How does my eye compare to the telescope?

GRADE LEVEL:
7-12

TIME OF YEAR:
Anytime

SCIENCE STANDARDS:
Science as inquiry

TIME NEEDED:
1-2 class periods

TEXTBOOK LINK:
Hewitt, ***Conceptual Physics,*** *8th Ed.* Ch. 25, Seeing Light, Ch. 27, Reflection and Refraction

The purpose of this exploration is to compare the performance of your own eye with the performance of the MicroObservatory online telescope.

- Both the eye and the telescope produce an image by focusing light onto an array of light-sensors.
- The telescope can image much fainter objects than can the eye, due to its much larger opening and its longer exposure time for gathering light.
- The telescope has greater sharpness of vision than the eye, but the eye has a much wider field of view.

Everyone knows that a telescope helps us see better, but why does it? Which features of a telescope make it such an important tool? And what can the eye do that the telescope can't? Use this series of activities to introduce students to the important features of the telescope and of their own marvelous instrument, the human eye.

Materials Needed

	For each team of students
	2 differently-colored small objects, such as 2 Pencils or 2 pens with different colored caps
	Protractor (provided in student guide)
	For the class
	For the teacher
	Flashlight
	Aluminum foil, 4 inches x 4 inches square
	Pin, for putting small holes in foil
	Penny

Opening Discussion

1. Ask whether any students have used a telescope, and if so, for what. Ask students, In what ways is a telescope like your own eye? Review with students the basic similarities between eye and telescope:

    - Both have an opening to let in light.

    - Both focus light to form an image. The eye uses a lens to focus the light; the MicroObservatory telescope uses a series of mirrors.

    - Both have a light-detector to sense the image. The retina of the eye contains about a million cells that are very sensitive to light. The telescope's silicon chip contains roughly a million individual "wells" that are very sensitive to light.

Comparison 1: Size of Opening

Students work in pairs for this and the following activities. How does your eye's light-gathering ability compare to the telescope's?

1. Have students look at the pupils of their partners' eyes. (The pupil is the black opening in the center that lets in light.) Students should observe the size of their partner's pupil, and then mark in their science journal the circle that most closely resembles the size of the pupil. They measure the width of this circle using the ruler, and enter the measured size on the DATA PAGE.

2. Have students compare the size of their pupil with the size of the telescope's opening, which is about 6 inches wide. About how many times more light does the telescope opening let in, compared to your eye? To answer this question, students must first decide which is the relevant feature: the *width* of the opening, or the *area* of the opening?

The area of the opening is the important factor. For example, if the pupil is one-quarter inch wide, then the telescope's opening is about 24 times wider than the pupil. But the *area* of the telescope's opening is 24 x 24 = 576 times as much as the pupil's—so **the telescope gathers 576 times as much light**! This is one reason that telescopes are so useful.

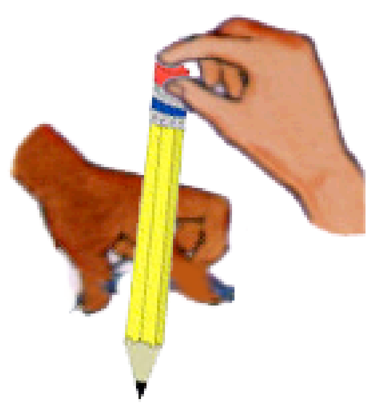
The larger aperture of telescopes enables them to gather much more light than the eye. This enables telescopes to detect much fainter objects than the unaided eye.

Comparison 2: Exposure time

The MicroObservatory telescope's light-sensing camera has a shutter which can remain open anywhere from 0.05 seconds to 60 seconds when you take an image. (You must specify this *exposure time* every time you take an image.) The longer the exposure time, the more light that the telescope can gather to make the image.

> Exposures longer than 60 seconds are not allowed, because the resulting image is often blurred due to vibrations and other factors affecting the telescope. The Hubble Space Telescope, free from vibrations as it floats in space, can take exposures that are many hours long!

The human eye does not have a shutter. In fact, we *seem* to see continuously, rather than as a succession of still images. However, the eye *does* have a kind of exposure time. Students can estimate their eye's "exposure time" by esimating their *reaction time* with the following activity.



1. Students work in pairs. One student holds a pen or pencil as shown, while the other student prepares to catch it. Most students will *not* be able to catch a pencil dropped in this way.

2. Have each pair of students estimate their reaction time. Is it a second? Is it a tenth of a second? Is it a thousandth of a second? Most students will feel comfortable that it is *roughly* a tenth of a second; the exact estimate does not matter.

3. Have students record their estimates on their DATA PAGE.

This experiment also shows that our eyes do not “accumulate” light over a long interval. If they had to accumulate light for a long time to make an image, our reaction time would be much slower than it is. But this experiment also shows that we do not see or react instantaneously; it takes time for the image of the moving pencil to be recorded and for our reaction to take place.

> *Approximately* every 1/15th of a second, your eye sends your brain another image. This fraction of a second is *roughly* the time it takes the nerve cells in your eye and optic nerve to gather light, fire, conduct an electrical signal to the brain, and prepare themselves to be ready to fire again. So your eye has about one-fifteenth of a second to collect light, before the process starts all over again.
>
> The "exposure time" of your eye is therefore roughly one-fifteenth of a second.
>
> That's why movies have at least 16 frames a second (28 frames a second for video): Any slower than this, and your eyes would see the flicker. But much faster than this would be useless, since your eyes can't detect motion over much less than one-fifteenth of a second.

How do the eye and telescope compare? To observe very faint objects, such as galaxies, you must use the longest exposure times—60 seconds for the telescope. This is about 900 times longer than the "exposure time" of the eye (about 1/15th second)! So the telescope can gather light for 900 times longer than the eye, to make a single image!

The long exposure time of the telescope’s camera enables it to gather much more light than the eye. This enables telescopes to detect much fainter objects than the unaided eye.

Combining the results from experiments 1 and 2: The telescope can collect 600 x 900 = 540,000 times more light than your eye! The factor of about 600 is due to the larger light-gathering area, and the factor of 900 comes from being able to collect light for a longer time per image.

And because celestial objects appear fainter as the *square of their distance*, the telescope can detect objects that are √540,000 times further than your eye can see, or about 735 times further than your eye can see.

Comparison 3: Sharpness of Vision

How sharp is your vision, and how does this compare with the telescope's? Here is a good way to estimate your eye's sharpness of vision.

1. Explain to students that they can estimate their sharpness of vision by seeing how close they must be to just make out two pinpoints of light side-by-side.

2. Prepare the experiment: Punch two pinholes through a square of aluminum foil, about 1/8 inch apart. Place the foil over the flashlight. You should be able to clearly see light coming through both pinholes.

3. While you hold the flashlight, have students stand as far as possible from the flashlight—e.g., at the other end of a corridor—and then have them move towards the light until they can *just* make out that there are two points of light side by side, rather than one point of light. This is the distance at which they can just *resolve* the two objects. Students will differ in their sharpness of vision, so some students will be further and some closer to the flashlight.

4. Have students estimate their distance from the flashlight. They can pace off the distance, e.g., using the estimate that the length of their foot is about one foot. Have them record their estimates on the DATA PAGE in their science journals.

NOTE: If you don't have enough room to do this activity, you can make the pinholes closer together, though this is harder to do!

Students will just be able to distinguish ("resolve") the two points of light that are 1/8" apart, from *approximately* 35 feet away. By contrast, the MicroObservatory can resolve two points of light that are 1/8" apart, from about 875 feet—which is 25 times further away.

We say that the telescope has 25 times better sharpness of vision, or equivalently, 25 times better *resolution* than the human eye.

Thus the telescope transports us the equivalent of 25 times closer to the scene we are observing. This is not a huge difference. For now, merely note the comparison. In the wrap-up discussion we'll examine what it means.

Misconception alert: Many students want to know how much the telescope "magnifies." Astronomers don't use the term magnification because it is misleading. For one thing, the magnification you see depends not just on the telescope but on how you display the image—e.g., on a large screen, on a small monitor, etc. Furthermore, a telescope could in principle magnify a scene enormously, yet if the image is blurry, the magnification won't help you see anything. Astronomers prefer to use the term "angular resolution," described below.

The resolution of the eye and telescope are usually expressed as an *angular resolution*. This is the angle of the smallest object you can distinguish in the image. Equivalently, it is the angle between two points of light that can just be distinguished, as in the experiment above.

> The eye's *angular resolution* is about 1/60th of one degree. (In the experiment above, this is the angle that two points of light 1/8" apart make when seen from 35 feet.)

The telescope's *angular resolution* is 2.5 seconds of arc (1/1440 degree) per pixel in a zoomed-in image. It is 5 seconds of arc (1/720) degree per pixel in a zoomed-out image. That is, each pixel in the image represents 5 seconds of arc.

For more detail on how to convert between distances and angular width, please refer to the How-To Guide, *A Wrangle With Angles.*

Comparison 4: Field of View

Now it's the humans turn to excel. For this experiment, students work in pairs. Each student tries the following:

1. Sit at a table, keeping your eyes straight ahead. With your left arm level and outstretched, SLOWLY bring your arm from behind your head into your field of view, while wiggling your thumb. Make sure you keep your eyes straight ahead; don't look to the left or right. When you can JUST see that your thumb is wiggling, stop moving your arm and have your partner measure the angle your arm makes with the straight-ahead direction. (Use the protractor provided or other device for estimating angles.)

2. Do the same with your right arm. The total angle, from left to right, where you can see an object, is your field of view.

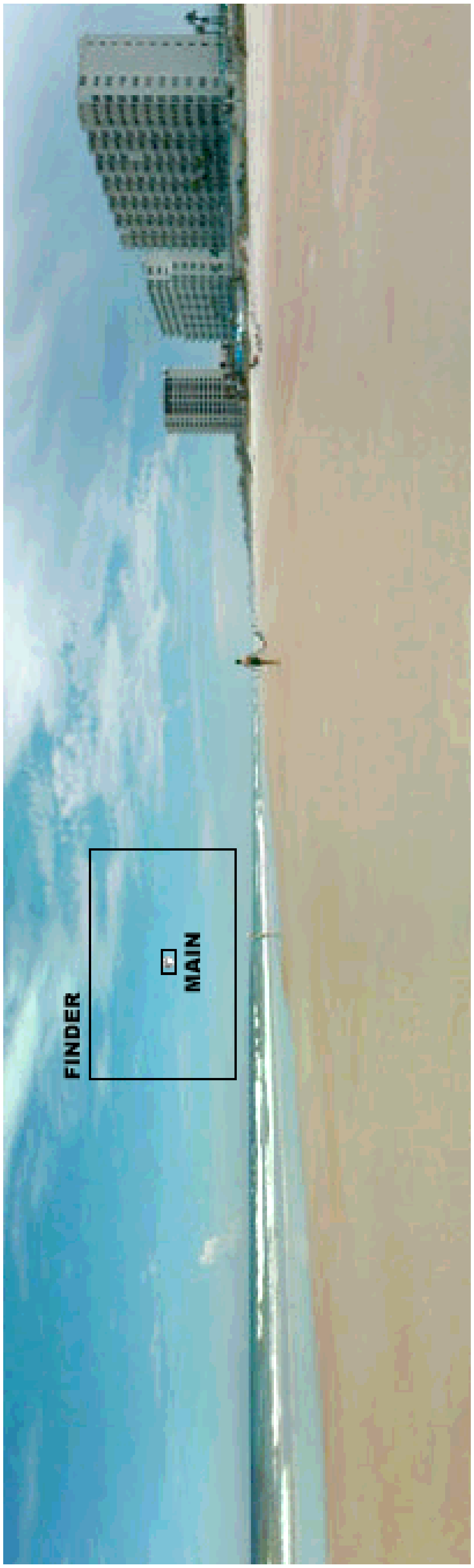
3. Have students record this angle on their DATA PAGE. Have students compare their eye's field of view, which is close to 150 degrees, with that of the telescope, which is only 1 degree for the "main camera" and about 10 degrees for the "finder camera."

4. Discuss with students: What's the advantage of having a wide field of view, as humans do? What's the advantage of having a narrower field of view, as telescopes do?

The Hubble Space Telescope has a field-of-view of only 0.006 degrees—about 100 times narrower than the MicroObservatory telescopes.

But its angular resolution is 100 times greater!

Having a wide field of view is a survival advantage for humans: We can quickly react to dangers such as animal predators or moving cars. By contrast, telescopes are usually designed to focus on just a small part of the sky.



YOUR EYE'S FIELD OF VIEW, COMPARED WITH TELESCOPE'S

If you were on this beach, your eye could take in the whole scene (more than 90 degrees wide).

The telescope's **main** camera has a field of view only about 1 degree wide (small box).

The telescope's **finder** camera has a field of view about 10 degrees wide (larger box).

Note how small the Moon appears in this image. (It's in the small box labeled **main**.) The Moon is about half a degree wide.

Comparison 5: Color vs. black-and-white

1. Students repeat the Field-of-View experiment, but this time they hold a colored object and move their arm until they can definitely make out the *color* of the object. As before, the partnering student measures the angular field of view. Make sure that students are careful to keep looking straight ahead, rather than gazing at the object as it moves.

2. Ask students, "How does your field of view for seeing the *color* of an object compare to your field of view for seeing the object at all?"

Humans have a much more restricted field of view for seeing color than for seeing shapes. That's because the color-sensing cells are concentrated in the central part of the retina (called the *fovea*), which is responsible for seeing in the forward direction. The cells around the outer parts of the retina, which are responsible for peripheral vision, are not sensitive to color.

In dim light, you may not be able to see color at all. The eye's color-sensing cells (called "cones") do not function at low light levels. By contrast, the eyes "rod" cells. which are responsible for night vision, are very sensitive to dim light but can not distinguish colors.

The telescope normally "sees" in black-and-white: the telescope's light-sensing silicon chip responds to the brightness of the light falling on it. However, the telescope also comes with three colored filters, for taking images at different regions of the color spectrum. In Exploration 3: *Astro-Photographer*, students can use these filters to construct full-color, true-color images of celestial objects.

Wrap-up and discussion

Discuss with students the main conclusions from their experiments:

- Telescopes and their cameras are useful because they can gather far more light than can the human eye.

  (A MicroObservatory telescope can gather as much as a half-million times more light than the eye.)

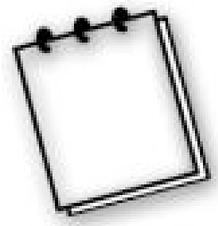
- Telescopes are also useful because they can distinguish two objects at a greater distance than can the human eye.

  (A MicroObservatory telescope has 25 times greater "sharpness of vision" than does the eye.)

- Telescopes usually have a much narrower field of view than the human eye.

  (A MicroObservatory telescope has a field of view of less than a degree, compared to the eye's 150-degree field of view.)

In the next exploration, students will use the telescopes to image a variety of celestial objects.



DATA PAGE:
Eye and telescope compared

YOUR EYE	THE TELESCOPE
Size of opening:	
Pupil is __**1/4**__ inch wide or less.	Aperture is 6 inches wide, fixed.
Exposure time:	
About __**1/15**___ second.	From 0.05 to 60 seconds..
Sensitivity to light:	
Retina very sensitive to light.	Silicon chip very sensitive to light.
Sharpness of vision:	
Two lights, 1/8” apart, at_**35**_feet. Resolution = __**60**_ arc-seconds	Two lights 1/8” apart, at 275 feet. Resolution = 2.5 arc-seconds
Field of view:	
More than _**150**___ degrees.	About 1 degree (main 'scope) About 20 degrees (finderscope)
Color vs. black and white:	
Color (in bright light) Black/white (in dim light)	Black and white. (But can make color image using filters.)
Seeing:	
Image from retina requires brain to interpret.	Records images, but does not "see."

