HOW-TO-DO-IT

Exploring the Anatomy of Your Own Eye

RECOMMENDED READING FOR *AP Teachers*

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Abstract

Features of the cornea, iris, lens, and retina can be explored by students on their own eyes with the 11 activities described in this article.

Key Words: *Blind spot; cornea; entoptic; eye; fovea; iris; optic nerve; Purkinje; retina; transillumination; vision.*

Your eye is a very accessible organ for self study. Any number or combination of the following activities can create interest in and enhance a study of the anatomy of the eye, and some can serve as an introduction to a study of vision and the brain. All can be done either alone or in pairs. Table 1 will give you an idea of the supplies needed.

○ The Cornea

The cornea is the tough transparent membrane at the front of the eye that does most of the focusing of images on the retina (see Figure 1).

1. Observing the thickness of the cornea by reflecting light off its surfaces.

"Glint" or "sparkle" is light reflected from the anterior (outer) surface of the cornea. Closer examination reveals a reflection from the posterior (inner) surface, first described by Purkinje (1823) and referred to as "P2" (Purkinje image II) here.

Find a location away from bright lights. Hold a mirror directly in front of one eye and a flashlight to the side about 0.5 m away. I find it most convenient to use a Mini Maglite (AA batteries) with the lens removed (candle mode). Orient the flashlight so that you can see its light reflected on the cornea in front of the iris. About 1 mm from this image (P1), toward the pupil, there will be a very much smaller and dimmer second image (P2) as shown in Figure 2. If you now move the flashlight in a half circle along your peripheral vision, being careful to always keep the images visible, you will be able to make the two images move to the other side of the pupil, with P2 always closer to the pupil than P1.

Students may find it easier to make this observation on someone else's eye. For more information, see Tscherning (1920).

The activities will give students a much better understanding of their eyes.

2. Demonstrating the shape, flexible nature, and underlying structure of the cornea.

A point source of diffuse light held near the eye after rubbing or pressing on a closed eyelid will cast a shadow of a rumpled cornea surface onto the retina (see Figure 3).

Make a 0.2- to 0.3-mm hole in a small square (~40 mm) of aluminum foil by laying it against a hard surface and twirling the point of a needle on it until a hole is just barely visible, then place a piece of matte-finish cellophane tape over the hole. (Alternatively, you can cut small pieces from an aluminum beverage can. Wearing safety glasses, gently tap on a needle with a small hammer until it barely pokes through, then tape the piece over a hole punched in an index card so that no sharp edges are exposed.) The smaller the hole, the sharper the shadows will be.

When you hold this small hole about 10 to 20 mm from your eye with a bright light behind it, you will see a disk of light bounded by the shadow of the iris. You will notice moving dots and lines within the disk. These will be the shadows cast by bubbles and films on the cornea and by "floaters," which are blood cells and bits of tissue suspended in front of the retina. Moving your point source of light from side to side will move the shadows and give you a sense of the distance these things are from the retina. Moving your eye will move the floaters whereas blinking will move the things on your cornea. See Walker (1982) for more information.

Once you have accustomed yourself to all the movement, try pressing gently on the center of your closed eyelid while moving your eye back and forth so you feel the bump of the cornea. Note that when you open your eye your vision is momentarily blurry. Now do this again but this time quickly open your eye and look at your point source of light and you should see an irregular network of fuzzy lines that quickly disappears. This is the Fischer-Schweitzer polygonal reflex (Westheimer, 2003) and you have just revealed something of the internal structure of the cornea. See Bron (1968) for photographs he made using fluorescein.

○ The Iris

The iris is located behind the cornea and in front of the lens. It controls the size of the pupil.

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Table 1. Required and optional supplies for activities (R = required; O = optional depending on how activity is done).

Activity	1	2	3	4	5	6	7	8	9	10	11
Flashlight [a]	R	O	O	O	R	R	O	R			
Small mirror [b]	O				O			O			
Aluminum foil		R	R	R	O		R	O			
Needle		R	R	R			R				
Tape [c]		R	R	R			R				
Convex lens			O								
Requirements vary									O	O	
Ping pong ball											O

[a] AA Mini Maglite with LED recommended; LED required for Activity 8 (see text).
[b] These activities may be easier to do in pairs, observing another person's eye, making the mirror unnecessary.
[c] Matte-finish cellophane tape; e.g., Scotch Magic brand "invisible mend" tape.

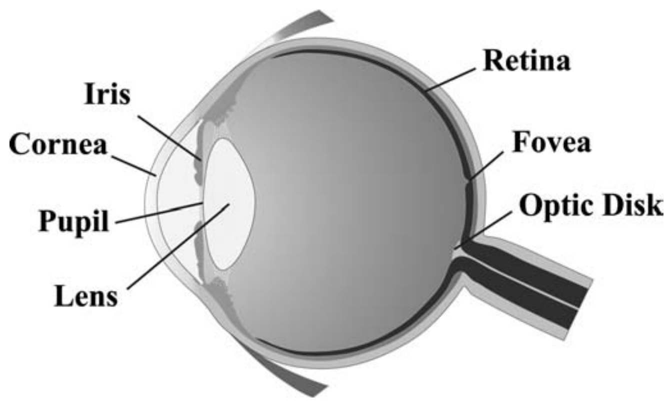

Figure 1. Schematic of eye.

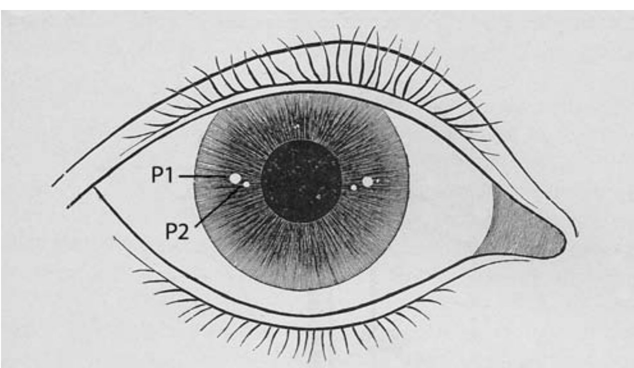

Figure 2. Appearance of P1 and P2 (adapted from Tscherning, 1920).

3. Seeing the shape and action of the iris.

Using the point source of light described in Activity 2, observe the slightly irregular shadow outline of the iris. Now cover and uncover your other eye and observe how the shadow of the iris within your first eye contracts and expands. Checking to see that the irises are working in tandem is something a doctor may do when a head injury is suspected.

You can also get a good look at the shape and action of your iris by looking through a magnifying lens held flat against a mirror.

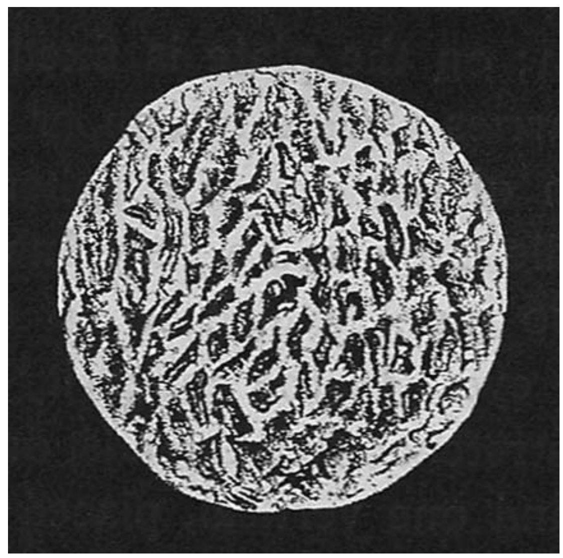

Figure 3. Cornea surface after rubbing it through the eyelid (Bull, 1894).

○ The Lens

The lens is behind the iris and is made of layers of long fiber-like cells with a hexagonal cross section. The locations where these cells overlap are called the lens sutures (Kuszak et al., 2004).

4. Seeing the suture lines and dark spots in the lens.

Using the same point source of light described in Activity 2, look carefully and you may see some faint lines radiating out from the center of the disk of light. These are the shadows of the suture lines in the lens (see Figure 4). If you have trouble seeing these, try using your other eye or a point source with a smaller hole.

5. Seeing light reflected off the front and back surfaces of the lens.

You can see light reflect off the back of the lens to make Purkinje image IV (P4). Hold a mirror directly in front of your eye. Shine a flashlight on your eye from an arm's length away, so that you see its reflection (P1) centered over your pupil (if the light is too bright, partly cover it with aluminum foil). Now move the light up and down and look for a much dimmer but still sharp image from the posterior surface of the lens (P4) moving the opposite direction, down when P1 moves up and vice versa.

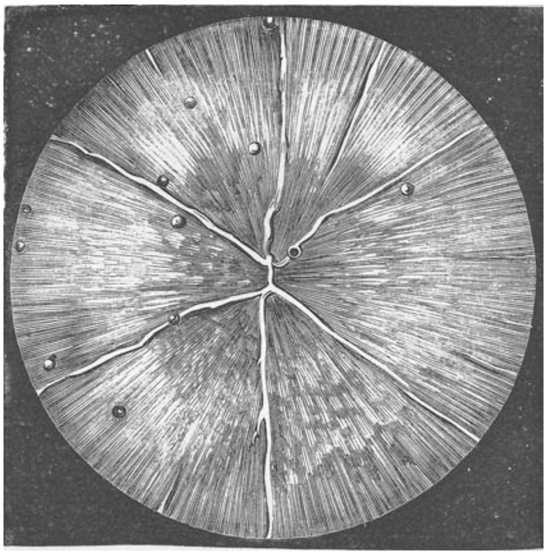

Figure 4. Shadows of suture lines in lens (Donders, 1864).

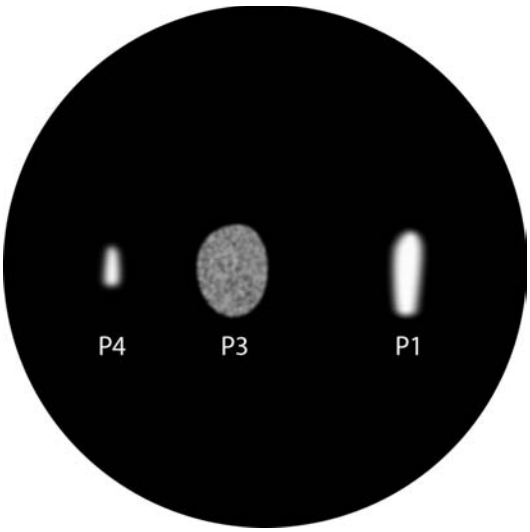

Figure 5. Purkinje's images in the pupil, made using a candle for a light source (adapted from Donders, 1864).

Between P1 and P4, you may see the image from the anterior surface of the lens (P3), which is indistinct, as shown in Figure 5, because of its surface nature (Navarro et al., 1986).

The changing size of the P3 image (and, to a much lesser degree, P4) helped convince scientists that our eyes focus by changing the shape of the lens (Tscherning, 1920). These images are also called Purkinje-Sanson images because Sanson (1838) noted that P4 should not be visible if a patient has a cataract and he advised physicians to use this test to avoid a misdiagnosis and unnecessary surgery. See Millodot (2008) for modern applications.

○ The Retina

The retina is the light-sensitive tissue on the back of the eye. The retina thins and is called the fovea (Latin for "pit") at the center of vision. Blood vessels and nerves lie on the retina, but blood vessels are not found near the fovea and nerve bundles arc away from it. Blood vessels and nerve bundles gather together and exit the eye at the optic disk.

6. Seeing the blood vessels and the fovea.

The blood vessels lying on top of the retina shade the light-sensing cells under them. The retina normally compensates for this shading and we don't notice anything. However, if we direct light from a different location than normal, we can cast shadows where they don't normally fall and momentarily see them.

Hold a bright, focused light at the extreme edge of your peripheral vision and move it so that it flashes across your pupil several times a second while looking straight ahead at a featureless wall. (It may help to have someone do this for you, but don't do this to someone without their permission, because it can trigger an epileptic seizure.) This causes a blinking spot of light to be focused on your retina, far from your center of vision (point *b* in Figure 6). The light from this spot casts shadows of your blood vessel network and the fovea (point *c* in Figure 6), and you should see something like what is shown in Figure 7. Next try moving the light in an arc along your peripheral vision. If you have a Maglite flashlight you can remove the lens cap so that you don't have to keep the light focused on your eye. Everyone has a different pattern, which is why a retinal scan is useful for identification.

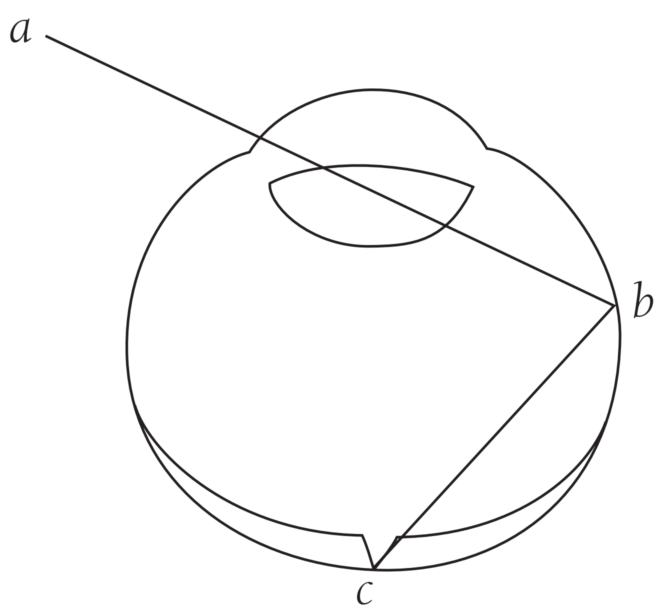

Figure 6. The image of the light acts as a light source within the eye that can cast a shadow on the fovea (adapted from Helmholtz, 1867).

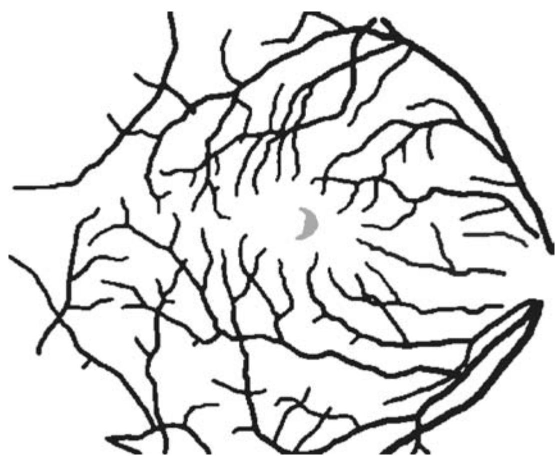

Figure 7. Shadows of blood vessels (also called "Purkinje's tree") and fovea.

7. Seeing the capillaries around the fovea.

Make a large pinhole (~0.8 mm) in a piece of aluminum foil and cover it with matte-finish cellophane tape. Hold the hole close to your eye and look through it at a bright light. Rapidly (~2 cycles/second) move the hole in small circles and you will see the shadow of the capillary network that surrounds the fovea. See Applegate et al. (1990) for more information.

8. Seeing the fundus.

This works well only with people with light skin. Briefly hold the exposed LED bulb on a Maglite flashlight against the upper outside eyelid of your left eye while looking in a mirror with both eyes open. If you tilt your head to the side so that you can just see your left eye past your nose, you will see the back of your eye (the fundus) glowing red through the pupil and maybe even the fine lines of blood vessels magnified by the cornea and lens (see Figure 8). Try changing the focus of your eyes or doing this with someone else. The LED will quickly get uncomfortably hot, so don't leave it on too long. For a cooler LED, substitute a Radio Shack Red LED (#2760086) with a 68-ohm resister soldered to one leg as shown in Figure 9.

Figure 8. Transillumination of the fundus.

Figure 9. Red LED with voltage dropping resistor plugged into a Mini Maglite flashlight.

9. Seeing leucocytes (white blood cells) moving in the capillaries.

Many people have seen minuscule bright spots moving in short, irregular paths when looking at the sky or a white surface after exerting themselves. These are the leucocytes moving through the capillaries on your retina (Sinclair et al., 1989). Schmid-Schonbein (1987) explains that the leucocytes deform to fit in the capillaries, causing a space to open up in front and red blood cells to pile up behind, which accounts for the elongated appearance of the bright spots and their dark tails. Zusne (1963) describes how to build a viewer and do class activities, although you might substitute Lee 079 Just Blue plastic (http://www.leefilters.com) in place of liquid filters and you should not have the light too intense (Harwerth & Sperling, 1971).

This phenomenon has been used with cataract patients to assess the proper functioning of the retina (McGraw et al., 1996).

10. Seeing nerve activity.

If you look at the right edge of a small red light in an otherwise dark field with a partly dark-adapted right eye, you will momentarily see faint blue arcs curving away from the light toward the right (see Figure 10). These blue arcs follow the paths of the nerves arcing away from the edge of the fovea (where the spot of light is focused) to the optic disk and were first described by Purkinje (1825).

You can easily see the blue arcs at night in your home in a room with some red LED indicator lights on equipment. Turn off the room lights and close your eyes for about 30 seconds. You should see faint arcs when you open your right eye and look at the right edge of a red light. If you look at the left edge you will see a blue spear or spike extending to the right. Blinking every second or so will help prolong seeing the blue arcs, as will shifting your view from side to side. If you look straight at the light, the arcs or spike will disappear, although you may see a blue haze. If you use your left eye, everything is reversed.

Alternatively, a cardboard tube lined with black paper and with either a red LED or a small opening covered with a red filter at the far end can be used in a well-lit room. Moreland (1968) describes a template that produces multiple arcs suitable for classroom demonstrations, and Walker (1984) reproduces this template. See the article by Wolfe (1991) for an explanation and graphics suitable for students.

11. Locating the optic disk.

You can locate the optic disk by noting where the blood vessels originate or the blue arcs terminate in Activities 6 and 10, respectively. If you keep one eye closed and blink with the other eye while looking at a uniformly illuminated surface (such as the inner surface of a ping pong ball cut in half to fit over the eye), you may see a gray disk at the location of the optic disk (Palmer, 1991).

Repeat Mariotte's experiment (a good example of the scientific method):

Figure 10. Purkinje's blue arcs (adapted from Purkinje, 1825).

> "to make…the rays of an object to fall upon the optic nerve of my eye, and to find the consequence thereof, I made this experiment; I fastened on [a] wall, about the height of my eye, a small round paper…and I fastened [another to the right] at the distance of about 2 feet; but somewhat lower than the first, to the end that it might strike the optic nerve of my right eye, while I kept my left shut. Then I placed myself over against the first paper, and drew back by little and little, keeping my right eye fixed and very steady upon the same; and being about 10 feet distant, the second paper totally disappeared. (Mariotte, 1668)

Helmholtz (1867) drew the outline of the blind spot in his right eye, reproduced here as Figure 11. He positioned his eye a distance three times the length of line A–B away from the paper, and, keeping it focused on the small cross (*a*), moved the tip of a pen in and out of the blind spot, marking the border and the beginnings of the larger blood vessels (one of which is marked *d*).

Search the Internet for "mapping your blind spot" for sites that allow you to draw the outline of your own blind spot using a mouse.

○ Suggestions for Assessment & Implementation

Ask students what they know or can deduce about the functions of the cornea, iris, lens, and retina while referring to diagrams, models, or a dissection. The light-focusing function of the cornea can be inferred by its shape and confirmed by noting the brief blurring of vision that follows rubbing of the eyes or the more profound blurring when one is underwater. These ideas can be elicited by careful questioning.

The iris allows a quick response to changing light levels. Less obviously, at high light levels, acuity is improved with a smaller pupil and the focusing is less critical (a pinhole camera is always in focus and has no lens), and under low light levels vision is better with a larger pupil because more light enters the eye. Students familiar with photography may readily understand these ideas.

Unlike the lens in a camera, the lenses in our eyes are organic, change shape to focus instead of moving in and out, and have significant imperfections. That a lens can have imperfections and still make a sharp image can be proved by putting bits of opaque tape on a magnifying lens and focusing the image of an overhead light onto a piece of paper. It can also be instructive to observe similar reflections on the lens from a pair of eyeglasses and a biconvex lens prior to Activities 1 and 5, respectively.

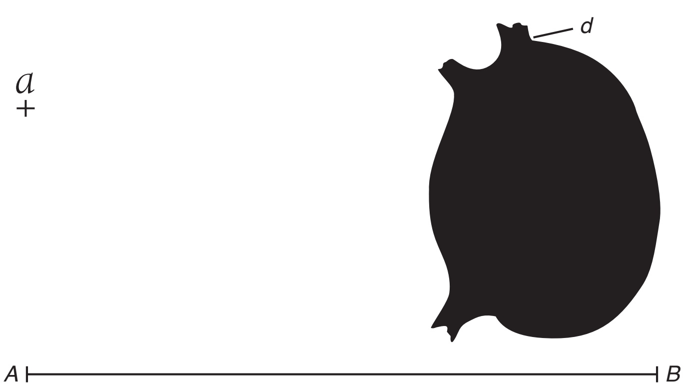

Figure 11. Helmholtz's drawing of the blind spot of his right eye (adapted from Helmholtz, 1867).

While a student may know the function of the retina, the consequence of its location can be a surprise – even things within the eye should be visible! Indeed, being able to see the shadows of blood vessels helped convince early researchers that the underlying tissue was responsible for sight.

Soliciting comments and guesses should give you a good idea of the understanding and misconceptions students have. Careful questions can lead to a desire to investigate. Be sure to master the activities beforehand so that you can more effectively judge appropriateness and help students. Discuss safety issues with students and allow for questions and answers before starting.

○ Conclusion

The activities described above will give students a much better understanding of their eyes. The tandem action of the irises, seeing nerve activity and *not* perceiving the blindspot (Ramachandran, 1992), offers transitions from a study of the anatomy of the eye to a study of vision and the brain. Brain activity is revealed by changes in pupil size (Hess, 1965) and by eye movements (Martinez-Conde & Macknik, 2007).

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