*Physics > Big idea PSL: Sound, light and waves > Topic PSL3: Making images*

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| **Key concept (age 11-14)** |
| **PSL3.2: Refraction and lenses** |

**What’s the big idea?**

A big idea in physics is waves because it is the key to explaining how energy can be transferred from one object to another object by radiation, even when the objects are not touching. Waves carry information that can be detected by humans or manufactured detectors. Understanding waves helps us to communicate, explore the universe, and transfer energy to where we want it.

**How does this key concept develop understanding of the big idea?**

This key concept helps to develop the big idea by building on the idea that objects are seen as if light from them is not deviated before it enters our eyes, in order to understand the effects of refraction and how refraction enables converging lenses to focus light and form clear images.

****The conceptual progression starts by checking understanding that light can refract as it moves between two transparent media. It then supports the development of idea that the sharper the angle at which light hits a glass block, the more it refracts, in order to enable understanding of how a converging lens can produce a focused image.

**Using the progression toolkit to support student learning**

Use diagnostic questions to identify quickly where your students are in their conceptual progression. Then decide how to best focus and sequence your teaching. Use further diagnostic questions and response activities to move student understanding forwards.

**Progression toolkit: Refraction and lenses**

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| **Learning focus** | All light from each point of an object that passes through a converging lens is bent (refracted) to a corresponding point in a sharp image. | | | | |
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| **As students’ conceptual understanding progresses they can:** | **C o n c e p t u a l p r o g r e s s I o n** | | | | |
| Recall that light can change direction (refract) when it passes across a boundary between transparent media. | Describe how the angle light passes across a boundary between two transparent media affects how much it is bent (refracted). | Explain why water can appear shallower than it really is. | Explain how the shape of a lens enables it to focus light. | Explain how light from an object can be focused by a converging lens to form a sharp image. |
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| **Diagnostic questions** | Magic finger | Bending light | How deep? | Lens bend | Through a lens |
|  |  |  |  |  |  |
| **Response**  **activities** | Refraction | | On the bottom | Getting focused | |
| Seeing the bottom |  | Half a lens |

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| --- | --- | --- | --- | --- |
| **Magic finger** | **Bending light** | **How deep?** | **Lens bend** | **Through a lens** |
|  |  |  |  |  |
| Simple multiple choice | Two-tier multiple choice | Simple multiple choice | Two-tier multiple choice | Confidence grid |
| **Refraction** | **On the bottom** | **Seeing the bottom** | **Getting focused** | **Half a lens** |
|  |  |  |  |  |
| Clarifying - practical | Predict, explain; observe, explain | Talking heads | Clarifying - demonstration | Predict, explain; observe, explain |

**What’s the science story?**

*Refraction*

When a light beam passes from one transparent medium into another, at an angle to the boundary between the media, its direction changes. This is called refraction.

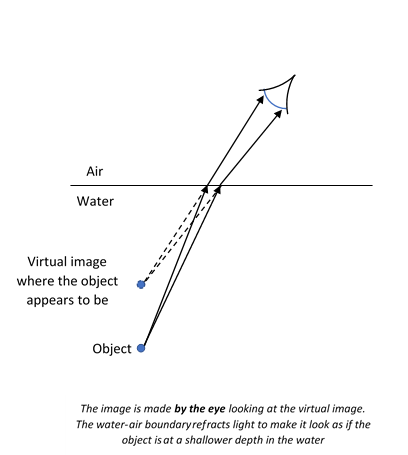
When we look at an object through a transparent medium, its image is not in the same place as the object, because of refraction of light at the boundary between the medium and air. For example, the image of an object under water is closer to the surface than the object really is. This can be explained by drawing two light rays from a point on the object that are refracted towards the eye, and identifying the point from which these appear to have come.

A convex lens refracts parallel light beams so that they meet at a point, called the focus. The thicker the lens, the closer the focus is to the centre of the lens.

A convex lens can form an image of an object. Many rays go from each point on the object to the lens, and all are brought together at a single point on the image.

**What does the research say?**

*Refraction*

A common strategy for teaching students about refraction is to demonstrate examples of refraction phenomena and to explain the observations using ray diagrams that show how light is bent by glass blocks. In this approach students may use a ray box to explore how light travels through a parallel sided glass block to understand the nature of refraction. They change the angles of incidence to establish: a change of direction only occurs at an interface; light travelling perpendicular to the interface is not refracted; and light bends towards the ‘normal’ when entering more dense medium and vice versa (Tear, 2011).

In order to understand how ray diagrams explain refraction: students first need to understand that light is emitted in all directions from each point of the source (Rice and Feher, 1987; Dedes and Kanstantinos, 2007; Galili and Hazan, 2000; Andreou and Raftopoulos, 2011); and the idea that rays *represent* the direction light travels in (Andreou and Raftopoulos, 2011).

A *virtual image* formed by refraction is not really an image – it is not a *real* image. As with observing reflections in a plane mirror, it is important to recognise that the observer is an inherent part of the optical system (Galili and Hazan, 2000; Andreou and Raftopoulos, 2011) and that the real image which we observe is formed on the retina of the eye. As with plane mirrors, it is helpful to use dashed, ruled lines to work out where each ray of light appears to come from; it is here that the object is seen to be because the image formed on the retina is exactly the same as if the object *were* here. The ray diagram shown here is used ‘to find where the object appears to be’.

Measuring angles of incidence and refraction and constructing accurate, labelled ray diagrams is normally carried out in later stages of learning at ages 14-16 (Department for Education, 2013; Department for Education, 2014). At ages 11-14 qualitative ray diagrams are usually sufficient to develop understanding.

*Lenses*

Often lenses (glasses, contact lenses) have one side that is curved in and one that is curved out, so describing lenses as concave or convex is not always helpful. It is more useful to describe lenses by their effect on light as converging or diverging (Tear, 2011).

Students often think of an image as a physical replication of an object which can travel, remain still or turn as a whole. They may ascribe active powers to mirrors, lenses or pinholes to manipulate images in order to explain how they appear in a particular way on a screen (Galili and Hazan, 2000). For example, Galili and Hazan (2000) found that over half of 14- to 15-year olds (n=64) thought that when a converging lens is removed, the inverted image it forms is replaced by an image the correct way up. These students are applying the misunderstanding that a lens actively flips an image that is already there.

Students can use ray boxes with three slits to observe how cylindrically curved lenses refract light rays (Tear, 2011). This is helpful in showing how light rays are refracted (bent) by a lens. Light is refracted differently from each part of the lens because it hits the lens at different angles. It has been suggested that this learning point can be made clearer by showing how a number of prisms can be used to refract light in the same way as the lens (Ziegler and Priemer, 2015).

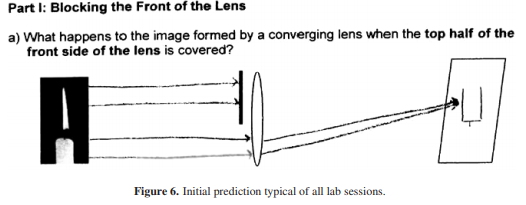
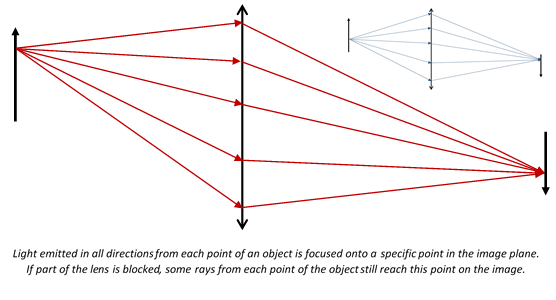


Image from Bryan and Slough (2009) showing a common student explanation for the misunderstanding that covering half of a lens results in half the image disappearing.

Bryan and Slough (2009) found it common for students aged 12-15 (n=73) to draw single parallel rays of light from each point of an object in order to explain a prediction that covering half of a lens results in half the image disappearing. Part of the reason students form this misunderstanding may be due to their being shown how a lens refracts three parallel rays of light from a ray box.

The misunderstanding that covering half of a lens results in half the image disappearing is held by the majority of students of all ages (Goldberg and McDermott, 1987; Galili and Hazan, 2000; Ceuppens et al., 2018; Favale and Bondane, 2013).

Bryan and Slough (2009) tested a range of computer simulations designed to improve understanding of image formation with students, in order to identify features that improved learning. They found that the number of rays included from each point did not have an effect on student predictions about image formation when part of a lens is covered. By contrast simulations in which rays were shown originating from different parts of the object had a positive effect on student understanding.

The diagram shown here illustrates rays of light form two points on an object being focused by a converging lens to corresponding points on the image. If part of the lens is blocked off then it can be seen that some rays of light from each point of the object will still be able to be focused by the lens to form part of a complete image.

**Guidance note**

Refraction is often taught to students aged 11-14 using ray boxes and geometric ray diagrams, which often introduces the misunderstanding that just one light ray from each point of the object is focused onto each point of an image. It is more fruitful to centre teaching on the key ideas of image formation that are commonly overlooked. A suitable progression of how an image is formed by a converging lens might start with the idea that rays *represent* the direction light travels in; use the idea that light moves out from each point of an object in *all directions*; and finish with *all* the rays which hit a converging lens from each point of an object being refracted by the lens to a single focused point in the image.

Measuring angles of incidence and refraction and constructing accurate, labelled ray diagrams is normally carried out in later stages of learning at ages 14-16. At ages 11-14 qualitative ray diagrams are usually sufficient to develop understanding.

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