Figure 1: Refraction in a Washbasin

Figure 2: Reflections in a Make-Up Mirror

Everyday, Everywhere Optics

Instructor Notes

Your house and your students' houses are filled with everyday optical experiments. For example, you can experiment with refraction in a washbasin as shown in Figure 1 or with reflections in a make-up mirror as shown in Figure 2. Figure 3 shows a waterglass lens and rainbows on the floor. There are reflections all around you outdoors, wherever you live – for example, at the "Bean" in Chicago (Figure 4) or Hessian Lake at Bear Mountain State Park in New York State (Figure 5).

The example we discuss here tells a story. It starts with students working at home in a washbasin (Figure 1) and culminates with an experiment you can do with an aquarium in your classroom or on your kitchen counter for remote classes (Figure 6). It is a story

Figure 3: A Waterglass Lens and Rainbows on the Floor

Figure 4: Reflections in Chicago's "Bean"

Figure 5: Reflections in Hessian Lake at Bear Mountain State Park

Figure 6: A Kitchen Counter Lab

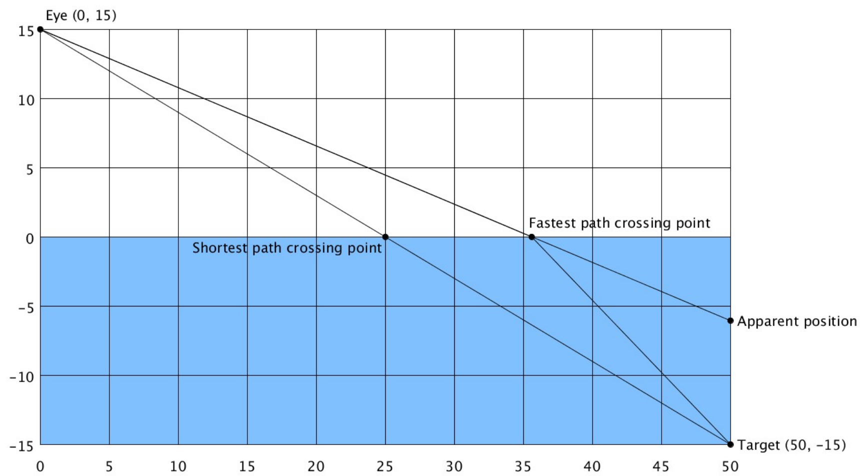

Figure 7: Fermat's Principle in an Aquarium

about the life of a scientist – a story of surprise and disbelief followed by vindication. This story has four chapters:

- It begins in your students' homes with the experiment shown in Figure 1.
- It continues in class the next day. Our plotline is the "scientific method" – the interplay between experimentation/observation and theory. We explore "Fermat's Principle." Its easiest form – "light rays traveling between two points follow the fastest possible path" – is almost anthropomorphic, as if light rays are like people in a hurry. It "explains" why light rays traveling between two points in a single medium travel along straight lines – because the shortest path between two points is a straight line.

  Figure 7 shows a straightforward application of Fermat's Principle that can be used to predict the phenomena we see when we look at the drain in the bottom of a washbasin. See Figure 1 on Page 1. In Figure 7 an eye located 15 cm above the surface of the water in an aquarium is looking at a target 15 cm below the surface of the water. Using the coordinate system shown in the figure the location of the eye is $(0, 15)$ and the location of the target is $(50, -15)$. The x-axis runs along the surface of the water.

  The shortest possible path from the target to the eye would be a straight line but this is not the fastest possible path for our anthropomorphic light because light travels faster (30.0 cm per nanosecond) in air than it does in water (22.5 centimeters per nanosecond). Both paths are shown in Figure 7. Notice that light travels a bit further

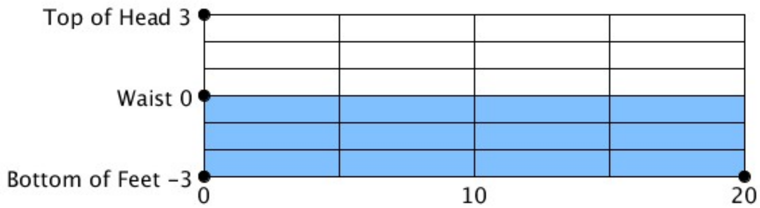

Figure 8: Fishing

in air than in water to take advantage of its higher speed in the air.

You can also see in Figure 7 why the drain at the bottom of the washbasin appears to be higher than its actual location. Your brain has learned from long experience that incoming light rays have traveled on straight lines. The "apparent path" – that is, the path that your brain assumes the incoming light ray took is the straight line that goes through the eye and the place where the fastest path crossed the water's surface. Your brain believes that the apparent position of the target is on the apparent path.

In preparation for the third chapter you review how students can find the minimum of a function using whatever technology they have been using. For the example shown in Figure 7 they would minimize the function

$$f(x) = \frac{\sqrt{x^2 + 15^2}}{30.0} + \frac{\sqrt{(50-x)^2 + 15^2}}{22.5}.$$

for $0 \leq x \leq 50$, where $(x, 0)$ denotes a possible point at which the light ray crosses the surface of the water.

- Chapter 3 occurs at home. Students look at a fisherman who is six meters tall standing up to her waist in a pool that is three meters deep and looking at a fish on the bottom of the pool 20 meters away. You might introduce this picture in Chapter 2 and ask if any of your students is a bow fisherman. If so, ask her about aiming. Bow fisherman have to aim low to compensate for the effects of refraction.

  In Chapter 3, however, we ask students to find out what the fish sees. See the student handout.

  The results are likely to be surprising. See Figures 9 and 10. Some students may even disbelieve their results. Ideally, students will even argue about the results. This sets the stage for Chapter 4 of our story in class the next day.

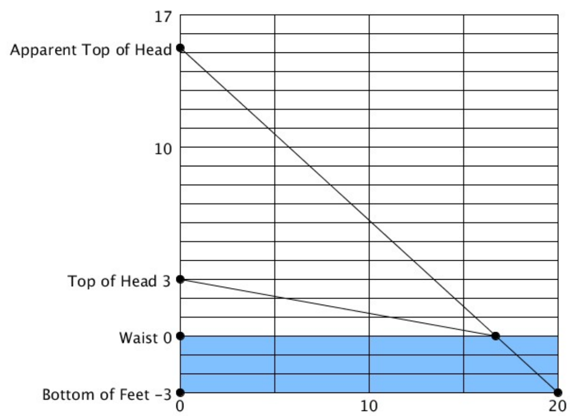

Figure 9: The Top of the Fisherman's Head Appears to be Floating High Above the Water

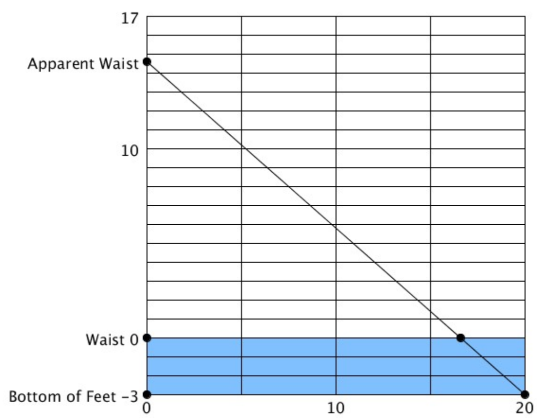

Figure 10: The Fisherman's Waist Also Appears to be Floating High Above the Water

- Following the scientific method we check the results experimentally using our countertop aquarium and an underwater camera. See Figure 11 and Figure 6. Our surprising result is right. But, because this is the real world, the story doesn't end neatly there. Our fish sees a reflection of the fisherman's legs above the water between the fisherman's waist and severed upper body!!! We are left with more questions.

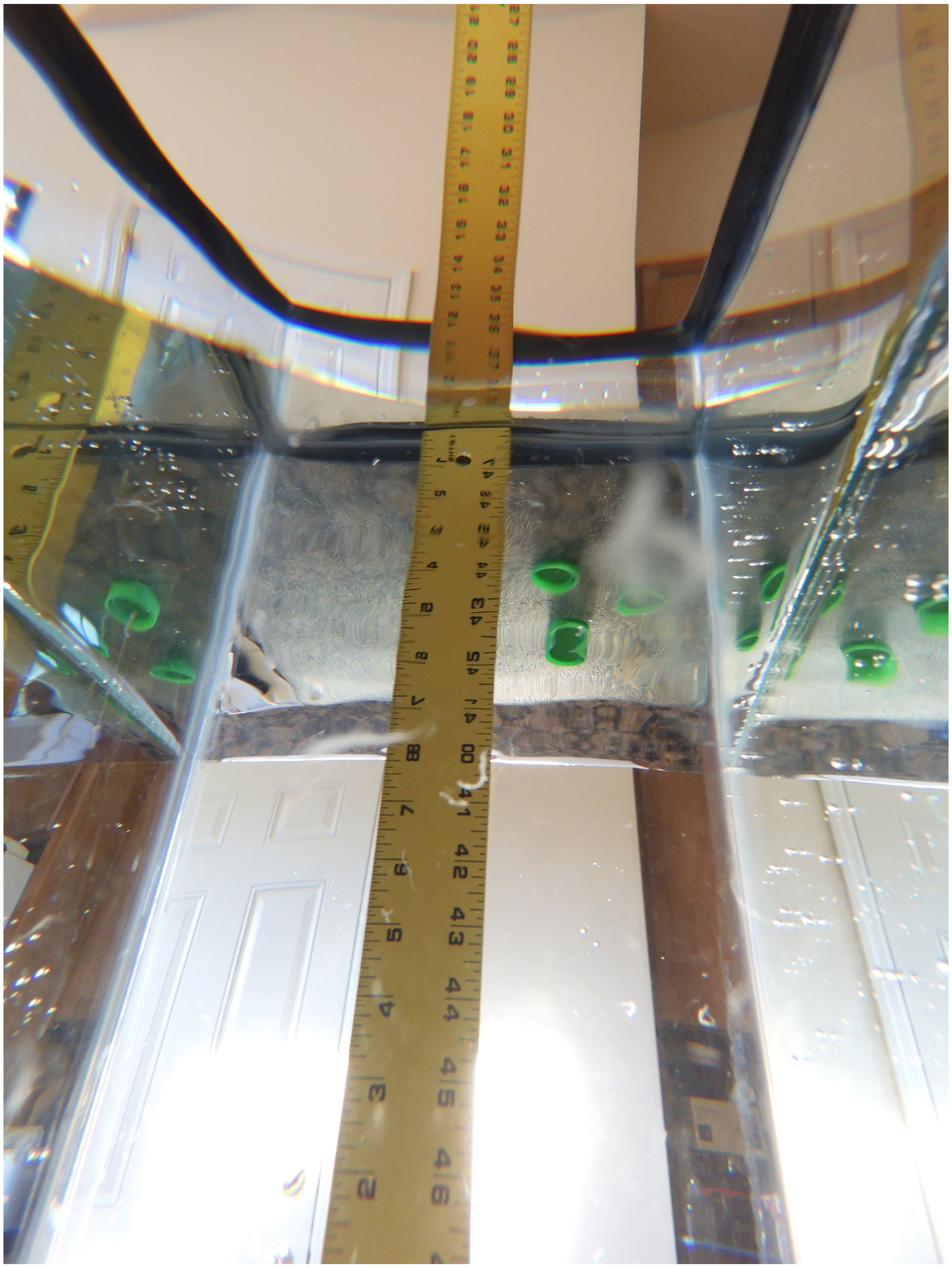

Figure 11: Fish's View