Optics in Action: Shaping the Future

Companion Lesson X-STEM All Access Video "Optics - So Much More Than Glasses"

Grade Band: Middle School - High School	**Topic:** Physical Science, Physics

Brief Lesson Description: Students explore optics to infer how light behavior drives technological advances

Performance Expectation(s):
MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
MS-PS4-3: Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.
HS-PS4-2: Evaluate questions about the advantages of using a digital transmission and storage of information.

Specific Learning Outcomes:
Students will be able to:

- **Explain** fundamental optical phenomena such as refraction, reflection, and total internal reflection.
- **Describe** how fiber optics work and demonstrate total internal reflection using hands-on models.
- **Analyze** the behavior of light waves as they interact with mirrors, lenses, and optical systems, examining reflection, refraction, and focal properties to understand wave behavior and image formation.
- **Develop and use models** to demonstrate how light interacts with different materials.
- **Evaluate** the advantages and limitations of digital optical data transmission compared to analog methods.

Narrative / Background Information

Optics is more than just how we see the world—it's the foundation of modern technology, communication, and scientific discovery. Understanding how light behaves allows us to manipulate it in ways that have transformed medicine, space exploration, and information exchange.

Prior Student Knowledge: Before engaging in this lesson, students should be familiar with:

1. **Basic Wave Properties**
   - Understanding of waves as energy transfer, including the concepts of frequency, wavelength, and amplitude.
   - Differences between mechanical waves (e.g., sound) and electromagnetic waves (e.g., light, radio, X-rays).
   - Reflection & Refraction Basics
2. **Prior exposure to how light bounces off surfaces** (mirrors, water surfaces)
   - Basic knowledge that light changes direction when entering a different medium (like a straw in water appearing bent).
3. **Simple Analog vs. Digital Concepts**
   - Familiarity with the idea that digital data is stored as 1s and 0s and transmitted as light pulses in fiber optics.
   - Some exposure to how signals (e.g., sound, images) can degrade in analog transmission vs. digital correction.

Science & Engineering Practices:	**Disciplinary Core Ideas:**	**Crosscutting Concepts:**
Developing and Using Models Develop a model to describe phenomena. (MS-PS4-2) **Obtaining, Evaluating, and Communicating Information** Integrate qualitative scientific and technical information in written text with that contained in media and visual displays to clarify claims and findings. (MS-PS4-3)	**PS4.B: Electromagnetic Radiation** The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. (MS-PS4-2) **PS4.B: Electromagnetic Radiation** When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. (MS-PS4-2) **PS4.C: Information Technologies and Instrumentation** Digitized signals (sent as wave pulses) are a more reliable way to encode and transmit information. (MS-PS4-3) **PS4.A: Wave Properties** Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-2)	**Structure and Function** Structures can be designed to serve particular functions by taking into account the properties of different materials, and how materials can be shaped and used. (MS-PS4-2) **Stability and Change** Systems can be designed for greater or lesser stability. (HS-PS4-2) **Connections to Engineering, Technology, and Applications of Science** **Influence of Science, Engineering, and Technology on Society and the Natural World** Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS4-2)

Possible Preconceptions/Misconceptions:

1. **Light Always Travels in Straight Lines**
   - **Reality:** Light does travel in straight lines in uniform media, but it bends (refracts) when it passes through different materials (e.g., from air to water). It can also be diffracted and scattered**. Example:** Students may struggle to understand why a straw appears "broken" in water or why lenses bend light to focus images.
2. **Mirrors and Lenses Work the Same Way**
   - **Reality**: Mirrors reflect light, while lenses bend (refract) it. **Example**: Some students think a concave mirror and a concave lens function similarly, but they produce different image effects.
3. **Refraction and Reflection Are the Same Process**
   - **Reality**: Reflection occurs when light bounces off a surface, while refraction happens when light changes speed as it moves between materials of different densities. **Example**: A common misconception is that mirrors and lenses work the same way because they "redirect" light.
4. **Digital Images Are Continuous Like Film**
   - **Reality**: Digital images and videos are composed of discrete pixels, and digital signals encode information as binary data (0s and 1s), unlike continuous analog signals. **Example**: When discussing digital transmission, students may not realize how compression and pixelation affect image quality.

LESSON PLAN – 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:
Purpose: Capture student interest and assess prior knowledge.

Perform two quick demonstrations:

1. **Clear polymer water beads in water**: Place clear fully hydrated polymer water beads in a pitcher of water prior to students entering the classroom. The polymer water beads will be "invisible" to their eyes at this point. Ask students to make observations and predict what will happen when you pour the water from the pitcher to the glass. Pour the water slowly from the pitcher to the glass (make sure you have enough polymer water beads that they become visible). Discuss their observations and how the index of refraction of the clear polymer water beads matches the water, making them nearly invisible. Don't have polymer water beads? show this video and ask students to make observations.

2. **Arrow reversal in water**: For this "trick" to work, students must be in front of the glass of water observing (any other angle and they won't see it). Draw an arrow on a piece of paper and place it behind a transparent glass of water. Move the paper (or water glass) back and forth and have students observe how the arrow appears to change direction due to light refraction. Here is a video.

Discussion Questions:
In the Engage activities, we saw how light can be manipulated to make objects appear invisible or distort their appearance. How might scientists and engineers use similar principles to develop technologies like cloaking devices, adaptive camouflage, or stealth technology? What challenges do you think they might face in making these technologies work in real-world applications?

EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:
Purpose: Allow students to investigate advanced optical principles hands-on.

Station instructions sheet

Prepare Student Groups:
- Divide students into small groups (3-4 per station) to ensure active participation.
- Assign roles within each group (e.g., data recorder, materials handler, observer, presenter) to keep students engaged.

Safety Review:
- Before beginning, review safety guidelines (e.g., laser safety, handling lenses and mirrors carefully, avoiding direct eye exposure to bright lights).

Station 1: Fiber Optics & Total Internal Reflection – Investigate how light travels through optical fibers and explore the concept of total internal reflection.

Station 2: Precision Mirrors & the James Webb Space Telescope – Explore how different types of mirrors focus and reflect light, and understand how the James Webb Space Telescope (JWST) uses segmented mirrors to capture deep-space images.

Station 3: Optical Data Transmission – Use a simple setup with LED lights and photodetectors to demonstrate how light can encode and transmit information.

Station 4: Adaptive Optics – Students experiment with different lens arrangements to simulate how telescope mirrors adjust to correct distortions in starlight.

Post Station Class Discussion Questions:
What optical behaviors did you observe in your station?
How do these behaviors help solve real-world challenges?

EXPLAIN:
Purpose: Solidify students' understanding of key optical principles and connect their hands-on investigations to real-world applications.

Show the episode titled "Optics - So Much More Than Glasses" As students watch the video, have them take notes about how light and optics are revolutionizing our world.

After the video, transition into teacher-guided learning and reflection:
Key Topics to Cover:

1. Total Internal Reflection (TIR)
    - What it is: The phenomenon where light is completely reflected within a medium instead of passing through.
    - Conditions: Occurs when light travels from a higher-index medium (e.g., water, glass, fiber optics) to a lower-index medium (e.g., air) at an angle greater than the critical angle
    - Real-World Applications: Fiber optic cables, endoscopes in medicine, and underwater communication
2. Light Behavior & Applications:
    - Refraction – Light bends when entering a different medium (Applications: eyeglasses, lenses, telescopes, mirages, optical cloaking devices)
    - Reflection – Light bounces off a surface (Applications: mirrors, periscopes, adaptive optics in telescopes)
    - Diffraction – Light spreads when passing through narrow openings (Applications: holograms, diffraction gratings in spectrometers, CD/DVD functionality)

Connecting to the Stations:

1. Students discuss their observations from the stations to explain how they observed these behaviors in their experiments and how they connect to the key concepts.
2. For each station ask students to explore the following questions with their team:
    - What was the main optical principle at work in the station?
    - How did the materials you used demonstrate this concept?
    - What is a real-world application of this principle?
3. **Final Reflection**: "If you were designing an advanced optical system (like a telescope, fiber optic network, or medical imaging device), which principle would be most important to understand, and why?"

Supporting Videos: these resources reinforce key concepts, helping students build a strong foundation in optics before applying their knowledge in discussions and activities
Total Internal Reflection Demo: Optical Fibers (2 mins) – Shows how TIR and fiber optics work
How Fiber Optics Works (6 mins)– Explains how fiber optics rely on TIR to transmit data.
Controlling Light with Lenses (2 mins) – Covers how light can be controlled through lenses, including eyeglasses, telescopes, magnifying glass, binoculars and cameras.
James Webb Space Telescope's Mirror Technology (4 mins) – An overview of NASA's James Webb Space Telescope's gold primary mirror and its significance in space observation.

Discussion Question:
How does understanding these properties of light lead to technological advancements?

ELABORATE: Applications and Extensions:
Purpose: Apply knowledge to real-world situations and deepen understanding.

Debate on Self-Driving Cars: Students will research and debate the implications of self-driving cars, focusing on how light and optics technology are crucial to their functionality. Topics include:

1. Ethics: Is it ethical to entrust lives to AI-driven vehicles? Should we trust AI to make split-second driving decisions?
2. Economics: What impact could self-driving cars have on jobs, industries, and the economy?
3. Infrastructure: How do cities need to change to accommodate autonomous vehicles?
4. Technology: How do sensors and optical systems ensure safety?
5. Enjoyment and Lifestyle: Will self-driving cars improve or diminish the experience of travel?

Students research, form arguments, and debate different perspectives before reflecting on how optical technology is shaping the future of transportation.

Potential Resources:
Where to? A history of autonomous vehicles
Computer History Museum 2016

[How driverless cars will change our world](#)
November 29, 2021 Jenny Cusack

[What's Lost When the Human Drivers Are Gone?](#)
March 13, 2025 Lauren Goode, Michael Calore, and Aarian Marshall

EVALUATE:

Formative Monitoring (Questioning / Discussion):
Questions in bold, italics can be used to check student understanding throughout the lesson. Additionally, student presentations in the explore section and case study handouts in the elaborate section can be used to monitor student progress.

Summative Assessment (Quiz / Project / Report):
Task: Students will create a model demonstrating an optical principle and present their findings to the class. Models can be physical (such as a functional fiber optic demo) or digital (such as a simulation of adaptive optics).

Presentation Guidelines: Students should explain the scientific principle behind their model, connect it to real-world applications, and describe its relevance to modern technology.

Score the presentation of their model using this rubric.

Elaborate Further / Reflect: Enrichment:
Purpose: Challenge students with an independent research project on cutting-edge optical technologies, such as LiDAR or quantum optics.

Potential research ideas:
Research how optical cloaking devices (invisibility cloaks) are being developed.
Explore how wave-particle duality is used in quantum cryptography.
Explore how LiDAR is used in paleontological and archeological applications and propose another potential use that extends human's understanding of the past.

CAREER CONNECTIONS

Advancements in optics have revolutionized the way we observe and interact with the world around us. From medical imaging that allows doctors to see inside the human body to laser communication systems that enable high-speed data transfer, the principles of light manipulation are at the core of modern technology. Scientists and engineers harness reflection, refraction, and wave properties to design innovative solutions across fields such as biomedical engineering, telecommunications, and aerospace. Whether developing more powerful microscopes, improving virtual reality experiences, or enhancing satellite imaging, careers in optics play a crucial role in expanding human knowledge and capability.

1. **Explore Career Clusters**: Have students visit USA Science & Engineering Festival Resources and explore careers in Optics and Lasers to discover opportunities in these growing fields.
2. **Choose a Career**: Students will select one career from the chosen industry cluster that interests them.
3. **Research the Chosen Career**: Using the provided graphic organizer or a class notebook, students will gather the following information about their chosen career:
   - Job description: Typical responsibilities and duties
   - Education and training required: Degrees, certifications, or technical training.
   - Skills and qualities needed: Key traits for success in the field
   - Average salary: Typical earnings for the role
   - Work environment and schedule: Typical working conditions and hours
   - Professional Organizations, Educational Programs, and Internship & Apprentice Opportunities

4. Students will select one of the following choice board activities to synthesize their research:

Career in Action	**Job Skills Match**	**Future You**
Find a reliable video or article about someone working in this career. Summarize what you learned and how it aligns with your expectations.	List at least five skills needed for this career. Identify which of these skills you already have and which ones you need to develop.	Write a letter to your future self explaining why this career interests you and what steps you plan to take to pursue it.

5. **Share findings**: Provide an opportunity for students to share their findings. This could be a class presentation, a gallery walk with posters or a peer discussion group.

SOCIAL EMOTIONAL LEARNING ACTIVITY

CASEL Competency Addressed: Self-Awareness & Responsible Decision-Making

Purpose: Students will explore how perception influences their thoughts, emotions, and decisions. By engaging in reflection and discussion, they will develop self-awareness and responsible decision-making skills.

Engage:
Opening Discussion: Ask students to describe an optical illusion they have seen before (e.g., ambiguous images, mirages, or depth illusions). Discuss how two people can see the same image differently.
Guiding Question: How does our perspective influence the way we interpret situations in life?

Explore:
1. Activity: Perspective Shifting
    - Show students an image like the "young woman/old woman" illusion or a reversible figure.
    - Ask students to describe what they see and discuss how their interpretations might differ.
    - Relate this to real-life scenarios where different perspectives lead to misunderstandings or conflicts.
2. Role-Playing Scenarios
    - Present students with real-world dilemmas (e.g., a disagreement between friends, a conflict over resources, or an ethical dilemma in technology).
    - Assign students different perspectives (e.g., the teacher, the student, the community, a family member) and have them discuss solutions from that viewpoint.

Explain:
1. Discussion: Connect perspective-taking to emotional intelligence. Explore questions such as:
    - Why do people see situations differently?
    - How can we respond when someone has a different perspective than us?
    - What skills help us navigate differing viewpoints?
2. Tie-In to Self-Regulation & Empathy: Explain how understanding different viewpoints helps with conflict resolution and collaboration.

Elaborate:
1. Journaling Activity: Have students reflect on a time when they misunderstood someone else's perspective or when someone misunderstood them. How did they resolve it? What could they do differently next time?
2. Connecting to Innovation: Discuss how inventors, scientists, and engineers must consider multiple perspectives when designing new technology (e.g., designing for accessibility, different user needs, cultural considerations).

Evaluate:
Exit Ticket: Students complete the sentence: "One way I can apply perspective-taking in my life is..."
Self-Assessment: Rate themselves on a scale of 1-5 on how well they consider others' perspectives and set a goal for improvement.

Extension:
Cross-Curricular Connection: Connect to history (different accounts of the same event) or literature (character perspectives in a story).
STEM Connection: Discuss how optics (e.g., lenses, mirrors, refraction) change how we see the world and metaphorically relate that to shifting perspectives in social situations.

Materials Required for This Lesson/Activity

Quantity	Description
1 per class	Computer with Projector and Internet Access
1 per group	Computer with Internet Access for Research
1 per student	Copies of rubrics as found in the Evaluate section
1 per station	Laser pointers
	Thick white paper to observe light behavior

	Binder clips to hold the lasers in place
	Water and transparent containers (demo, station 1 and station 4)
10g pack	clear polymer water beads, for demonstration
1	Clear 2 liter bottle- for use in station 1
2-3	Fiber optic wands- for testing total internal refraction in Station 1
2 each	Flat mirror, concave mirror, convex mirror- for use in stations 2 & 4
6 squares each	Aluminum foil- for use in station 2 Transparent plastic wrap- for use in station 4
1 each	LED flashlight and photodetector- for use in station 3
1 each	Concave and convex lenses- for use in station 4
1	Bucket- for use in station 1

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