textbooks often depict light as rays emanating from a light source, indicating only the direction light travels. Such diagrams are of limited value in that they do not explain what light is (Robertson 2008). Conceptually, students are typically introduced to light as a type of wave. The wave model portrays light as a series of waves originating from a source and moving in straight lines until reflected, absorbed, or passed through objects in its path. Different colors of light correspond to different wavelengths. Children struggle to understand this model because it is highly abstract. Why do we draw light going in straight lines when water waves go up and down? And what is it about light that is waving up and down anyway?

Light can be represented more concretely using the photon model. According to this scientific model, light emanates from sources as tiny “packets” of energy (called photons) that move in straight lines and are reflected, absorbed, or passed through objects. Photons can be represented as little “balls” of light flying through space. Scientists account for the phenomenon of light using both the photon and the wave model. Given that the photon model more concretely represents light, this model offers a greater opportunity for children to meaningfully learn this concept.

The following lessons describe how to teach light and color using the photon model. We recommend using these lessons in an upper elementary context (grade 6). Copies of the accompanying student handouts and teacher key are available (see NSTA Connection).
Day 1: Light
This lesson began as a class discussion in which the teacher posed questions, such as “What do you think allows us to see things?” “Why can I see you sitting in front of me?” and “How is it that we can tell the color of your shirt?” Students shared comments such as, “Our eyes act like a mirror and reflect what we see into the back of our head, which our brain turns into a picture” and “Our eyes emit light that goes out and bounces on objects and then comes back to our eyes.”

While examining their ideas about light, the teacher asked students to consider why humans cannot see around corners or through most solid objects. Students responded to this question with hesitancy and as the teacher urged them to be more explicit in their responses they soon realized that their models didn’t account for these observations. At this time, the teacher introduced the idea of scientific models and their use in science. He emphasized that although scientific models are never perfect, a good scientific model should be useful for explaining phenomenon and predicting what will happen.

Because all of the student-generated models were underdeveloped and insufficiently explained why humans can see things (or can’t), the class recognized that they needed a new model.

Next, the teacher introduced the photon model of light. He emphasized the following features: (1) Photons are like little balls that shoot out of light sources (e.g., lightbulbs or the Sun); (2) Photons move in straight lines unless they hit something. When hitting something, photons can be reflected, absorbed, or pass on through; and (3) You can only see the photons that enter your eyes.

This new model was demonstrated for students using white, 3 in. Styrofoam balls. The teacher held a tub of balls (15–20 count) at his side and told students he was going to act like a light source. A student was positioned a short distance (2–3 m) from the teacher and designated as a human observer. The teacher gently tossed balls one at a time to the student who caught each one and placed them in a tub at her side. During the demonstration, the teacher explained to the class that the student could “see” him because he (the light source) was sending out photons that were going into the student’s eye. To check student understanding, students filled in a diagram using circles to represent photons to show the direction of their path (Figure 1).

A second demonstration illustrated how the photon model accounts for humans seeing objects that do not emit their own light. The teacher acted as a light source again, a second student was selected to play the part of the “object” to be seen, and the original student maintained her role as the “eye.” The teacher gently tossed a series of balls one at a time to the “object,” who caught the ball and then threw it carefully to the “eye.” Thus, students have depicted photons emanating from a light source, reflecting off an object, and entering an eye. Students were again asked to demonstrate their understanding by drawing in photons and arrows on a diagram of a man looking at a box (Figures 2a and 2b).

**Figure 1.** Photons shown leaving a light and entering an observer’s eyes.

**Figure 2a.** Photons should be drawn leaving the light, hitting the box, and then reflecting into the observer’s eyes.

**Figure 2b.** Student depiction of Figure 2a.
Before continuing with the model, a class discussion was held to assist students in consolidating their understanding. The teacher emphasized two important ideas: usually not all photons reflect off of an object (some are absorbed), and many of the photons that reflect off of an object never enter into anyone’s eye, but rather, they reflect in different directions and are never seen. Students were encouraged to revise their diagrams (if necessary) by drawing in some photons that did not end up in the observer’s eyes.

Apply Understanding

Next, students were placed in small groups and asked to apply their understanding of the photon model by completing the following tasks:

1. Get a mirror. Place a pencil on your table. Put a book halfway between the pencil and your eyes so that you cannot see the pencil. Next, find a way to hold the mirror so that, without moving your head, you can see the pencil by looking in the mirror. Why can you see the pencil in the mirror?

   Together, the teacher and students drew a diagram showing how the photons were getting to their eyes. To assist students with this challenging question, the teacher posed supporting questions such as “Where do photons come from in this room?” and “How might the mirror help to get the photons to go from the pencil to your eyes?” (This task demonstrated to the students that mirrors work by reflecting photons. Photons are emitted from the light source, travel to the pencil, reflect off the pencil, and then reflect off the mirror to our eyes so we can see the pencil.)

2. Hold a book an inch above your table and observe that the table below the book is darker than the rest of the table. How can you explain this observation using the photon model? (The table area under the book is darker because few photons from the lights can hit that portion of the table, reflect off the table and hit the book, [because the book is in the way] and then reflect into your eyes.)

3. Laser light can cause blindness if pointed directly at a person’s eyes. Thus, this next activity should only be done as a teacher demonstration. A flashlight can substitute for a laser pointer if necessary. (The room should be dark.)

   The teacher should shine a laser pointer at a wall across the room. Students must explain why they can see light reflected off the wall, but they can’t see the light as it travels across the room. Next, ask a student to clap together two chalk erasers just above the laser light path. Suddenly, the path of the laser beam can be seen traversing the room. Students must explain why they could see the light beam after adding chalk dust to the air by considering the following questions: How do photons get into our eyes now? (Some photons from the laser reflect off of chalk dust in the air and enter our eyes.) Why weren’t photons going into our eyes before chalk dust was present? (Clean air did not reflect the photons, so they kept traveling in a straight line and didn’t hit anyone’s eyes.) In summary, students were asked to depict photons reflecting off of chalk dust and entering their eyes (Figure 3).

Day 2: Color

On Day 2, the photon model was extended to take into account how humans see colors. The teacher masked off the top of an overhead projector so that only a narrow strip of light projected onto the screen. The rest of the room was dark. A diffraction slide was hung over the lens of the projector, resulting in a rainbow of colors on either side of the narrow strip of light (Figure 4a, p. 40). (The same effect can be achieved by providing individual students with an inexpensive pair of diffraction glasses, Figure 4b, p. 40; see Internet Resources.)
The teacher paused here and reviewed some basic features of the photon model that were introduced during the last lesson. Holding a white Styrofoam ball in his hand as he did previously, he reminded students that humans don’t see objects, they see photons. We see things when photons bounce off of objects and enter our eyes. Then he asked, “If all photons are white like this Styrofoam ball that I’m holding, then everything would appear white to our eyes, but obviously this isn’t the case. What do you think is going on?” Students responded by saying “maybe photons aren’t just white” and “photons must come in different colors.” The teacher used these responses to suggest to the class that a more complete model for light was emerging.

Photons are not just white. They come in different colors. When different colored photons are mixed together, white color is perceived, but when photons are separated, different colors can be seen.

This idea was demonstrated using a large bin of 3-in. colored plastic balls (see Internet Resources). The balls represented photons of different colors. To portray a white lightbulb, the teacher gently threw balls of random color to a student who caught them and placed them in the tub at his side. Because all the colors were mixed together, humans would perceive the color as white. To represent a colored lightbulb (such as the red light of a laser pointer), only red balls were thrown. Because only red photons were present, the observer saw the light as red.

Students practiced this idea by drawing photons on diagrams as shown in Figure 5. The lamp labeled white should emit different colors of photons. A green lamp would emit only green photons. (Some colored lightbulbs are not truly monochromatic. As a result, some colored lightbulbs will emit more than one color when reflected through a prism.)

The final idea introduced to students used the photon model to explain why objects (nonlight sources) are different colors. The teacher pointed at his bright orange shirt (worn intentionally for this lesson) and proceeded to review with students how the photon model accounts for different colors. The main idea he emphasized was that photons must come out of the lights, bounce off the shirt, and go into people’s eyes. He asked questions, such as “What sorts of photons come out of the room lights? How do you know? (Different colors must be coming out.) What photons do you think go into your eyes from my shirt? (Orange.) If photons of different colors hit my shirt, then why might only orange...
ones go into your eyes? What happens to all the other colors?

These last questions were difficult for students to answer and required careful discussion. Some students thought only orange photons must come out of the lights, but that did not explain why everything did not look orange. Other students thought that maybe the teacher’s shirt gave off orange photons, but that could not be correct, because his shirt did not look orange when the lights were off.

Eventually, the following explanation emerged: Photons of all colors hit the shirt. The orange ones were reflected, and the shirt absorbed all the other colors. This idea was demonstrated with the colored balls. One student represented the lights in the room and tossed differently colored balls one at a time to the teacher. The teacher caught and kept (absorbed) all the balls except the orange ones, which he threw to another student—the “eye.” Additional practice with this idea involved selecting other colored objects around the room and depicting with colored balls that color(s) were absorbed (caught) and reflected (bounced off).

Assessment

Student understanding of light and color was assessed using a game of “Light Charades.” Each group of students was given a scenario to act out involving a light source (e.g., red light) and a colored object (e.g., red T-shirt). Groups acted out their scenario using the colored balls to depict photons. The rest of the class was charged with identifying the color of the light and the color of the object that the group was portraying. More challenging scenarios can be introduced as well, such as depicting the color of a red rose when using a green light source (i.e., the rose appears black).

Altogether, the lessons described here promote opportunities for children to meaningfully understand and apply the concepts of light and color using a scientific model—the photon model—in ways that are consistent with how children think and learn.

Samuel Sportel (sls8@calvin.edu) is a science teacher at Holland Christian High School in Holland, Michigan. Crystal Bruxvoort is an assistant professor in science education and chemistry at Calvin College in Grand Rapids, Michigan. James Jadrich is a professor in science education and physics at Calvin College in Grand Rapids, Michigan.