GENERATION
BEYOND

EDUCATOR GUIDE

TOPIC
Under—the—Radar

KEY LEARNING OBJECTIVES

Students will be able to:

- Describe the reflection of light
- Investigate the reflection of light on different surfaces and in different conditions

LESSON OVERVIEW

In this lesson, students will investigate electromagnetic radiation: specifically, visible light and radio waves. Students will begin by exploring the concept of visibility as they learn about light's properties and how it is reflected. They will also learn how radar uses radio waves to detect the position of distant objects. By substituting light waves for radio waves, they will apply what they have learned to create a model of a radar system. In doing so, students will analyze data about reflected light, and they will consider what can interfere with the operation of radar, such as obstacles or noise. Lastly, they will think about ways to deliberately evade radar.

The accompanying presentation was created with PowerPoint so that it can be used in a variety of classrooms. If you are using a laptop with an LCD projector, simply progress through the PowerPoint by clicking to advance. All of the interactive aspects of the presentation are set to occur on click. If you are using an interactive whiteboard, tap on each slide with your finger or stylus to activate the interactive aspects of the presentation. It does not matter where you tap, but you can make it appear as if you are making certain things happen by tapping them. In the notes for each slide there will be information on how to proceed.

CONTENT AREAS

Waves, Physical Sciences

ACTIVITY DURATION

3 class sessions (45 minutes each)

GRADE LEVEL

Grades 9–12

ESSENTIAL QUESTIONS

1. How does light interact with matter?
2. How do radar systems use radio waves to detect properties of objects?

MATERIALS

Dim light, such as a small lamp with a low wattage bulb
One laser pointer per group
One flat mirror per group
String
Protractors
"Mirror Reflection" Student Activity Sheet
"Modeling Radar" Student Activity Sheet
"Engineering Design Journal" Student Activity Packet
One camera with manual control of shutter speed, aperture, and exposure time per group
5 sheets of aluminum foil per group
5–10 different materials to test (e.g., black construction paper, white loose-leaf paper, LCD screen, cotton towel, tissue paper, etc.)
5 white LED flashlights
One sheet of white printer paper

BACKGROUND INFO

Scientists and engineers regularly take advantage of electromagnetic radiation to detect the properties of objects. Electromagnetic radiation can be used to analyze the chemical composition of distant stars, the velocities of speeding cars, and the temperature of sick patients. As its name suggests, electromagnetic radiation consists of waves of energy that have both a magnetic and an electric field. Electromagnetic waves are measured by their wavelength (the distance between the crests of the wave) and their frequency (how many waves pass a point over a specific period of time.) Wave frequencies are measured in a unit called the Hertz, and one hertz is equal to one wave per second.

There are seven basic kinds of electromagnetic radiation: radio waves, microwaves, infrared waves, visible light, ultraviolent waves, x-rays, and gamma rays. This lesson will focus on radio waves and visible light. Though radio waves have a much longer wavelength and a lower frequency than visible light, both waves travel at the speed of light.

Visible light is the only portion of the electromagnetic spectrum that the human eye can see. Light is a transverse electromagnetic wave that has energy and travels through space. Light travels in small packets of energy called photons. When photons interact with matter, they excite electrons that absorb the photons. The excited electrons temporarily gain energy; as the electrons return to their original energy level, the photons are released. Depending on the structure of the material, these photons can be released in a direction that travels back toward the source of the incident light, causing a reflection.

Radio waves, on the other hand, are invisible to the human eye. They are used to transmit signals in radios, cellphones and televisions, and they are used to transmit data using systems like radar. Radar stands for radio detection and ranging. In other words, radio waves detect objects and bounce back as an echo so that the range (or distance) of the object from the source can be measured. Radar systems use reflection to measure where objects are. A radar system has two basic components. One component is a transmitter that emits low frequency radio waves. Because low frequency radio waves have long wavelengths, they are less likely to be scattered by molecules in the air. The other component of radar systems is a radio wave receiver. The receiver detects the radio waves that are reflected by objects in the environment. Depending on how long it takes for the radio waves to be reflected, the radar system can calculate the distance and velocity of the object reflecting the wave.

This guide was created to give educators ideas and strategies for presenting the content in the digital lesson. It provides slide-by-slide details for educators to be prepared to engage with students as they explain, discuss, and investigate the content in the presentation. The presentation is designed to cover three 45-minute class sessions, but it is flexible, depending on the students' needs and time available.

Because visible light is also a type of electromagnetic radiation and can be more easily manipulated by students than radar, this digital lesson will guide students in exploring light as they seek to solve a challenge problem scenario involving radar. After developing an understanding of the design of radar systems, students will think about what can disrupt the function of such a system. Since the system fundamentally depends on the ability of the receiver to detect reflected radio waves in the environment, many strategies to evade radar detection focus on preventing the receiver from detecting or recognizing these reflected waves. Engineers can use materials that absorb radar to prevent reflection in the first place. They can also contour the shape of the material in such a way as to direct radio waves away from the receiver. Lastly, they can use bright jamming signals to prevent the receiver from finding the reflected waves in all the noise. In this lesson's Challenge Activity, students will investigate how to use these three strategies to design new radar-evading technologies.

NATIONAL STANDARDS

Next Generation Science Standards

High school

PS4.A: Wave Properties

The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.

Defining and Delimiting Engineering Problems

Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.

Optimizing the Design Solution

Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.

PROCEDURE
DAY 1
Engage (Slides 1–2)

Overview: Students are introduced to the problem of designing aircraft that can hide from radar systems. Before they can design such a vehicle, though, they will first develop an understanding of light's properties. By investigating how light moves and interacts with matter, students will begin to understand what makes an object visible to the human eye. Students will observe the light of a dim lamp. Based on what they know about light, they will think about how light helps them see in the dark. They will make a list of surfaces that are easily seen in the dark and surfaces that are difficult to see in the dark. Then, they will speculate on how light and matter interact to produce vision.

Slide 1

- Introduce students to what it really means to fly under-the-radar using an academic vocabulary strategy to unpack the mission!
    - Guide individual students to use a scrap piece of paper and rip it into seven pieces. Ask them to write a vocabulary word on each piece: RADAR, Surveillance, Electromagnetic Radiation, Evade, Stealth Aircraft, Reflection, and Absorption. Students should then be directed to mix them up.
    - In small groups of 3-4, have students discuss which words are familiar and share their understanding of the meanings.
    - As a whole group, briefly have students share and review the words and their meanings.
    - Next, ask small groups to predict what their STEM challenge might be about.
    - Explain to students that, as the STEM challenge, they will work with a partner to place the vocabulary words in order as they are heard in the segment.
    - Play the Under-the-Radar video.
- After the video segment concludes, have students discuss the sequence of topics from the segment, using the order identified for the vocabulary words. Then, ask them to discuss how the terms and concepts might be used to solve the challenge introduced in the video.
- Distribute the Engineering Design Journal packet to students and use the first page to clarify the requirements of the Challenge Activity. Sometimes people don't want flying objects to be seen! In this challenge, students will help design an invisible aircraft.
- Explain that before anyone tries to solve an engineering problem, they must ensure that they actually understand the problem! Divide students into small groups and allow them time to work together to fill out *Step 1: Identifying the Problem* in their Engineering Design Journal packet.

Slide 2

- Once they understand the problem, tell students that the first step in creating an invisible aircraft is to understand the concept of light. In other words, what factors lead us to seeing an object?
- Turn off the light in the classroom and, if possible, cover the windows and doors with blackout curtains so that the room is completely dark. Give students some time to adjust to the dark room. Then ask them, "What do you see?" Allow students to think about what causes darkness. Give students a few moments to mentally note down their observations (they will not be able to take notes in the dark).
- Then, turn on a dim light. Ask students to observe the classroom and note what objects are easy to see and what objects are hard to see. Some surfaces that might be easy to see include glossy posters, blackboards, mirrors, and polished metal doorknobs.

- After students have had a chance to note their observations, turn on the lights. Arrange students in groups and ask each group to use a T-Chart to write or draw examples of objects that are easily seen in the dark and objects that are more difficult to see.
- After they have finished brainstorming, ask each group for ideas about what is similar about the objects that are easily seen in the dark.
- Display slide 2 to the class. Explain that reflection is what happens to light when it bounces off an object. Sometimes, reflected light enters the eye and is perceived by the brain, causing vision. Objects that reflect more light are more easily detected by the eye in the dark.

DAY 1

Explore (Slides 3–4)

Overview: In this section, students will learn how light interacts with matter. They will conduct an activity to investigate how light is reflected by mirrors. They will use this information to compare surfaces that reflect light (like mirrors) and those that scatter light (like walls).

Slide 3

- Begin this section by giving each group of students a mirror, a laser pointer, and the "Mirror Reflection" Student Activity Sheet. Have them direct the laser pointer at the mirror at different angles. Using the handout, students should map the angle at which light hits the mirror and the angle at which light leaves the mirror. They should diagram how the position of the reflected light changes as the angle of light from the laser pointer (the incident light) changes.
- Then advance to slide 3. Ask students to compare their results with the diagram on the slide. Explain that light is reflected in such a way that the angle of the incident light from the normal (an imaginary line that is perpendicular to the reflective surface—in this case, the mirror) is equal to the angle of the reflected light from the normal.
- Based on this information, ask students to consider how light is reflected when the light is directed straight at the surface. Hint to students that this reflection is equal to a 0 angle. After students have realized that the light is reflected straight back to the source, explain that this is why we can see our own reflection in the mirror. Light (i.e., from a lamp or the sun) reflects off our face and strikes a mirror, which reflects the light right back to our face!

Slide 4

- Prompt students to compare mirrors and walls. If light is also reflected from walls, why can't we see our reflections in walls?
- Then have students examine the wall carefully. How is the surface of the wall different from the surface of a mirror? Students will realize that the surface of the wall is rough while the surface of a mirror is smooth.
- After students have discovered that a wall is rough, present slide 4. Explain that when light is reflected by a rough surface, it is scattered in all directions. This means that the image of our face that would otherwise be reflected off the wall is scattered in many directions. This is why we cannot see our face on the wall.

DAY 2

Explain (Slides 5–6)

Overview: In this section, students will model a radar system with a laser pointer, mirror, and paper. Using this model, they will explain how radar can detect distant objects.

Slide 5

- Tell students that now that they understand how light contributes to visibility, they must also understand how tracking systems like radar can "see" objects that are too far away for our eyes to see. An airplane will only be truly invisible if it can evade these systems!
- Explain that radar systems use radio waves to detect distant objects. Radio waves are one form of electromagnetic radiation, otherwise known as energy-carrying waves. The visible light with which students were experimenting is another form of electromagnetic radiation. But, unlike light, radio waves are invisible.
- Present the information on Slide 5. Explain that radar systems have two essential parts: a transmitter that emits radio waves and a receiver that detects radio waves. (Typically, the radio waves are emitted and received via an antenna.) Explain that because radio waves can't be seen by the human eye, students will be substituting visible light to simulate the radio waves.
- Pass out the "Modeling Radar" Student Activity Sheet to student groups. Using the diagram presented on slide 4, have students use a laser pointer, a mirror, and paper to model how radar systems can function. The laser pointer is the transmitter, the mirror is the object, and the paper is the receiver. Have students experiment ways to position the laser pointer, paper, and mirror so that the laser pointer light is reflected off the mirror onto the paper. After this activity, students should realize that a radar system detects objects only when the radar transmitter and receiver are directly facing the object. This is why radar systems typically perform circular sweeps such as that illustrated on slide 1. The radar is constantly rotating so that it is facing as many directions as possible. Students might compare this to human vision—in order to see objects behind us, we have to turn around.
- Using their results, have student groups draw a diagram of how they know where the mirror is based only on the light that appears on the sheet of paper. Have students explain their model to the class.

Slide 6

- After all the groups have shared their ideas, show slide 6. This slide diagrams how a typical radar system functions. Explain that the transmitter sends out low frequency radio waves. When these waves hit an object, they are reflected back to the receiver. Depending on the angle of the receiver, the radar can determine the direction of the object.
- Explain that modern radar systems can also determine how long it takes for reflected radio waves to reach the receiver. This can be used to determine the distance of the object—the farther away the object is, the longer it takes for reflected waves to reach the receiver.

DAY 2

Elaborate (Slides 7–8)

Overview: In this section, students will be presented with two scenarios in which radar function is impaired. In the first scenario, a low-flying aircraft approaches a radar system from behind a mountain. In the second scenario, an aircraft travels with two drones that send out strong radio waves. Students use what they know about radar function to explain how radar function is impacted in these situations.

Slide 7

- Present slide 7 to students.
- Have students imagine that a radar system is located near a mountain range. An aircraft approaches the radar from behind the mountain, as shown in the diagram. How will this affect the radar system's ability to function?
- Give students time to discuss this scenario in their groups. Then each group should apply what they learned in the previous activities and draw a diagram showing how the transmitted radio waves are blocked by the mountain.

Slide 8

- Present slide 8 to students.
- Have students imagine that an approaching aircraft is traveling with several drones. The drones also carry radio wave transmitters. What will the radar detector "see"?
- Give students time to discuss this scenario in their groups. Then each group should draw a diagram showing multiple points appearing on the detector.
- Students should realize that this will confuse the radar system because it will not have a precise location of the approaching aircraft.
- To check for student understanding, ask them how the radar system will be impacted if there are more drones or if the drones approach from different angles. Students should realize that increasing numbers of drones approaching from wider angles will confuse the system even more.
- Time permitting, ask students to brainstorm ideas for how the radar system can differentiate its radio waves from those emitted by drones. Some ideas students may come up with include encrypting the radio waves so that they broadcast a specific code pattern or using a different frequency of radio waves than the drones use.

DAY 3

Evaluate (Slide 9)

Overview: In this section, students will complete the Challenge Activity to investigate different strategies for evading radar. Students will interact with three different stations, using equipment prepared for the activity. In one station, students will determine how much laser pointer light is reflected by different materials. In a second station, students will contour aluminum foil to investigate how laser pointer light is reflected by different shapes. In the last station, students will determine how much directed white light is required to drown out laser pointer light.

- Divide the class into small groups. Make sure each group has a laser pointer and a camera. The camera should be set to manual so that all the pictures taken use the same shutter speed, aperture, and exposure times.
- Remind students of their challenge: to recommend designs for radar-evading aircraft. Explain that today is the day that they will develop their recommendations!
- Reiterate that students will use visible light waves from a laser pointer rather than radio waves in their investigations. Both are forms of electromagnetic radiation, so conclusions drawn from tests with a laser pointer are still relevant to the study of radar.
- Explain to students that they will be role-playing different careers in aerospace as they travel to the different stations. Distribute the *Career Cards* randomly within the groups of three students. Ask students to summarize in their small groups the similarities and differences between the careers on the cards. Ask what conclusions they can draw about the types of careers that are part of the aerospace industry. Each career will take the lead at a different station.
- Set up three stations around the classroom for student investigations.
    - Briefly review the stations (as described below). Tell students to refer to Step 2 of their Engineering Design Journal as they complete these activities. A notes space is provided in the journal for students to record any observations that may help them solve the Challenge.
    - In the first station, provide students with different materials to test. Some materials to consider include black construction paper, white loose-leaf paper, LCD screen, cotton towel, and tissue paper. Students will shine the laser pointer at the different materials and observe how much light is reflected by each material. The Materials Analyst will lead this station.
    - In the second station, provide square sheets of aluminum foil. Students will contour the foil into different shapes and record how light from the laser pointer is reflected by each shape. The Aeronautical Engineer will lead this station.
    - In the third station, provide a sheet of white paper and several white LED flashlights. Students test how many flashlights are required to obscure the light of the laser pointer reflecting off of the white paper. The Avionics Technician will lead this station.
- Once the stations have been completed, give students the opportunity to debrief the Career Cards they used throughout the lesson. Ask students to consider the following:
    - Which job would you like to have? Why?
    - Which job seems the most important? Why?
    - What is a common requirement among many of the jobs?
    - Which job seems the most difficult? Why?

Slide 9

- Remind students that radar systems function by detecting reflected radio waves. Based on this principle, engineers have found ways to prevent the receivers of radar systems from detecting these waves. Three strategies are shown on this slide. Click on the slide to advance each strategy.
    - Absorption: The aircraft can be made from materials that absorb radar light instead of reflecting it.
    - Redirection: The aircraft can be shaped to reflect radio waves away from the radar receiver.
    - Jamming: Other objects in the area can emit radio waves that obscures any reflected radio waves arriving at the receiver.
- Instruct students to turn to Step 3 of their Engineering Design Journal. Using the ideas above and the knowledge they have gained over the past several class periods, students will conclude this activity by brainstorming radar-evasion designs. They will ultimately write a short summary that incorporates data from their investigations and recommends specific design elements that would enable an aircraft to successfully avoid radar.

MIRROR REFLECTION | PRINTOUT FOR SLIDE 3

In this activity, you will investigate how light from a laser pointer is reflected by a flat mirror.

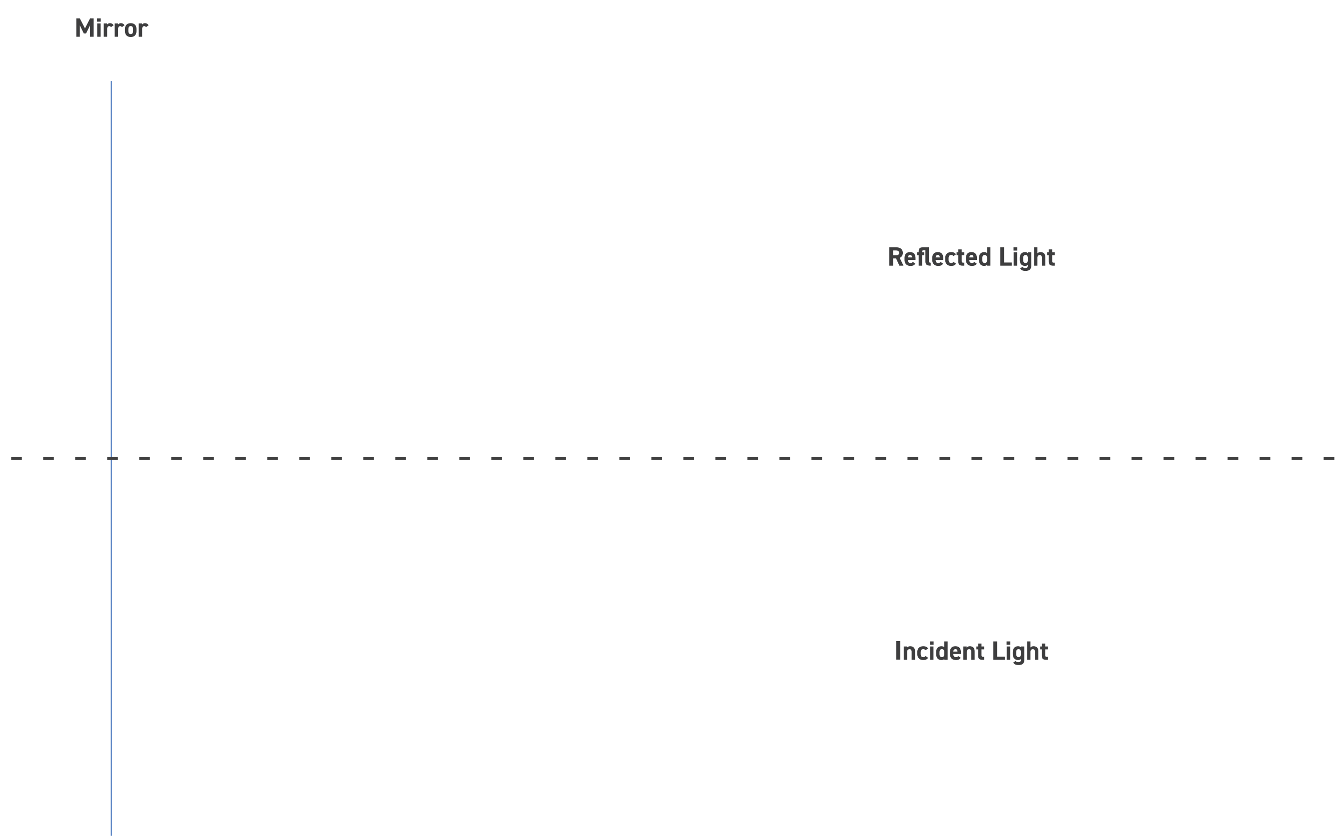
MATERIALS

Flat mirror
Laser pointer
String
Protractor

PROCEDURE

1. Stand a mirror vertically on a desk and point a laser pointer at the mirror. Locate where the reflected laser point appears in the room.
2. Use a string to trace the path of the light from the laser pointer to the mirror. Use a protractor to measure the angle between the light and the mirror. In the "incident light" half of the diagram below, draw a line to document the angle of the light from the laser pointer to the mirror.
3. Use a string to trace the path of light from the mirror to the reflected light. Use a protractor to measure the angle between the mirror and the reflected light. In the "reflected light" half of the diagram below, draw a line to document the angle of the reflection from the mirror to where the reflection appears in the room.
4. Conduct four trials in total, repeating steps 1–3; for each trial, change the angle between the laser pointer and the mirror.

Create diagram with a line for a mirror bisected with a dotted line, with halves labeled "incident light" and "reflected light," as shown below. Set the size of the full page for student writing.



MODELING RADAR | PRINTOUT FOR SLIDE 5

A radar system uses a transmitter and a receiver to locate where objects are in space. But the transmitter and receivers typically are unidirectional—they point in one direction only. How can they be used to track objects that move? In this activity, you use a mirror, a laser pointer, and a piece of paper to model a radar system and explain how radar detects objects in space.

MATERIALS

Flat mirror
Laser pointer
White paper

PROCEDURE

1. Assign one student to hold the mirror, another student to hold the laser pointer, and a third student to hold the paper.
2. The students holding the laser pointer and the sheet of paper should stand next to each other, facing the same direction. These two students form the "radar system."
3. Have the student with the mirror stand several feet away. Adjust the arrangement of the radar system so that when the laser pointer is pointed at the mirror, a reflection is created on the sheet of paper. When a reflection is created, the radar system "sees" the mirror.
4. Now have the student with the mirror choose a new location. Is the laser pointer still reflected on the sheet of paper?
5. Then have the students holding the laser pointer and sheet of paper move together. How do they have to position themselves so that the laser pointer is again reflected on the sheet of paper?
6. Based on your experience, what can you say about how a radar transmitter, radar receiver, and object in space need to be arranged so that the receiver can detect the object? How does this explain why radar surveillance typically occurs in sweeps (i.e., by rotating in a circle so as to progressively scan the entire region)? In the space below draw a model of how you think a radar system works.

As a **Materials Analyst,** you develop, process, and test materials used to create a range of products, from computer chips and aircraft wings to shoes and skateboards. You work with metals, ceramics, plastics, composites, and other substances to create new materials that meet certain mechanical, electrical, and chemical requirements.

As the **Aeronautical Engineer,** you design airplanes and other types of aircraft. You focus on the aerodynamics, navigation, and guidance of aircraft.

As the **Avionics Technician,** you install, inspect, test, and repaid avionics equipment. This includes radar, radio, and navigation in aircraft vehicles.