Lesson Plan: Refraction of light at boundaries

OVERVIEW

This lesson is broken up into several small units. The focus is on observations of optical phenomena resulting from the refraction of light and the subsequent modeling of this using Snell's law. The qualitative features of the mathematical statement should be emphasized.

Students should leave

- understanding that light rays change direction at an optical interface, and that this change related to its speed
- knowing what light does at an air-water interface
- understanding there is a difference between physical objects and images we see, which is the result of the paths of light rays
- knowing that different colors refract at (slightly) different angles

1. Introduction: "Broken pencil" demo

Objective: Motivate the study of refraction using an optical illusion that results from everyday objects. Students should carefully observe and compare images from objects which result from refraction at an air-water interface.

Materials:
- Clear plastic cups
- Straws (or other rod-like object)
- Water

Procedure:
** Fill the cup about 1/2 full with water.*
** Immerse the straw in the water, in the center of the cup. Observe from the side of the cup the appearance the physical straw and its image in the water.*
** Move the straw from side to side, watching how the appearance of the straw "breaks".*
** Allow students to try for themselves, experimenting with different positions and different viewing angles.*
** Have students use side-to-side head motion (or look using left and right eyes individually) to determine where the image is formed for a given straw location.*
** Have students describe how the magnification depends on the position in the cup relative to their eyes.*

Questions:

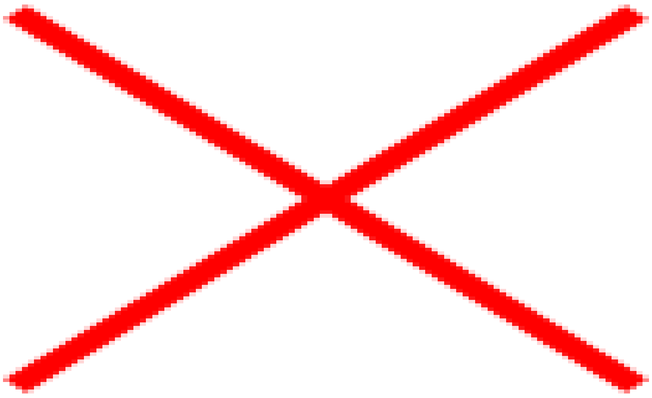
- How is the position of the submerged image related to the physical position?
- What happens when you view it from above?
- Where is the magnification greatest?
- Does the lower half ever appear smaller than the top half?

(Answer: When straw is displaced from the center inside cup, the image is formed between the straw and the nearest wall of the cup. However, the magnification is >1 no matter which side you view the cup from.)

** Take the straw out and put it behind the cup, and again study how the image compares to the physical object.*

2. Refraction mini-lesson

<u>Materials:</u>
- Graph paper
- Handout with circles
- This table



** Explain refraction at an interface to students using your own words or you can pull from what is written below:*

> Air and water are two different *optical media*. When light moves through a medium, it travels at constant speed in a straight line (like a particle). In air or space, light moves about 700 million MPH. That means it only takes 1.3 seconds for light from the Moon to reach Earth! In water, light travels slower—only ~500 million MPH. We can distinguish optical media according to how fast light moves through them.
>
> When light passes through the boundary of two different media, its speed will change, and this is also accompanied by a change in its direction. This phenomenon is known as *refraction*. Light can also be reflected at a boundary, although we are not studying that right now.

- To understand refraction, we need the concept of a *surface normal*. At any given point on a surface, we construct a line that passes perpendicularly through the surface at that point.

** Have students draw some curves, and practice drawing normal lines at points along the curves. Show by example, and encourage the use of straight edge (if available) for the normal lines.*

- Now that we know what a surface normal is, **we can state rules for what happens when light is transmitted through a water-air boundary: (Snell's law)**
- If the ray goes <u>from water to air</u>, the refracted ray makes a larger angle with the surface normal.
- If the ray goes from air to water, the refracted ray makes a smaller angle with the surface normal.
- In either case, larger incident angles result in larger refracted angles.

Mathematically, $n_{air} \sin(\theta_{air}) = n_{water} \sin(\theta_{water})$.
($n_{air} = 1$)

** On the graph paper, practice drawing incident/refracted rays at air-water interfaces. Use a* *straight interface and construct a series of triangles which all have a common length of 15 units along a normal line. The table above then tells you how big to make the "opposite" sides in order to achieve the given angles.*

**Since geometric accuracy cannot be expected on the curved lines, but it may be useful to note that, for rays going from water to air, total internal reflection occurs at 49 degrees incidence.)*

** Explain the broken straw illusion to the students using the concepts of refraction and light ray paths. You can use your own words or pull from below. Support your explanation using drawings!*

- Suppose we are viewing the cup in front of us, with the straw displaced to our left.
- The rays from the straw which travel through the water directly at us get refracted to our right when they hit the boundary. So these rays do not actually make it to our eye.
- However, the rays that are emitted slightly to our left get refracted to the right at the cup boundary, so it is possible for these rays to hit our eye.
- When we look at the lower half of the straw, we are seeing the rays that had to refract through a part of the boundary which was farther out to the side than the straw is, so that they could make it to our eye.

3. Multiple images

<u>Objective:</u> Observe that multiple images of the same object in a cup of water can be seen simultaneously; understand this in terms of refraction and the different orientations of the boundary surfaces.

<u>Materials:</u>
- Cups and water from earlier
- 1 coin per cup

** Place a coin in the center at the bottom of the cup. Fill the cup so there is about 3 inches of water in it (it is important that there is enough water in the glass). Set the glass on a table. Move your eye so that it is parallel (even) with the surface of the water in the glass. Now while looking at the surface of the water, slowly change your angle of observation of the surface from parallel to the surface to looking straight above the coin in the glass.*

<u>Possible questions:</u>
- How many coins do you see on the surface when you begin looking parallel to the surface?
- Is there a position where you could see more than one coin while viewing the surface? Where does this happen?
- What do the coins look like – are any of them inverted (upside-down)?

** Prompt the students to consider the refraction happening at the water's surface and on the cup sides. If you can see three coins, one of these (the "top" coin) is actually due to reflection at the back wall, followed by refraction at the water's surface.*

4. Color-dependence of refraction

<u>Objective:</u> Study how refraction varies slightly depending on the color of light. Use this fact to separate white light into its different components using a prism.

<u>Materials:</u>
- Prisms (triangular)

- Paper

So far we have treated all light as refracting in the same direction. This is not quite true, and in general different wavelengths of light refract at different angles. For example, when violet light escapes from glass into air, it refracts at a slightly greater angle than red light does.

** Step outside and use the prisms to separate sunlight and cast it onto surfaces such as a piece of paper. Note the order of the colors in relation to the orientation of the prism and the direction of the sunlight.*

** Inside the classroom, stand a prism on its side on a table with a piece of paper underneath.*
** Lay a flashlight on the table and point it so the light goes through the prism.*
** Observe again how the white light is separated into its components.*
** Now stand another prism up next to the first one and make the separated light pass through it. (This 2nd prism should be rotated 180 degrees relative to the 1st prism and placed so they are touching)*

- What happens to the light after it passes through both the prisms?