Lesson 3: Is seeing believing?

I. Overview
Students continue to learn about the physiological basis of vision introduced in Lesson 1, while extending their understanding to the basic optical principles that underlie vision. By using spectrophotometers to investigate the emission, reflection, absorption, and transmission of light, students explore the differences between their visual perceptions and the physical properties that contribute to them. This lesson relates to the crosscutting concepts of patterns and cause and effect: mechanism and explanation. When students perceive a color, they will be able to explain the optical principles behind their observations.

Connections to the driving question
In this lesson, students will learn how humans perceive different colors depending on how their cone cells are stimulated. This will give students the background to understand that organisms with cones that are sensitive to different wavelengths of light will not see colors the same way humans do.

Connections to previous lesson
In the previous lesson, students sorted colored candies under different colored lights in order to observe the effect that the environment can have on perception of color. This lesson continues to use the colored lights from the previous lesson, but now students are challenged to learn the physical principles of colored light.

II. Standards

National Science Education Standards
- Science as Inquiry
- Identify questions and concepts that guide scientific investigation (pg. 175)
- Design and conduct scientific investigations (pg. 175)
- Use technology and mathematics to improve investigations and communications (pg. 175)
- Scientists rely on technology to enhance the gathering and manipulation of data... (pg. 176)

Benchmarks for Science Literacy
- Light from the sun is made up of a mixture of many different colors of light, even though to the eye the light looks almost white. Other things that give off or reflect light have a different mix of colors. 4F/M1
Human eyes respond to only a narrow range of wavelengths of electromagnetic waves—visible light. Differences of wavelength within that range are perceived as differences of color. 4F/M5*

There are a great variety of electromagnetic waves: radio waves, microwaves, infrared waves, visible light, ultraviolet rays, X-rays, and gamma rays. These wavelengths vary from radio waves, the longest, to gamma rays, the shortest. 4F/M8** (BSL)

Something can be "seen" when light waves emitted or reflected by it enter the eye—just as something can be "heard" when sound waves from it enter the ear. 4F/M2

### III. Learning Objectives

<table>
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<tr>
<th>Learning Objective</th>
<th>Assessment Criteria</th>
<th>Location in Lesson</th>
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<tbody>
<tr>
<td>Define and describe key terms in optics</td>
<td>Clear, concise, accurate definitions of the following terms provided: electromagnetic radiation, the visible spectrum, wavelength, absorption, reflection, transmission, emission</td>
<td>Verbal questions in each section of the demonstration; Student Sheet Q. 9</td>
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<tr>
<td>Account for how the human visual system can interpret a wide variety of colors.</td>
<td>Cites examples based on the RGB (additive) color model and unequal activation of a combination of the three cone types to produce many possible combinations of colors</td>
<td>Verbal questions in Activity 2 of the demonstration</td>
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<tr>
<td>Distinguish between the physiological and optical interpretations of light.</td>
<td>Example from the demonstration is described in which a color that was observed did not correspond to the wavelength of a solitary peak on the spectrum</td>
<td>Student Sheet Question 4</td>
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<tr>
<td>Interpret a light intensity spectrum.</td>
<td>Accurate sketch and description of the peaks that are observed</td>
<td>Graphs in the Student Sheet; Verbal questions in Activity 1 of the demonstration</td>
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### IV. Adaptations/Accommodations

This lesson is structured as one demonstration that is projected for the entire class. The demonstration can be student-led or teacher-led. If materials and time allow, this lesson can be structured using stations in which students work in small groups.

### Safety

Consumption of the dyed water should be strictly prohibited. Although the dyes used during this activity
are deemed safe for use in foods by the Food and Drug Administration, some of them may cause allergic reactions (sometimes severe) in some students.

The desk lamps and bulbs become hot over time while in use. In addition, fluorescent light bulbs contain trace amounts of mercury and should be disposed of properly.

V. Timeframe for lesson

Opening of Lesson
- Review previous lessons in unit, introduce the driving question, and introduce the electromagnetic spectrum with a diagram and discussion – 10-15 minutes

Main Part of Lesson
- Activity 1: Monochromatic/White Light Emission interactive demonstration – 10 minutes
- Activity 2: Emission from Multiple Lights interactive demonstration – 15 minutes
- Activity 3: Reflection interactive demonstration – 20 minutes
- Activity 4: Transmission vs. Absorption interactive demonstration – 15 minutes

Conclusion of Lesson
- Summary discussion – 10 minutes

VI. Advance Prep and Materials

Opening of Lesson

Materials:
- Overhead projector connected to computer
- Teacher presentation slides “The Electromagnetic (EM) and Human Visual Spectra” and “Additive (RGB) Color Wheel” diagrams (U1_L3_Teacher_Presentation_Slides.pptx)

Preparation:
- Open up the teacher presentation slides on the computer

Activity 1: Monochromatic/White Light Emission interactive demonstration

Materials:
- Copies of the student sheets titled “Color Investigations” (U1_L3_StudentSheet_ColorInvestigations.docx) should be made before class. It includes:
  - Essential Background
  - Monochromatic/White Light Emission (spectra & questions)
  - Emissions from Multiple Lights (spectra & questions)
  - Reflection (spectra & questions)
Absorption/Transmission (spectra & questions)

- Optional: Sample Spectra Results (U1_L3_TeacherSupplement_SpectraResults.docx)
- Vernier SpectroVisPlus (Model #: SVIS-PL) Spectrophotometer with SpectroVis Optical Fiber Light Probe (Model #: SVIS-FIBER)
- Desk lamps, one for each different-colored light
  - Note: Alternatively, light bulbs can be switched out of a single lamp
- Assorted monochromatic fluorescent light bulbs (include green, blue, red, purple and yellow if possible), 1 per class
- 1 full-spectrum (white) fluorescent light bulb

Preparation:
- Connect probe, spectrophotometer, and computer
- Open LoggerPro software
- Screw in bulbs of various colors
- Plug in the desk lamps with light bulbs next to the computer/spectrophotometer setup. Ideally, there should be one desk lamp for every light bulb.
- If an insufficient number of desk lamps are available, be careful when switching out light bulbs. Emphasize caution since the light bulbs may become hot during use.
- Run through the demonstrations to observe the resulting spectra ahead of time. A document called U1_L3_TeacherSupplement_SpectraResults.docx has been created to provide you with some sample results. It may be helpful to review this document ahead of time.

Setting up Logger Pro for Activity 1, 2, and 3
- Open Logger Pro.
- Plug the USB cable of the Vernier spectrophotometer into the computer (this not only permits communication between the devices but also powers the spectrophotometer). The software should recognize the presence of the spectrophotometer. (If this isn’t the case, restart your computer, leaving the spectrophotometer plugged into the computer’s USB port.)
- Insert the “cuvette” adapter of the light probe into the cuvette chamber of the spectrophotometer, aligning the arrow on the adapter with the arrow next to the chamber.
- Under the “Experiment” menu, choose “Change Units” then “Spectrometer: 1” and select “Intensity.”
- The sampling units might need to be adjusted, do this under the “Experiment” menu.
- Press the green “Play” button in the menu bar to begin scanning, and press the “A” button in the same bar to have the computer auto-scale the y-axis.

Activity 2: Emission from Multiple Lights interactive demonstration

Materials:
- 1 piece of white paper
Preparation:
- Change light bulbs as needed

Activity 3: Reflection interactive demonstration

Materials:
- Assorted candy-coated chocolates such as M&M’s
- Assorted shiny spherical Holiday tree ornaments

Activity 4: Transmission vs. Absorption interactive demonstration

Materials:
- Plastic Cuvettes (Model #: CUV)
- 4 beakers (50 ml or larger)
- Red, blue, green, and yellow liquid food coloring (McCormick Assorted Food Color and Egg Dye)
- Water (40 ml per beaker)

Preparation:
- Fill each of the beakers with 40 ml of water
- Place 10–15 drops of red food coloring in the first beaker, 3 drops of green food coloring in the second beaker, 4 drops of blue food coloring in the third beaker, and 3–4 drops of yellow food coloring in the final beaker. These amounts of food coloring will insure that light will be both absorbed and transmitted at the expected wavelengths. Water dyed too lightly will transmit too much light, and water dyed too heavily will absorb the majority of the light.

Setting up Logger Pro for Activity 4
- Open Logger Pro and then plug in the spectrophotometer. The software should recognize the presence of the spectrophotometer plugged into the computer’s USB port.
- Under the “Experiment” menu, choose “Change Units” then “Spectrometer: 1” and select “%Transmittance.”
- To calibrate the spectrophotometer, place an empty cuvette into the cuvette chamber of the spectrophotometer.
- Under the “Experiment” menu choose “Calibrate” then “Spectrometer: 1.”
- Wait for the spectrophotometer to warm up, and then click on “Finish Calibration.”
- After the calibration is finished, click on “OK.” Remove the empty cuvette from the cuvette chamber.

Homework and Assessments

Materials:
- Copies of “Your eyes are good at physics” (U1_L3_Reading_YourEyesAreGoodAtPhysics.docx)
- Copies of the student sheets titled “Color Investigations” (students already have this)
- Answer key for “Color Investigations” (U1_L3_StudentSheet_ColorInvestigations_Answers.docx)
VI. Resources and references

Teacher resources
- Online Color Scheme Generator: http://www.colorschemer.com/online.html
- For background science knowledge, see
  U1_L3_TeacherResource_BackgroundScienceKnowledge.docx

References
- The Electromagnetic (EM) and Human Visible Spectra. Retrieved from http://www.antonine-education.co.uk/physics_gcse/Unit_1/Topic_5/topic_5_what_are_the_uses_and_ha.htm
VII. Lesson Implementation:

Opening of Lesson:
Begin by asking students what they learned about color perception from the paint chip sorting activity. Ask students what they learned from doing the candy sorting activity.

- Students should recall that the paint chip sorting activity helped reveal differences in individuals’ color perception.
- The candy sorting activity showed how environmental conditions affect color perception.

**Teacher Pedagogical Knowledge**
Using students’ responses to guide the class is one way to differentiate instruction. By asking students what they understood as well as specifically asking students to explain and apply key concepts, student understanding can be assessed.

Note students’ answers, and choose the conceptual emphasis throughout the lesson accordingly. For example, if the students understand basic optical concepts (e.g., the EM spectrum, transmission vs. absorption), consider emphasizing sensory physiology.

Explain to the students that while the paint chip lesson focused mostly on the *intrinsic* aspects of visual perception (how the eyes and the brain work to interpret light), today’s lesson explores the *extrinsic* factors that affect how we see the world.

Ask students to generate a list of some properties or important facts about light, based on previous activities, readings and their prior experiences. A class list can be recorded on the board.

**Teacher Pedagogical Content Knowledge**
Revealing students’ preconceptions about light is important for two reasons. First, it helps students consider what they already know about the topic. Second, it provides a means of assessment so that the lesson may be modified to meet students’ needs accordingly.

Inform students that in the main part of the lesson they will observe several demonstrations to help them better understand how optics and sensory physiology combine to allow for visual perception.

Ask students, “What type of light do we see?” and use this discussion to connect to the concept of the electromagnetic spectrum.
Project the “The Electromagnetic (EM) and Human Visible Spectra” diagram (found in the supplemental materials).

- Point out the relatively small region called **visible light** that human eyes can perceive.
- Explain that there are many forms of energy that we can’t see.

Ask a student to identify the other types of energy that are displayed on the diagram.

- The diagram also lists gamma rays, x-rays, ultraviolet, infrared, and radio waves.
- If students are curious, microwaves are a subset of radio waves on this diagram. Other diagrams make the distinction between radio and microwaves.
- Stress that from a physical perspective these are all variations of a single form of energy known as **electromagnetic (EM) radiation**.

Explain that electromagnetic radiation is special because it can be treated as waves or particles called photons. Therefore every kind of EM radiation has an associated **wavelength**, the physical distance between two successive peaks in that wave.

- If it is applicable to the class goals, illustrate a basic wave and define wavelength. Label wavelength on the illustration.

Refer again to the “The Electromagnetic (EM) and Human Visible Spectra” diagram, and ask students what they know about each form of radiation listed.

[A video clip is being produced which will introduce students to the different types of electromagnetic radiation. It will be added to the lesson materials when it is completed.]

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**Teacher Pedagogical Knowledge**

Integrating video clips into instruction can provide students with an additional representation of a target concept. Some students will be able to remember the concept better when it is presented in a multimodal format. Videos, for example, appeal to visual learners.

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Check for student understanding. Ask students which forms of radiation are associated with high and low energy.

- Highlight on the diagram that EM radiation associated with shorter wavelengths, like gamma, X-rays and ultraviolet, is higher in energy and therefore more harmful to living tissue.
  - Explain that this is why it is recommended that people wear sunscreen when out in the sun or why they wear a lead vest when having a dental X-ray.
- Highlight on the diagram that EM radiation associated with longer wavelengths, like radio waves, infrared, and visible light, is lower in energy and thus less harmful to living things.
The last part of the opening to this lesson involves introducing students to the equipment that will be used. Ask students if they know how scientists measure different wavelengths.

- Tell students that scientists use spectrophotometers to measure energy wavelengths (i.e. UV and visible light).
- If students are unfamiliar with the instrument, show them the different parts.

**Teacher Content Knowledge**
The spectrophotometer is a device used to measure how much light something, like a light bulb, emits at different wavelengths within the visual spectrum when used in conjunction with a portable optical probe that fits into the cuvette chamber.

**Main Part of Lesson**

**Activity 1: Monochromatic/White Light Emission**
Proceed to dim the room lights, and turn on the desk lamp with the blue light bulb. Point the spectrophotometer probe at the bulb, and project the resulting spectrum generated by LoggerPro so that students can see. There should be a prominent peak in the blue range of the spectrum.

- See the Sample Spectra Results (*U1_L3_TeacherSupplement_SpectraResults.docx*) to see an example spectrum.

**Scientific Practices: Analyzing and interpreting data**
The data from this activity is automatically graphed by the computer. Take time to help students interpret what the graph means. Doing so will provide a good example of a task that many scientists do while conducting research.

Ask students to interpret the graph and to explain the significance of the observed peak.

- Emphasize that this spectrum parallels the visible spectrum diagram shown before in that colors are organized by increasing wavelength on the x-axis. Relative intensity is plotted on the y-axis.
- This peak indicates the blue light bulb emits the most intense light in the blue region of the visible spectrum.
- Have the students draw the spectrum generated on Graph 1 provided in the Color Investigations Student Sheets.

Ask students what questions they could come up with from observing the first graph.
• Expected responses: Why are there other peaks besides the one in the blue wavelengths? What causes the additional peaks?
• Leave these questions unanswered for now to motivate students’ attention as the demonstration continues.

Ask students to predict: What happens to the graph when the probe is moved farther from the light source?

• Have students use a dashed line to draw their predictions of how the graph would change on Graph 1. They should add a key to their graph once they have multiple lines on it.
• The general profile of the spectrum should remain the same, but everything should be scaled. This reflects the fact that relative intensity is being plotted on the y-axis. The software should readjust the scale automatically after a few seconds.

Show students what happens by moving the probe farther from the light source.

• Ask students how what they observed compared to their predictions.

Teacher Pedagogical Content Knowledge
By having students record their predictions, they become more engaged in the activity. If predictions are made aloud in the class, only a few students will be able to voice their thoughts. The rest of the class may not have committed to a prediction. If all students are asked to write their predictions, then they commit to their thinking. This sets students up to look for evidence to support their predictions during the demonstration, or it provides a situation in which students must modify their original thinking.

Repeat this experiment with a few other monochromatic light bulbs (red, green, yellow, purple) to illustrate what the spectra of these light bulbs look like.

• Ask students to predict what they will see with each light bulb. Have students sketch at least one prediction on Graph 2 using a dashed line. Then show students the graph that results, and have students sketch the result using a solid line. Remind students to add a key to their graphs.
• Feel free to copy additional blank copies of the graph if additional space for student predictions is needed. Consider alternative approaches to generating predictions such as calling students to the board to make a sketch, or have students do a think-pair-share.
Teacher Pedagogical Knowledge

The think-pair-share technique can be used throughout this lesson in order to engage more students by a single question. First, all students are asked to think individually. Then students pair with a neighboring student and share their responses. Remind students to discuss similarities and differences in their responses. This allows the teacher to listen to conversations and assess multiple students at once.

As a final run, repeat the experiment with a white (full-spectrum) light bulb.

- Ask students to predict the spectrum they expect to see generated with the white light bulb by sketching it on Graph 3 using a dashed line. Then have students sketch the spectrum generated by the white bulb with a solid line.

Depending on your class goals and your students’ interests and abilities, consider asking these additional questions:

- Is the white light bulb really “full-spectrum”?
  - No, white light bulbs do not emit light at equal intensities at all wavelengths, as the spectrum should reveal.

- What sort of spectrum would a truly full-spectrum light bulb generate?
  - A spectrum with uniform intensity (flat horizontal line) at all wavelengths.

- Where in the visible spectrum is the white light bulb generating the most energy?
  - This will depend on the type of fluorescent white light bulb being used, but it will correspond to the highest peak.

Turn the lights back on after this first demonstration activity.

Activity 2: Emission from Multiple Lights

Introduce the next activity by asking students, “Where do you suppose other colors, like grey, brown, maroon, etc., come from?” Use this discussion to introduce the concept of color mixing.

Ask students what they remember learning about color mixing in earlier grades, and in particular how the “primary” colors mix to form the “secondary” colors.

- Most students will identify the primary colors as “blue, red and yellow” and the secondary colors as “purple, orange and green.”

Explain that what they learned is valid in the context of paints or the printing process. Visual perception involves the capture of light by the eye. To explain the perception of colored light, refer to the RGB (“red-green-blue”) model or the additive color model. This is the same model that is used to generate colors on computer screens and other electronic displays.
Ask students what types of cone cells humans possess (learned in Lesson 1). Remind students that retinas contain three varieties of cone cells: those that absorb light best at blue, green and red wavelengths. Blue, green and red can be thought of as “primary physiological colors.”

Project the “Additive Color Wheel” diagram from the teacher presentation slides (U1_L3_Teacher_Presentation_Slides.pptx), and highlight these three colors. Direct students to the Essential Background Information in their packets also. Explain when we perceive the color red, it is because red light is exclusively activating our “red” cones, whereas green and blue result from the exclusive activation of our “green” and “blue” cones, respectively.

**Crosscutting Concepts: Systems and system models**

Students are connecting to their knowledge of the human visual system. Students should have previous knowledge of the parts of the system, and now they are building to understand the functions of the parts of the visual system.

Using the color wheel, ask the students, “Based on the positions of yellow, cyan and magenta on the wheel, how do you think we perceive these three colors?”

Explain that yellow, cyan and magenta can be thought of as “secondary physiological colors.” Each results from the simultaneous and equal activation of two types of cone cells (as suggested by the fact that they appear in overlapping regions of the primary colors on the color wheel).

- For example, a yellow chair appears yellow under full-spectrum (white) lighting because both red and green wavelengths of light are being reflected from the chair into the eye, activating the “red” and “green” cone cells equally and simultaneously; reference the additive color wheel to reinforce this.

Ask students what happens when all three-cone varieties are activated simultaneously and equally.

- The resulting perception is that of white color, as illustrated on the color wheel.

Ask students if they know anything about the concept of “complementary colors.”

- Explain the “complementary physiological color pairs” are blue & yellow, red & cyan, and green & magenta (colors across from each other on the additive color wheel).
- Explain an object of color X best absorbs light at the wavelength of its complementary color.

Given this information, ask the students what color of light a yellow chair would best absorb.

- A yellow chair would best absorb blue light.

Students may want to know how humans perceive such a wide variety of different colors if we only possess three different varieties of cone cells. To answer this question, remind students that perception
of the color magenta, for example, results from the simultaneous and equal activation of red and blue cones. Ask them what would happen if these two cones were activated simultaneously but unequally. Explain that it is when two or three of the different cone varieties are activated unequally that you perceive non-primary or non-secondary physiological colors, such as orange, brown or purple.

Teacher Content Knowledge
A simulation that can be used to illustrate the principle of simultaneous but unequal cone activation by analogy is the “Online Color Scheme Generator” (http://www.colorschemer.com/online.html).

The “R” (red), “G” (green), and “B” (blue) inputs on the left margin of the webpage may each be set anywhere from 0 to 255. After pressing “Set RGB,” the square in the top left corner will change depending on how each of the three primary colors has been weighted. For example, a setting of “R: 0, G: 0, B: 255” will yield “pure” blue, while “R: 255, G: 0, B: 255” will yield “pure” magenta.

To check students’ understanding of the principles of the additive color system, ask the following questions. Encourage students to refer to the color wheel as needed.

- What color will a yellow chair appear under red light?
  - Red. From a red light bulb, there is no green light available to reflect off of the chair, so whereas the both the red and green cones would be activated under normal lighting (giving an appearance of yellow), under red lighting, a yellow chair should appear red, as only red light will be reflected from the chair and only the “red cones” will be activated.

- What color will a yellow chair appear under blue light?
  - Black. Under blue lighting, there is neither green nor red light to activate the corresponding cones; since the blue light is absorbed by the yellow chair, such a chair will appear black under blue lighting. Explain that black results from the absence of the other colors.

- What color will a yellow chair appear under green lighting?
  - Green. Under green lighting, a yellow chair should appear green, as only green light will be reflected and only the “green cones” will be activated.

Emphasize to students that the RGB color model helps to account for what humans perceive, but that perception does not always agree with outside reality. Ask students to give examples of this principle.

- Remind them of some of the illusions they observed in Lesson 1 of this unit.

Dim the overhead lights and use the spectrophotometer to illustrate differences between sensory physiology and optics. Tell students that you will use the red and green bulbs simultaneously, and have
them write a prediction of what color(s) they think the light will be in the space provided below Graph 4. Then have students sketch a prediction of the spectrum on Graph 4 using a dashed line.

After predictions have been made, begin shining the two different light bulbs at a central point such as onto a piece of white paper. Position the probe so that it is at this central point, facing each of the 2 light bulbs equally.

Have students use a solid line on Graph 4 to sketch the actual spectrum that resulted. Have students record what color(s) the light actually was in the space provided below Graph 4.

- The light will be yellow in the area where the green and red lights overlap.

Try different combinations of colors (such as red and blue or blue and green) for students. Ask students to make predictions verbally, and ask students to support their predictions. Ask students the following questions for every light combination:

- What is the resulting color of light you see on the white paper when we combine the emissions from different light bulbs? Is there a peak at this color in the combined spectrum of these light bulbs? Why or why not?
  - The light should be magenta when the red and blue bulbs are used. The light should be cyan when the blue and green bulbs are used. Sample spectra can be viewed in the Sample Spectra Results document (U1_L3_TeacherSupplement_SpectraResults.docx).

Lastly, prepare to use a combination of the red, green, and blue bulbs simultaneously. Have students write a prediction of what color(s) they think the combined light will be in the space provided below Graph 5. Then have students sketch a prediction of the spectrum on Graph 5 using a dashed line.

After predictions have been made, begin shining the three different light bulbs at a central point such as onto a piece of white paper. Position the probe so that it is at this central point, facing each of the 3 light bulbs equally.

- Have students use a solid line on Graph 5 to sketch the actual spectrum that resulted.
- Have students record what color(s) the light actually was in the space provided below Graph 5.
  - The light will be white in the area where the green, blue, and red lights overlap.

Activity 3: Reflection
Ask students if all the light that hits their eyes results from direct emission from a light source. Point out that the spectrophotometer activities implemented so far have only involved direct emission, which is the process of generating light (or other EM radiation).

Ask the students, “What else can happen to light if it doesn’t travel directly from a source to our eyes?” Guide students to explain the concept of reflection: the process by which light contacts and is redirected by some form of matter.
Show students the two sets of colored objects, assorted candy-coated chocolates and colored Holiday tree ornaments, and have students predict how these different objects could be used to illustrate differences in reflection. Start by using a white light bulb and two different objects of the same color (such as a red candy and a red ornament).

The ornaments should be considerably more reflective than the candy-coated chocolates.

### Student Misconceptions

Some students struggle with the idea that light reflects off of objects like the candy (Ramadas & Driver, 1989). Students may think that light only reflects off of metallic objects or mirrors because they look shiny. Consider drawing a diagram showing students the path light takes from a source and reflecting off an object, some of which enters our eye allowing us to see the object.

Using students’ ideas, carry out a short demonstration that illustrates how light is reflected. The room lights will need to be dimmed as in previous demonstrations. Engage the whole class by asking how and why they would like the light source positioned relative to the object and, in turn, how they would like the probe positioned relative to both. Students can be asked to carry out the demonstrations for the class. Remember an objective in these demonstrations is to have the probe catch as much of the reflected light from the object as possible.

Experiment with different sorts of orientations and distances, and have the students observe how the reflected spectra change accordingly.

- Have students draw the spectra for the red candy and ornament on Graph 6. Then allow students to compare spectra for different objects and different colors of light.

### Teacher Pedagogical Content Knowledge

The reflection of wavelengths off of certain surfaces, such as the candies, may be difficult to detect with the light probe. Consider recording the spectrum of a surface, such as the table top or desk, without an object as a control. Also, consider changing the light source by going outside to use light from the Sun. The relatively higher intensity light can produce results that are more easily detected. See U1_L3_TeacherSupplement_SpectraResults.docx for sample results with additional explanation.

Check for understanding. Ask students, “Based on what you have learned about optics, do the reflected spectra being generated make sense to you? For example, if you shine white light on a green ornament, what wavelengths of light would you expect to find on the reflected spectrum?”
The expectation would be that green would be the wavelength most prominently reflected, while magenta would be most readily absorbed.

If this is not what the associated reflected spectrum shows, ask the class what accounts for the discrepancy. See the discussion of sample results provided in U1_L3_TeacherSupplement_SpectraResults.docx.

Do the colors you see when reflecting different colors of light off differently colored objects correspond to the spectra generated from these objects?

**Activity 4: Transmission vs. Absorption**

Ask students to briefly review and summarize how light is emitted from a source (emission) and how it is reflected off an object (reflection). Ask students if there are any other ways in which light can interact with an object or substance before it reaches the eye.

- Light can also pass through or be absorbed by some objects or substances (transmission and absorption respectively).

One way to introduce this is by asking students if they were to hold a clear pane of glass up to a white light source, what would happen to the light when it reached the pane of glass. Ask students what color the light would be on the side of the pane opposite the light source. Since the light is passing through the glass (i.e. being transmitted through the glass), it would remain white on the side opposite the light source.

Ask students what color the light on the side of the pane opposite the light source be if the glass were tinted red.

- Only the red light would be transmitted through the pane of glass.

Follow up by asking students what happened to the rest of the light.

- Explain that much of the light in the non-red regions of the visual spectrum have been absorbed by the glass. This is known as absorption.

The following demonstration using different colored water and the spectrophotometer can be used to demonstrate the concepts of transmission and absorption. Give one of the plastic cuvettes to the students and have them pass it around the class.

Explain that cuvettes are tools designed to hold liquid samples that are measured during experiments using the spectrophotometer. By placing a cuvette into the spectrophotometer cuvette chamber, absorbance and transmission of light can be measured.

Show students the beakers filled with the dyed water. Ask the class to identify the color of the liquid in each beaker.

- There is red, blue, green, and yellow water.
After identifying each of the colors, fill one cuvette for each of the colors (students can be asked to do this over the sink to prevent any damage caused by spilling). Consider using plastic droppers to avoid spills.

After the cuvettes have been filled, place each in the cuvette chamber and measure the transmittance and absorbance. Refer back to the directions earlier in the lesson plan to set up the software correctly. Also note that the y-axis labels and scales change.

Choose one color, and have students draw transmittance and absorbance spectra for that color on Graphs 7 and 8.

The following questions can be used throughout the activity:

- Where in the visible light spectrum does the liquid transmit the most amount of light?
- Does the liquid only transmit light in the area of the spectrum that corresponds to the color of the liquid? Why or why not?

**Conclusion of Lesson**

In closing the lesson, ask students how visual perception is both a product of physical properties and anatomy/physiology. In answering this, have students draw upon what they have learned in the first two lessons.

Additionally, press students to think about whether or not “seeing is believing.” How do human visual perceptions differ from what is occurring in their optical environment?

The questions in the Color Investigation Student Sheet pertaining to each activity should be completed for homework. Tell students that they should use the spectra they drew in their packets and the discussions from the lesson to finish the questions. Student responses will allow you to assess student achievement of the learning goals for this lesson. An answer key is provided for teacher convenience (in U1_L3_StudentSheet_ColorInvestigations_Answers.docx).

An additional homework assignment can be the reading “Your Eyes Are Good at Physics.” This reading provides the opportunity for students to apply what they have learned throughout this lesson and to see this information in a different manner. Alternatively, consider assigning this reading before the lesson to give students relevant background information.