



## From Pinholes to Space Telescopes: Using the Galileoscope to Explore Light, Optics, and How Telescopes Work

### An NGSS Storyline Approach to Classroom Instruction

by Brian Kruse (Astronomical Society of the Pacific)

When Galileo turned his telescope to the night sky over 400 years ago, he set into motion a fundamental change in the way science is done. Galileo did not invent the telescope, that honor is generally given to Hans Lippershey, a Dutch-German spectacle maker, who filed for a patent on what we now call the refracting telescope in 1608. It is even possible Lippershey was not the first to use a combination of lenses in a device to see distant objects more clearly. We do know Galileo made improvements to the telescope, and turning it to the heavens made a series of observations that changed our view of Earth's place in the greater cosmos. His telescopes were not particularly good compared to modern instruments, providing magnifications of up to 30-times, though with a fairly narrow field of view. Other innovators may have turned to the sky before Galileo, but he did something remarkable: he systematically recorded his observations, and published the results of what he discovered and inferred about “how the heavens go.”

The International Year of Astronomy was convened in 2009 to celebrate the 400<sup>th</sup> anniversary

of Galileo's iconic observations. To help support educational efforts surrounding this celebratory year, a few astronomers designed a modern version of Galileo's telescope, and the Galileoscope was born. Designed for ease of assembly, and disassembly, the Galileoscope features optics better than those Galileo used. Two eyepieces are included, one with a modern version of the Keplerian design providing a magnification of 25-times, and a field of view of 1.5-degrees. The other mimics the eyepiece lenses Galileo would have experienced, with a magnification of 17-times, and field of view of less than 0.5-degree. Using the Galilean eyepiece with the Galileoscope will give the user a real appreciation of what Galileo was able to accomplish.

As a tool in modern classrooms, the Galileoscope (Figure 1) provides a glimpse into how telescopes work, with its components useful for investigating how light behaves and images are formed. Telescopes of all types and sizes are able to provide a window to astronomical phenomena, both within and beyond the solar system. In some ways, the telescope itself is a phenomenon learners can investigate. The Galileoscope can help bring the

workings of giant telescopes into the classroom, providing a platform for a variety of explorations into how light and optics work together to form images in our telescopes and cameras, and in our own eyes.



Figure 1: The Galileoscope

Telescopes have two important functions:

- To gather light, and
- To form an image

An important caveat to dispense with right away is the primary goal of using a telescope is NOT to magnify. Of more importance is to resolve objects that are very faint. A typical backyard telescope may only use magnifications from about 30-power up to 80-power. Many objects even millions of light years away are larger than the full moon in the sky. For example, the Andromeda Galaxy is 2.5 million light years away ( $5.9 \times 10^{13}$  times farther than the moon), and takes up over  $3^\circ$  of the sky compared to  $0.5^\circ$  for the moon. Only under the darkest skies are we able to see this galaxy with the unaided eye, and yet it is far larger than the bright and close by moon. (See Figure 2).

Galileo was the first person known to systematically study astronomical phenomena unavailable to the unaided eye. He was among the first to employ

observation, analysis, interpretation and argumentation from evidence in the service of scientific discovery - the same very same practices used by every scientist today and promoted by the Framework for K-12 Science Education and Next Generation Science Standards (NGSS).

Investigating how Galileo's telescope works provides an opportunity to engage students in an NGSS storyline, with a coherent sequence of investigations that give them an in-depth understanding of the how they work to provide images of astronomical phenomena. Basically, an NGSS storyline incorporates an Anchoring Phenomena, something students are able to observe for themselves, which can lead to a Driving Question for the overall investigation. A set of sub-questions lead to investigations which move

into student development of an initial model to explain the phenomena, which may prompt further questions and investigations to refine the model. Eventually, the students come to a point where they form a final consensus model explaining the phenomena. At any time during the instructional sequence, it is recommended to probe for student understanding using a variety of formative assessment strategies.

This is what such a storyline may look like:

## **Anchoring Phenomena and Driving Questions**

### **Anchoring Phenomena:**

- Everyone in a room can see the same details, why is that possible?
- Objects in the night sky look like points of light.
- Some objects appear fuzzy.
- Looking through binoculars or a telescope reveals objects and details unseen with the unaided eye.
- When I squint at a fuzzy object it appears to get sharper, why does this happen?

### **Potential Driving Questions:**

- What are the points of light in the night sky?
- How can I make the points of light brighter so I can see them better?
- How can I make the points of light larger so I can see them better?
- Why don't the points of light have any color?
- Why are some of the points of light brighter than others?



*Figure 2: Composite image of the Andromeda Galaxy and the Moon (Image: Robert Sparks)*

## Sequence of Investigations

### Exploration 1: How Do Our Eyes Form Images

The beginning of an investigation of telescopes may begin before or after a culminating event where learners have the opportunity to make observations with large telescopes. As with any new unit, it is best to start with an assessment of what prior ideas students are bringing to the table, such as with a probe for student ideas about the purposes of using a telescope, or how their eyes form images. Many people, including adults, hold the misconception telescopes are primarily used to magnify distant objects, so probing for this idea is important.

In a classroom, or any group of learners, how many people are able to see the educator's nose? Barring any physical obstructions, everyone in the room is able to see each other's noses, and not just the educator's. Much as a bursting water balloon splashes in all directions, the room is literally awash with light reflecting off every possible surface.

- Have learners sketch their ideas of what is going on, where the light comes from, and how we are able to see everything.

Telescopes, as well as other optical devices such as cameras share some common characteristics with our eyes.

- Brainstorm the characteristics and similarities between a variety of optical devices.

The two basic properties are each device has a hole where the light comes in, and there is some sort of surface on which an image is formed. Ask students to identify these characteristics in various optical devices. In a camera, the hole is the aperture in the lens, allowing light to reach either the film or a digital sensor where an image is formed. The eye has a pupil and a retina. When in a bright

environment, the pupil contracts, narrowing the size of the aperture, thus restricting the amount of light entering the eye.

- Using a set of index cards with various sizes of holes in them, have students read some text, making a comparison of a) the sharpness of the text, and b) how bright the image is when reading the text. Have learners who normally wear glasses take them off for this exploration.

Introduce a piece of white poster board, and ask why the board is white. Make the suggestion the

white board is a combination of the multitude of images of everything in the room, including everyone's noses. (See Figure 3.)

- Ask learners to think about how they might test that idea, and suggest investigations they might undertake.

To simplify things, turn on a red compact fluorescent light plugged into a power strip. Turn off the overhead lights. What color is observed on the white poster board?

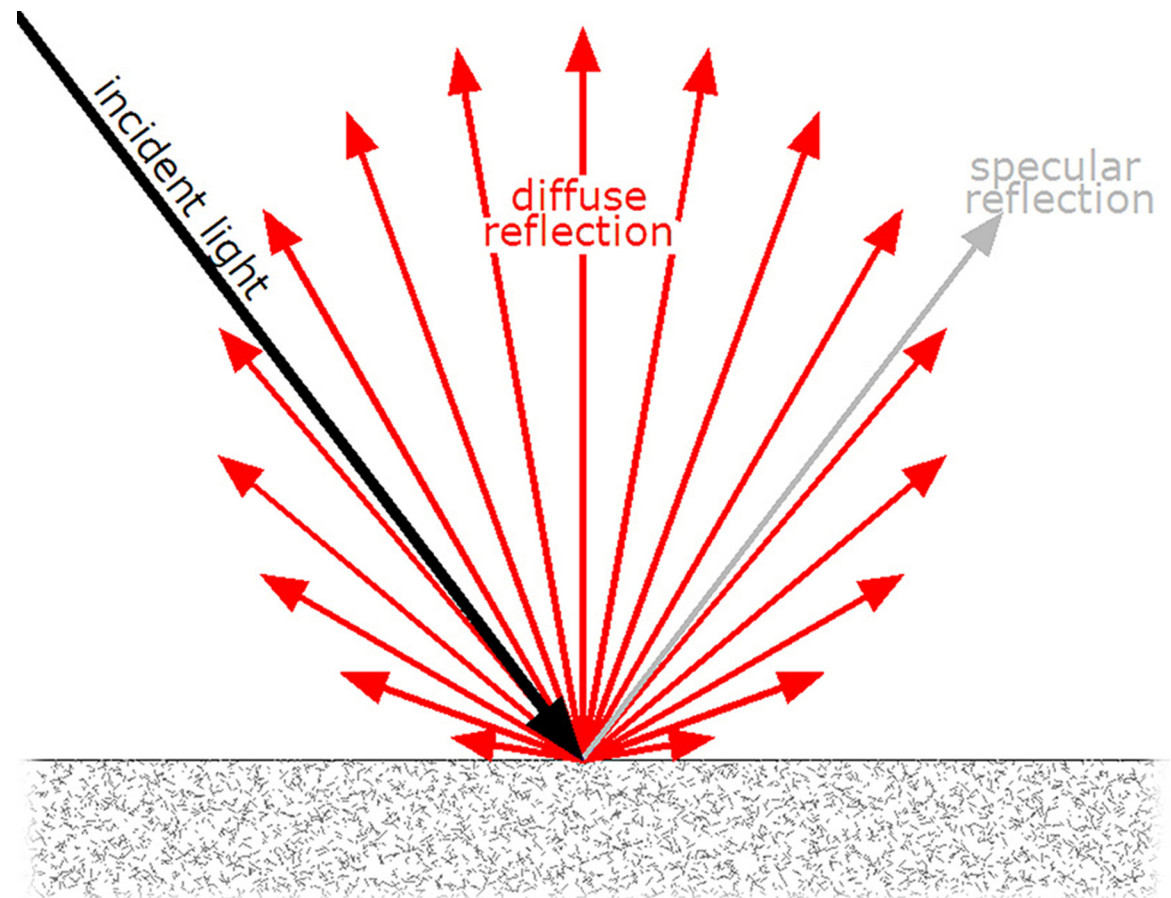


Figure 3: Drawing showing diffuse reflections from a surface (Image: GianniG46 at Wikimedia, CC BY-SA 3.0)



## Exploration 2: Modeling Image Formation

One can create a simple model of the eye or other optical device using a tube, a piece of aluminum foil, and a piece of wax paper. Wrap the foil around and covering one end of the tube, securing it with a rubber band. Do the same on the other end with a piece of wax paper. Tracing paper, or vellum also works well. If you are unable to make the room sufficiently dark, the use of a piece of black construction paper to make an extended tube on the end with the wax paper screen will work to block most of the ambient light.

- Make a single hole in the aluminum foil using a quick poke with a pushpin to make sure the hole doesn't get too large. (See Figure 4.)



Figure 4: Making a pinhole projector (ASP/Joycelin Craig)

- Point your model eye at the single red light and look at the wax paper screen, describe what you observe.
- Educator: move the light from left to right, have the learners observe and describe what happens.
- Move the light up and down, observe and describe what happens.
- Add a blue light to the power strip. (See Figure 5.) At this point it is advantageous to ask learners to predict what they might observe when you repeat the movements of the lights. Have learners observe and describe what happens. (See Figure 6.)

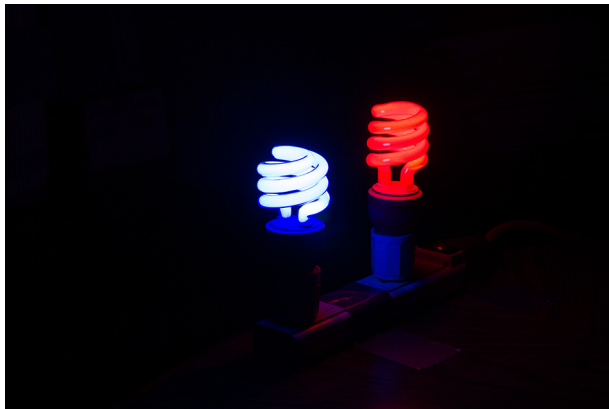


Figure 5: CFL bulbs in a power strip (Image: ASP/Brian Kruse)



Figure 6: Projected image through a single pinhole (Image: ASP/Brian Kruse)

- Have learners sketch what they think is taking place when the light passes through the pinhole. To help them visualize what is taking place, they can model what is happening using string or bamboo skewers to trace the light as it goes through the pinhole. (See Figure 7.)

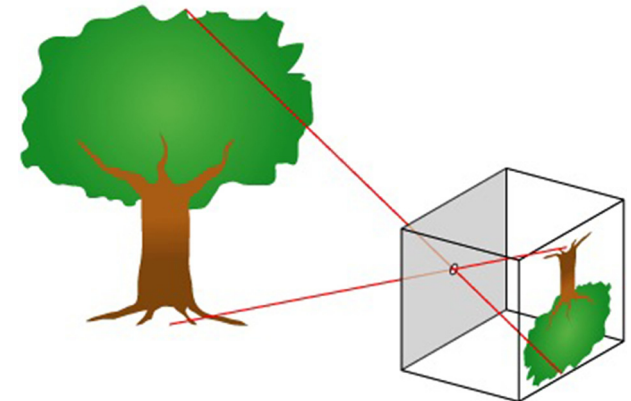


Figure 7: Drawing showing the formation of an image in a pinhole viewer (Image: DrBob at Wikimedia, CC BY-SA 3.0)

- Learner descriptions of what they observe about the images of the lights may include: the projected images are upside down (inverted), and left right reversed. Probe: do they think the same thing is what is happening in their eyes?



Figure 8: A group of educators looking through their pinhole viewers (Image: ASP/Joycelin Craig)

### Exploration 3: What Happens When There is more than One Hole

Using the same materials as in Exploration 2, have the students predict what they think they might observe if there was a second hole in the foil.

- Make a second hole in the aluminum foil with a pushpin. Have learners observe and record what they observe. They should pay particular attention to the sharpness and brightness of the individual images, as well as their orientation.
- Extending the model, have learners predict what would happen if you add more holes to the aluminum foil.
- Have students incrementally add additional holes, one, two, four, a dozen, then lots of holes. Have them observe and record as before, making note of the number of images in relation to the number of holes, and the sharpness and brightness of the individual images. (See Figure 9a and Figure 9b.)
- At this point it is important to have students notice what happens when individual images overlap. What happens to the sharpness and brightness of the images when they overlap? When the number of overlapping images increases?

This brief investigation will lead directly into the next.

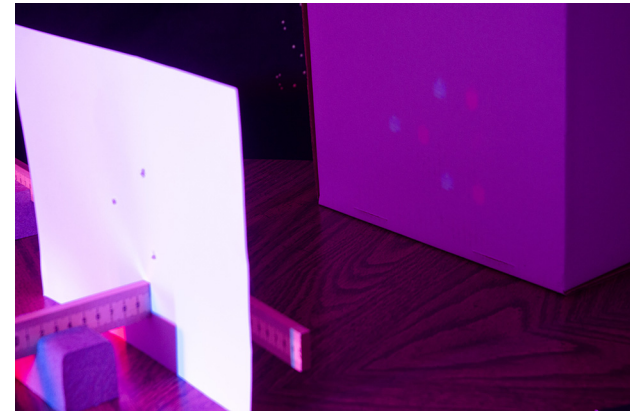


Figure 9a: Projected images through three pinholes (Image: ASP/Brian Kruse)



Figure 9b: Projected images through many pinholes (Image: ASP/Brian Kruse)



#### Exploration 4: What Happens as the Holes Get Larger

Review with the students what they observed in the previous Explorations, asking them to use their observations as evidence to explain the phenomena of images that are upside down and left-right reversed. Ask what they observed when there were a great many holes, and what happened to the quality of the images. They may note the images became fuzzy when they overlapped, with the effect increasing when the number of overlapping images increased. They may also note all of the images are similar in their brightness, and all of them are inverted and left-right reversed.

- Ask students to predict: what do they think they might observe if a single hole incrementally got larger.
- Take a fresh piece of aluminum foil and replace the one from the previous Explorations. As before, poke a single hole in foil, observe and record as before. Learners should observe the same thing they saw in Exploration 2.
- Increase the size of the hole by moving the pin around in the hole, or using a pencil or pen. Observe and record, paying particular attention again to the sharpness and brightness of the image. (See Figure 10.)

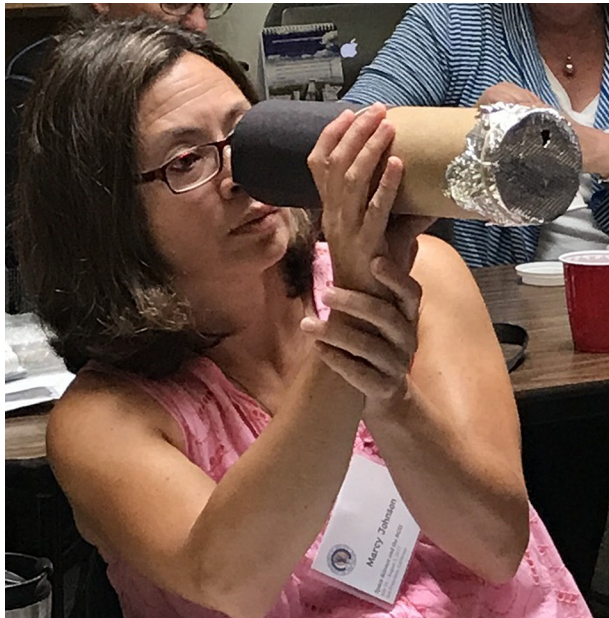


Figure 10: Using a pinhole viewer with an enlarged pinhole  
(Image: ASP/Joycelin Craig)

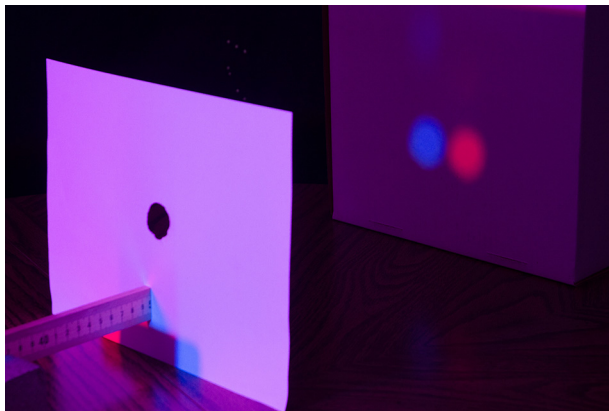


Figure 11: Projected images through a single large pinhole  
(Image: ASP/Brian Kruse)

- What happened to the image? It got fuzzier, and brighter, though it was still inverted and left-right reversed.
- Predict what might happen as the hole is enlarged further. Observe and record as in the last step.
- Incrementally increase the size of the single hole, until a large, thumb-sized hole is in the foil, observe and record.
- What was observed? Compare the size, sharpness, and brightness of the images formed when the hole is incrementally increased in size. How does the image formed with a single very large hole compare with that from many overlapping images formed from many holes? (See Figure 11.)
- What if the hole was the size of the tube, or no tube at all, how does the image on the screen compare to lights shining on the white poster board as observed in Exploration 1?

Learners may conclude the following: the bigger the hole, the brighter the image, though at the same time the image is fuzzier. At this point they have enough evidence to argue the contention made in Exploration 1 about how the white poster board is in essence a set of myriad overlapping images of the lights. Learners may also, with prompting, develop a mental model of what is happening to the image their eyes form under varying light conditions as their pupils get larger and smaller. As an extension of this last point, they might brainstorm:

- What are some devices where the aperture changes in size, letting in more or less light, and how does that affect the images they form?

## Exploration 5: If Big Holes Make Fuzzy Images, How do Telescopes Make them Sharp

In the previous explorations, learners discovered a projected image will get fuzzier and brighter when the pinhole gets larger. So, how do telescopes create a sharp image even with a huge aperture? How do our eyes make a sharp image when the iris changes the size of the pupil allowing a variable amount of light to form an image on the retina? The clue comes from the concept developed earlier that a fuzzy image from a large hole (or no hole at all) is effectively a set of many overlapping images.

An introductory discussion for this Exploration might explore the question:

- What fills the opening of the pupil; the end of a Galileoscope?
  - A lens! (See Figure 12)



Figure 12: The objective lens in the aperture of a Galileoscope (Image: ASP/Brian Kruse)

Which brings up the question:

- What does a lens do to the light coming through the pinhole?

In this Exploration, learners will have the opportunity to find out. In this Exploration, it will also help to set aside the pinhole viewer, replacing it with a piece of white poster board or other stiff paper. The use of a tracing paper (or vellum) screen will also prove effective. Some things they might try out include the following:

- Take a thin double convex lens and put it so it covers the thumb-sized hole in the aluminum foil. Observe what happens to the image on the screen, paying particular attention to the number of images, their orientation, and how sharp and bright they appear. Also note what happens when the distance between the lens and screen changes. Record your observations. (See Figure 13.)

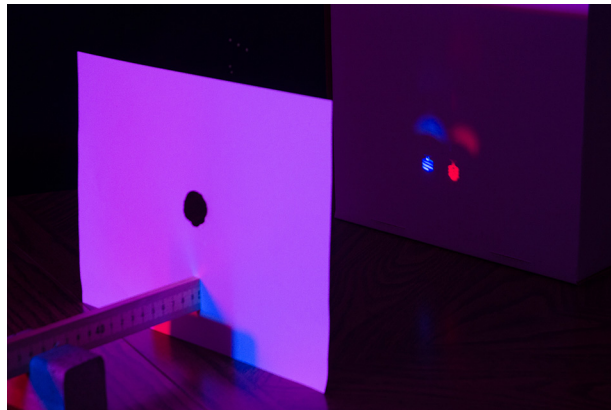


Figure 13: Projected images through a single large pinhole with double convex lens immediately behind the pinhole (Image: ASP/Brian Kruse)

Students may have noted a single, bright image was formed when the lens was placed in the hole. The image is inverted, and left-right reversed as it was with the pinhole images. They also will have had to change the distance from the lens to the screen until the image comes into focus. The distance between the lens and the image is an important property of a

lens called the focal length, with the image formed at the focal point. The actual focal length of a lens is measured with a point light source at a theoretical infinite distance away. Closer light sources may actually appear to have a dimension, resulting in light rays that are not parallel. Thus, to focus an image, the distance between the screen and the lens is shortened or lengthened as needed. To further explore the lens property of focal length, have the learners try using a thicker double convex lens, making a comparison between it and the thinner lens used above. (See Figure 14.) They should record the following observations: focal length (distance between the lens and the focused image), the size and orientation of the image, and the sharpness and brightness of the image. They should also try using a concave lens to see if it is able to form a projected image.

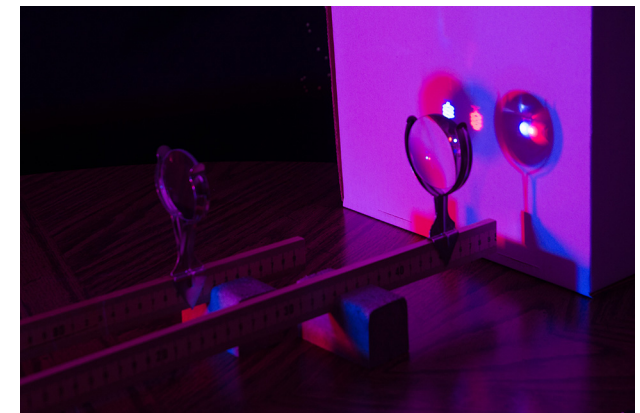


Figure 14: Projected images through two double convex lenses with different focal lengths onto a screen (Image: ASP/Brian Kruse)



- During this Exploration, learners should have the opportunity to model what they think is happening to the light as it passes through a lens. They can do this through the use of string to trace the path of light from a light source within the room, to and through the lens, thence to the screen where the projected image appears. Bamboo skewers are also useful to help them visualize what is taking place. A small piece of foam with several skewers poked in to form parallel rays can help with this visualization, particularly since they can curve the foam to model the convex and concave shapes of a lens, then observe what happens to the bamboo light rays on the side away from the light source. This will also help them understand how a thicker lens with greater curvature will have a shorter focal length than a thinner lens. The foam and skewer model also will help demonstrate how a convex lens results in converging light rays, and a concave lens in diverging light rays. (See Figure 15a through Figure 15d.)

Additional things to investigate during this Exploration include:

- Explore what happens when the lens is placed on the screen side of a single small pinhole, then incrementally increase the number of pinholes until there are a great many. This serves to demonstrate and reinforce the idea of how a lens takes multiple images and organizes them into a single image. The single image is sharp, and brighter than any individual image since it combines the light of all the images.



Figure 15a: Bamboo skewers in foam modeling the passage of light rays through a flat piece of glass (Image: ASP/Brian Kruse)

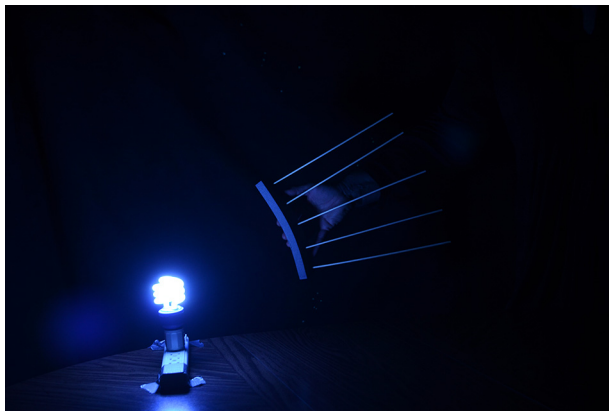


Figure 15b: Bamboo skewers in foam modeling the passage of light rays through a concave lens, resulting in diverging light rays (Image: ASP/Brian Kruse)



Figure 15c: Bamboo skewers in foam modeling the passage of light rays through a convex lens, resulting in converging light rays (Image: ASP/Brian Kruse)

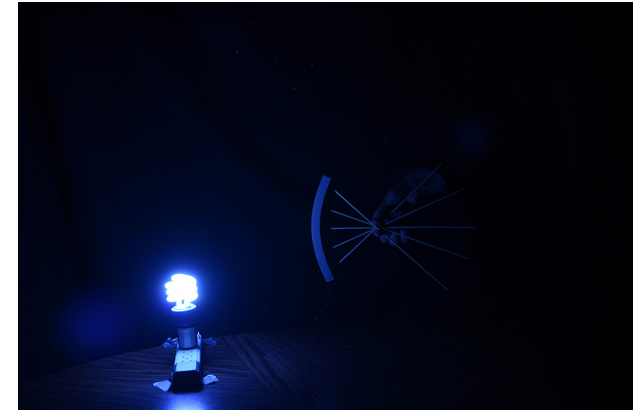


Figure 15d: Bamboo skewers in foam modeling the passage of light rays through a convex lens with shorter focal length, resulting in converging light rays (Image: ASP/Brian Kruse)



A particularly impressive demonstration involves taking a sheet of paper and poking 30 or so pinholes into a circular area with diameter of 10cm. Holding the paper with the pinholes 20 cm from a piece of white poster board, project a group of images onto the poster board. While observing the pinhole images, place a 10 cm double convex lens with a focal length of 20 cm on the screen side of the paper with the pinholes, allowing it to cover all of the pinholes. (See Figure 16a and Figure 16b.) Before introducing the lens, have students predict what they think they will observe, then have them observe what happens to the 30 or so images when the lens is introduced.

Extend the examination of the phenomena of the lens organizing the light from the 30 or more pinholes into single bright images of the lights.

- While projecting the image as in Figure 16b, have learners predict what they might observe if you removed the paper with the pinholes. Remove the paper with the pinholes, leaving the lens in place. Observe and record your observations.

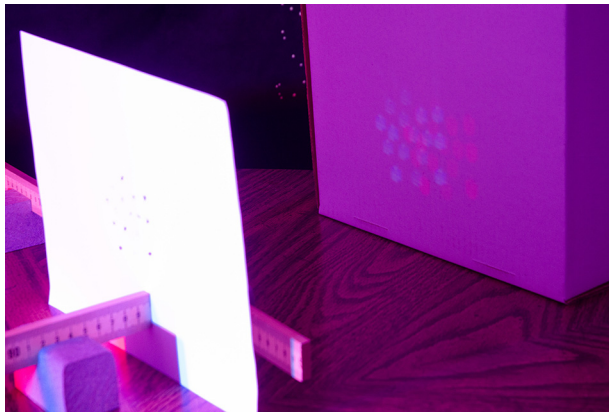


Figure 16a: Projected images through many pinholes  
(Image: ASP/Brian Kruse)

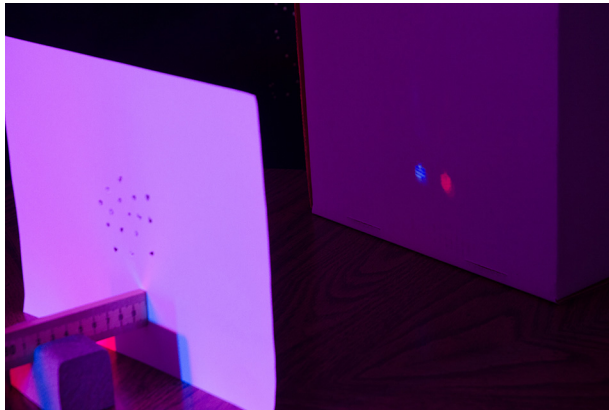


Figure 16b: Projected images through many pinholes and a convex lens immediately behind the pinholes  
(Image: ASP/Brian Kruse)

### Exploration 6: But, I Thought Lenses Were for Making Images Larger?

One of the great misconceptions about telescopes is they are designed to magnify the images of distant objects. While many distant objects are rather small, as noted in the introduction to this article, many objects are quite large, though very dim. Thus, to adequately observe them, astronomers need an instrument to collect a lot of light, making the objects brighter. Many manufacturers will advertise small telescopes as magnifying up to 400 power, which is not useful at all with even a giant telescope. Some magnification is necessary to bring out many of the finer details of even the largest objects in the night sky.

Most people are familiar with using lenses to magnify, perhaps from using magnifying lenses in life science activities, or to see tiny print in a document. (See Figure 17.) In this Exploration, learners will have the opportunity to observe and think about a configuration of object, lens, and their eye to form a magnified image.

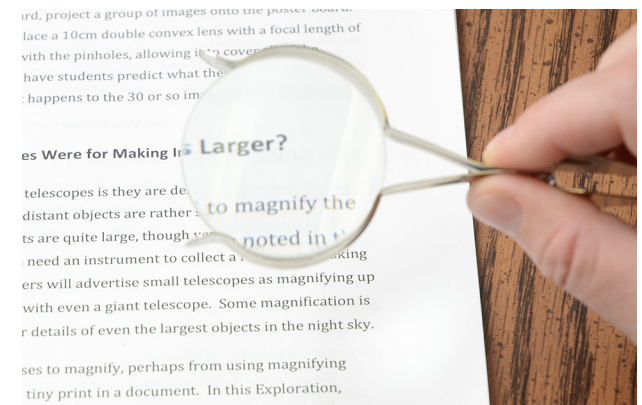


Figure 17: A convex lens used as a magnifier  
(Image: ASP/Brian Kruse)

- Have learners try using the various lenses to magnify something easily observed, such as the print on a document. They should pay particular attention to the distance between the document and the lens, the distance between the lens and their eye, and the orientation of the image. They can then make a comparison between the images the lenses were able to project on to a screen, and the magnified image they observe.

For a lens to act as an effective magnifier, the object observed is less than one focal length from the lens. The distance between the lens and the eye is also less than one focal length. This also results in an image that has a normal orientation: right side up, and not left-right reversed.

For more advanced learners, this is a good opportunity to explore and discuss the difference between a real image and a virtual image. The projected image on to a screen is a real image, while the image observed when using a lens as a magnifier is a virtual image. Learners may find it useful to use the foam and bamboo skewers to model what is taking place, and the relationship between the lens and its focal length, the object under observation, and their eye.

### Exploration 7: How Do Lenses Work Together in a Telescope?

Up to this point, the Explorations have looked at how individual lenses can modify an image to either project or magnify the object under investigation. In a refracting telescope, such as your Galileoscope, there are two sets of lenses that work together to form the final image seen through the eyepiece. In this Exploration, learners will create combinations of lenses to model how a telescope works.

This Exploration will require the use of a different screen for the projected images from a lens. While previous Explorations used a piece of white poster board or paper for a screen, this one will use a screen made of tracing paper (or vellum). This allows for the viewing of the projected image from either side.

- Set up a thin double convex lens to project an image of a distant light source on to the screen. Focus the image so it is sharp, and viewable from both sides of the screen. (See Figure 18.) Remember to note the orientation of the image on the screen.
- Using a different lens as a magnifier, observe the image on the screen. Are the learners able to create a magnified image of the distant light? Have them observe the orientation of the magnified image, as well as the sharpness and brightness, and what they have to do to bring the image into focus.

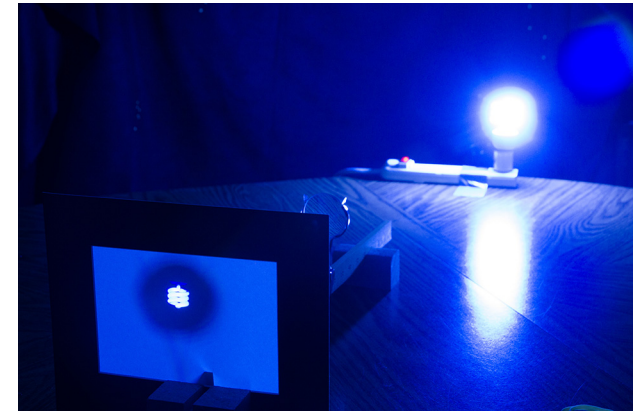


Figure 18: Projected image through double convex lens onto a tracing paper screen (Image: ASP/Brian Kruse)

- Working in teams, have one learner observe the magnified image of the distant light. While the image is centered in the second lens and forming a straight line between the light, first lens, and the projected image, have the other learner remove the screen from between the lenses. What happened to the image the first person was observing through the lens acting as a magnifier? If all went accordingly, the magnified image remained behind, even though the screen was no longer there!

What the learners constructed in the last step was a simple telescope where two lenses were used to create an image: the first lens organized the light into an image, the second was used to magnify the image to bring out smaller details. To focus the “telescope,” the distance between the lenses is adjusted slightly until the observed image of a distant object is sharp.



## The Galileoscope

If one were to enclose the open telescope created in the last Exploration in a tube, it would look very much like a Galileoscope. The power of using a Galileoscope in an instructional sequence investigating light and optics is they are easily disassembled so learners can examine the two sets of lenses, and how the instrument is focused to form a sharp image when looking through the eyepiece. The Explorations in this article detailed a potential sequence for learners to go through as they incrementally build a model of how a telescope, and other optical devices form images.

With a functioning Galileoscope, learners can then observe and investigate a variety of distant celestial, and terrestrial objects. The Moon and larger planets such as Jupiter and Saturn are great targets for observing. Recreating Galileo's iconic observations of the changing positions of the moons of Jupiter, and the changing phases of Venus are possible with the Galileoscope. Alternatively, in lieu of making observations of the objects themselves outside of school hours, the educator can place printed copies of images of the moons of Jupiter and phases of Venus on one end of a large open space, with Galileoscopes set up at an appropriate distance so the size in the eyepiece is similar to the actual objects.

## Acknowledgements

This article is funded in part by the Gordon and Betty Moore Foundation. This funding supported the development of a series of professional development opportunities and resources for educator use in both formal and informal settings.

A very special thank you to Robert Sparks from the National Optical Astronomy Observatory (NOAO), for the contribution of an image, and his work in developing many of the activities adapted and described in this article.

Thanks also to Eric Muller and Linda Shore for their development of the pinhole sequence at the Exploratorium.

## Next Generation Science Standards

### Performance Expectations with Disciplinary Core Ideas:

- 1-ESS1-1: Use observations of the sun, moon, and stars to describe patterns that can be predicted.
  - DCI ESS1.A: The Universe and its Stars
    - Patterns of the sun, moon, and stars in the sky can be observed, described, and predicted.
- 1-PS4-2: Make observations to construct an evidence-based account that objects in darkness can be seen only when illuminated.
  - DCI PS4.B: Electromagnetic Radiation
    - Objects can be seen if light is available to illuminate them or if they give off their own light.
- 1-PS4-3: Plan and conduct investigations to determine the effect of placing objects made with different materials in the path of a beam of light.
  - DCI PS4.B: Electromagnetic Radiation
    - Some materials allow light to pass through them, others allow only some light through and others block all the light and create a dark shadow on any surface beyond them, where the light cannot reach. Mirrors can be used to redirect a light beam.
- 4-PS4-2: Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.
  - DCI PS4.B: Electromagnetic Radiation
    - An object can be seen when light reflected from its surface enters the eyes.

- 5-ESS1-1: Support an argument that the apparent brightness of the sun and stars is due to their relative distances from the Earth.
  - DCI ESS1.A: The Universe and its Stars
    - The sun is a star that appears larger and brighter than other stars because it is closer. Stars range greatly in their distance from Earth.
- 5-ESS1-2: Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.
  - DCI ESS1.B: Earth and the Solar System
    - The orbits of Earth around the sun and of the moon around the Earth, together with the rotation of Earth about an axis between its North and South poles, cause observable patterns. These include day and night; daily changes in the length and direction of shadows; and different positions of the sun, moon, and stars at different times of the day, month, and year.
- MS-ESS1-1: Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.
  - DCI ESS1.A: The Universe and its Stars
    - Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.
- DCI ESS1.B: Earth and the Solar System
  - This model of the solar system can explain eclipses of the sun and the moon.
- MS-ESS1-2: Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.
  - DCI ESS1.A: The Universe and its Stars
    - Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe.
  - DCI ESS1.B: Earth and the Solar System
    - The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them.
    - The solar system appears to have formed from a disk of dust and gas, drawn together by gravity.
- MS-ESS1-3: Analyze and interpret data to determine scale properties of objects in the solar system.
  - DCI ESS1.B: Earth and the Solar System
    - The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them.
- MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
  - DCI PS4.B: Electromagnetic Radiation
    - When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.
    - The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g. air and water, air and glass) where the light path bends.
    - A wave model of light is useful for explaining brightness, color and the frequency-dependent bending of light at a surface between media.
    - However, because light can travel through space, it cannot be a matter wave, like sound or water waves.
- HS-ESS1-4: Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
  - DCI ESS1.B: Earth and the Solar System
    - Kepler's laws describe common features of the motions of orbiting objects, including the elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.



## Science and Engineering Practices Emphasized in These Investigations:

- Analyzing and Interpreting Data
- Developing and Using Models
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence

## Crosscutting Concepts Emphasized in These Investigations:

- Patterns
- Cause and Effect: Mechanism and Explanation
- Scale, Proportion, and Quantity
- Structure and Function
- Systems and System Models

## Resources

- [Exploratorium Pinhole page](#)
- [Teaching With Telescopes](#)
- [Galileoscope observing guide](#)
- [Galileoscope activity manual](#)
- [Moons of Jupiter activity](#)
- [Revolutionary Venus activity](#)

## Materials List for the Galileoscope Storyline

### Materials for each pair learners:

- 1 plastic film can
- 2 index cards
- 1 push pin
- 1 sheet black construction paper
- 2 4x4 inch squares wax paper
- 4 - 8 4x4 inch squares aluminum foil
- 1 three-inch diameter tube at least ten-inches long
- other miscellaneous tubes of varying diameters and lengths
- several rubber bands
- string or twine
- tailor's tape or other flexible measuring tool
- 1 - 2 double-convex lenses of varying focal length (e.g. 20cm and 7.5cm)
- 1 - 2 concave lenses (either double-concave or plano-concave) of various focal length
- white poster or railroad board approximately 18x24 inches
- vellum or tracing paper attached to a cut matte frame with opening of 5x7 inches
- extension cord and power strip
- Red, Green and Blue CFL bulbs in socket plug adapters
- 5 bamboo skewers
- 1 piece flexible foam approximately 1x8 inches