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

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| **Key concept (age 11-14)** |
| **PSL3.1: The ray model of light to explain images** |

**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 knowledge that light rays represent the movement of light in straight lines, in order to develop students’ understanding of how an image forms in a pin-hole camera, and why an object’s reflection in a plane mirror appears to be behind the mirror.

****The conceptual progression starts by checking understanding that light rays represent the direction in which light moves. It then supports the development of the idea that light is emitted in all directions from each point of an illuminated source, in order to enable understanding of the formation of images with a pinhole and the nature of reflections formed in a plane mirror.

**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: Explaining images made by a pinhole**

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| **Learning focus** | Only some light rays from each point of an illuminated object can pass through a pinhole, hitting a screen at distinct points to make an inverted 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** | | | | |
| Describe what a light ray represents. | Describe the direction in which light travels from a light source. | Describe how light rays are emitted from each point on an extended light source. | Describe how light rays pass through a pinhole. | Explain how an image is formed on a screen behind a pinhole. |
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| **Diagnostic questions** | Light ray | Light direction | Light bulb moment | Pinhole laser | Pinhole penguin |
| Pinhole lamp |
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| **Response**  **activities** |  |  |  | Light through a hole | Pinhole camera |

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| **Light ray** | **Light direction** | **Light bulb moment** | **Pinhole laser** | **Pinhole lamp** |
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| Confidence grid | Simple multiple choice | Two-tier multiple choice | Confidence grid | Simple multiple choice |
| **Pinhole penguin** | **Light through a hole** | **Pinhole camera** |  |  |
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| Two-tier multiple choice with a confidence grid | Talking heads | Predict, explain; observe, explain |  |  |

**Progression toolkit: Explaining how an object is seen when reflected in a plane mirror**

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| **Learning focus** | A plane mirror reflects light rays from each point of an object so they appear to come from distinct points behind the mirror and the reflection is seen as if it were behind the mirror. | | | | |
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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** | | | | |
| Compare the reflection of an object in a plane mirror to how the object looks.  **P** | Describe where the reflection of an object appears to be in a plane mirror. | Explain why the reflection of an object in a plane mirror appears to be behind the mirror. | Explain why an object appears back to front in a plane mirror. | Draw a ray diagram to show how an object is seen when reflected in a plane mirror.  **B** |
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| **Diagnostic questions** | Mirror reflection | | Behind the mirror | Mirror writing |  |
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| **Response**  **activities** |  | Reflection hunt | | What turns round? |  |
|  | Drawing a reflection | |

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| Key: | | | |
| **P** | Prior understanding from earlier stages of learning | **B** | Bridge to later stages of learning |

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| **Mirror reflection** | **Behind the mirror** | **Mirror writing** | **Reflection hunt** | **What turns round?** |
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| Confidence grid | Simple multiple choice | Confidence grid | Predict, explain; observe, explain | Clarifying - demonstration |
| **Drawing a reflection** |  |  |  |  |
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| Application and practice |  |  |  |  |

**What’s the science story?**

*The ray model of light to explain images*

A light ray is an imaginary line that shows the direction in which light is travelling.

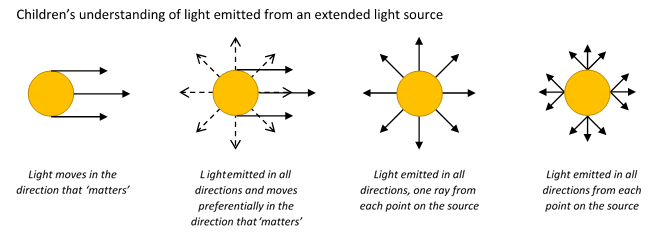
By drawing light rays, we can explain how an image is produced by a pinhole camera. Light from any given point on the object can only pass through the pinhole in one direction, and must all come to the same point on the screen. This results in a sharp, inverted (top to bottom and side to side) image of the object appearing on the pinhole camera screen.

When an object is placed in front of a plane mirror, we see a *reflection* of the object which appears to be behind the mirror. By drawing any two light rays that go from the same point on the object to the mirror, and are then reflected towards the eye, the position of the reflection of this point on the object can be located. By doing this with several points on the object, we can locate the position of the whole reflection. It is the same distance behind the mirror as the object is in front.

**What does the research say?**

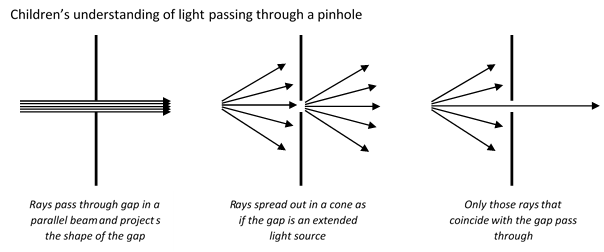
*Light rays*

Galili and Hazan (2000) found over half of 14- to 16-year-olds (n=166) consider rays to be actual physical things that are the constituents of light. The fact that rays are imaginary lines that show the direction in which light is travelling is rarely made explicit in teaching (Andreou and Raftopoulos, 2011).

Students’ understanding of image formation is largely dependent on the way they perceive light emission from extended light sources. Rice and Feher (1987) found when students are presented with a lamp in front of an optical device (pinhole, mirror, prism, lens) about half of 9- to 13-year-olds (n=62) described light rays moving parallel to each other from the light source in a ‘preferred direction’ towards the device. This view was maintained even when a cylindrical lamp was used that clearly lit the room in all directions. In Galili and Hazan’s study 40% of students aged 14-16 had the misunderstanding that just one ray was emitted from each point on a light source.

*Image formation by a pinhole*

In order to explain image formation students need to understand that light is emitted in all directions from each point on the source (Rice and Feher, 1987; Dedes and Kanstantinos, 2007; Galili and Hazan, 2000; Andreou and Raftopoulos, 2011). A suitable conceptual progression of how an image in a pinhole camera forms might start with the idea that rays *represent* the direction light travels in; use rays to show light moving from a luminous or illuminated object towards a pinhole; and finish with *one* ray from each point, out of infinitely many, passing through the pinhole and contributing to the formation of an image (Andreou and Raftopoulos, 2011).

Without the correct understanding of light emission from extended sources students make mistakes in explaining how light passes through a pinhole. Galili and Hazan (2000) found over a third of students aged 14-16 thought light passed through a pinhole in a parallel beam. A further third thought that light spread out after the pinhole as if the hole was an extended source of light, and after instruction this *increased* to more than half.

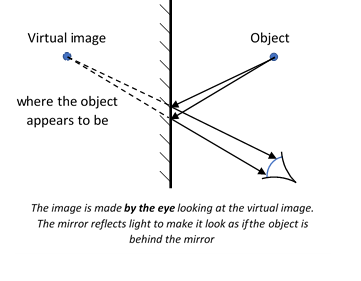
Using ray diagrams to teach image formation often introduces the misunderstanding that each point on an image is related to its corresponding object point *by a single light ray* which transfers it. Galili and Hazan (2000) found just 5% of 14- to 16-year-olds have this misunderstanding before tuition (n=62), but after studying image formation (n=102) this increases to almost 50%.

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). In describing how light passes through a pinhole to form an image Rice and Feher (1987) found up to 20% of 9- to 13-year-olds ascribe such active power to the hole.

*Reflections in plane mirrors*

Unlike pinholes, plane mirrors do not form (real) images that can be projected onto a screen. Notwithstanding, many students think that a mirror forms an image that can be viewed as if the mirror were a photograph (Ceuppens et al., 2018; Galili and Hazan, 2000). About a quarter of 13- to 15-year olds in a study by Fetherstonhaugh and Treagust (1990) thought that light stays on a mirror during reflection. Before teaching, Galili and Hazan (2000) found that about half of students thought that mirrors duplicate (reflect) objects by creating an image. This misunderstanding fell significantly after teaching, but over a quarter of students aged 14-16 persisted in thinking that the image travels to a mirror and *bounces off* it, and that if there were obstacles between the object and the mirror, the obstacles prevent the image from reaching the mirror. Other studies have shown it is common for students to think that a mirror inverses the image from right to left (Bendall, Goldberg and Galili, 1993; Galili, Goldberg and Bendall, 1991; Galili and Goldberg, 1993).

Many textbooks talk about an ‘image’ that is ‘laterally inverted’, but this is not true (Gee, 1988). It does *appear* that the reflection is back-to-front, but this is because of the direction in which we observe the reflection, rather than something the mirror has done to it.

In ‘looking’ at an object, **an eye forms a real image** of the object on its back surface (the retina). When looking at a reflection of the same object in a plane mirror, the reflected light rays from the object enter the eye in exactly the same way as they would have if they had originated from the object placed in a position behind the mirror that corresponds to where it is in front of the mirror (but without the mirror there). The reflection however appears laterally inverted. This is because to turn from looking at the side of the object facing the mirror to looking at the reflection of the object in the mirror, *the observer* must rotate through 180o. Likewise, if the observer were to hang upside-down from the ceiling the image would appear to rotate in the vertical plane.

The virtual image in a plane mirror does not exist. It is created in the brain in order to make sense of the image on the retina in relation to everyday experience.

A challenge to understanding how an object is seen in a plane mirror is the fact that the observer is an inherent part of the optical system (Galili and Hazan, 2000; Andreou and Raftopoulos, 2011). It is perhaps helpful to discuss the *reflection* of an object in a plane mirror and the formation of an image by the eye looking at the reflection. The position of the virtual image is where the object appears to be and could be labelled ‘where the object appears to be’. The ray diagram shown here is used ‘to find where the object appears to be’.

**Guidance notes**

The teaching of geometric optics appears to introduce misunderstandings about light rays that become common amongst students unless the nature of light rays is addressed in the teaching. Time is spent at the start of this conceptual progression understanding light rays and in particular how each point of a light source emits light in all directions. It is emphasised that the paths of light traced by rays on a diagram are a few of many possible rays. This understanding is fundamental to understanding image formation by a pinhole. Pinhole cameras are investigated in order to develop and consolidate students’ understanding of these ideas.

Significant numbers of students and adults hold persisting misunderstandings about reflections in plane mirrors. Reflections are usually described in text books as *virtual images* and described as images that cannot be projected onto a screen. This description can reinforce the misunderstanding that an image is a physical representation of an object that can be manipulated and which moves as a whole. If instead the observer’s eye is included in the analysis, a more concrete description of how a real image forms on the retina can be used. In this version the mirror reflects light in such a way that it arrives at the eye in exactly the same direction as light from an object placed behind the mirror. The second conceptual progression in this key concept starts by observing and describing reflections and then uses the idea of light rays to explain the formation of reflections that are seen as images in the eye.

In this key concept the term ‘virtual image’ is not used for the reasons explained above, instead what we see in a mirror is referred to as a reflection.

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