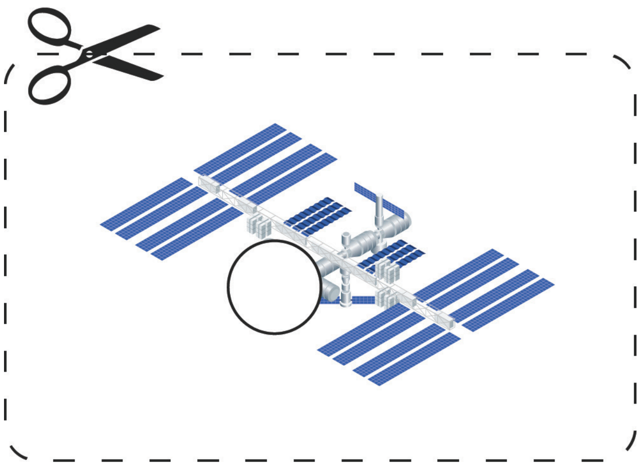


EXAMPLE MAZES AND SOLUTIONS



Templates and Cut-outs

PRINTABLE INTERNATIONAL SPACE STATION "GOAL"



PRINTABLE GROUND STATION STARTING POINT