Light, vision and colour

Introduction

Historically, it was a considerable scientific achievement to understand vision in terms of the eye as a sense organ that receives light that is scattered from objects. Early ideas of vision held by thinkers such as Plato and Aristotle, and then the great Islamic scientists, were of vision as some sort of active engagement of the world by the eye; almost as if some sort of 'signal' was sent out by the eye to perceive objects. Students have difficulty in understanding the eye as a passive receiver of light. They also have difficulty with the idea of light as an independent entity that travels through space so that the role of a light source in helping us to see, and the relationship of colour of an object to the colour of the illuminating light, is problematic. Further still, ideas about how images are formed in mirrors and lenses are problematic without scientific notions of vision, and of light as a travelling entity. It is therefore important to be aware of the children's ideas when teaching them about light, vision and colour.

Key concepts of light, vision and colour

The activities in this topic are designed to explore the following key concepts:

Early years

- Sight is a very important sense we use to interpret our world.
- Light is an entity that travels through space in straight lines.
- Some objects (a globe, the sun, a flame) are sources of light; most things we see reflect light.
- Having two eyes is necessary for judgment of depth.
- The image in a mirror is inverted, and symmetrical with the object.
- Curved mirrors cause images that have distorted shapes when compared to the object in front of the mirror.
- Coloured lights and paints can mix to form other colours.

Middle years

- We see when light is reflected from objects into our eyes.
- Ordinary surfaces reflect or scatter light in all directions. Mirrors reflect light at an equal angle to the incoming light. Many surfaces, such as polished floors, both scatter and reflect light.

- Shadow shapes are areas of no reflected light or areas where the reflected light is less intense that the surrounding area.
- Most objects we see are due to scattered light from the objects.
- Some surfaces reflect more light than others. Black surfaces reflect the least light.
- Our brain puts together the stereo view we have of the world.
- Our eyes and brain can be misled.
- An image is produced when light that is reflected or emitted from an object changes direction before entering the eye to be seen.
- Our image in a mirror is equally far behind the mirror as we are in front of it.
- Light can change direction going into or out of water or glass, which results in an image of the object that may be a distorted shape when compared with the object.
- Glass and water can split light into their constituent colours as they bend.
- White light consists of all the rainbow colours.
- Colours of light and pigments can be mixed together in different ways to give different results. Colours of light mix differently from colours of paint, pencil or crayon.

Students’ alternative conceptions of light, vision and colour

Research into students’ ideas about this topic has identified the following non-scientific conceptions:

- Young children often make no connection between the eye and the object in the vision process. No explanation for the processes of vision is given: ‘we see with our eyes’ is sufficient explanation for the vision process.
- Older children often think of vision as something emanating from the eye to the object: a ‘visual ray’, or ‘active eye’ model of vision.
- Older children also think that light only needs to illuminate an object for vision of that object to occur; this is the ‘general illumination’ model.
- It is possible to see in situations where there is no light; it is totally dark.
- Light is only a source (for example, candle flame), an effect (for example, patch of light on a wall), or a state (for example, brightness); there is no recognition that light exists as an entity in space between the source and the effect it produces (young children thinking).
- Light from dim sources remains at the source; light from other sources of light travels away from the source a few metres or more, depending on the brightness of the source (young children thinking).
- Light from a source travels further at night than during the day.
- Shadows are entities independent of light; light allows shadows to be seen, rather than shadows being a result of absence of light (young children).
- Light stays on the mirror during reflection.
- Light does not reflect off non-mirrored surfaces.
- The image of an object in a plane mirror lies on the surface of the mirror.

- Lenses are not necessary to form images.
- The function of a colour filter is to dye white light the colour of the filter.
- White light is pure, not a mixture of coloured light.
- The rules for mixing colour paints and crayons are the same as the rules for mixing coloured lights.
- Colour is an innate property of an object.

Activities

Nature and transmission of light

The following activities are fruitful for exploring students' ideas about the nature and transmission of light and the formation of shadows.

Teaching note: Primary-school students find the idea of light as an entity in itself, travelling through space, a difficult idea. The ambiguity of language does not help their confusion, since in English we use the word 'light' in a variety of ways. 'Daylight', 'this is the lightest room in the house', 'it is becoming less light' or 'the fading light' implies a general state of 'lightness' that is different to the scientific sense of the word. 'Turn on the light' and 'give me a light' refer to sources of light. 'The candlelight flickers on the walls' refers to the visible effects of light, while 'a beam of light', 'light from the candle' or 'light takes just over eight minutes to reach us from the sun' refer to light as an entity that travels. The last sense is the one most often used in science.

No wonder there is confusion! It is not that there is a 'correct' use of the word, but we need to be aware of the sense in which the word is being used by students to engage with their ideas. Conversely, one might argue that understanding 'light' requires being able to distinguish between these various meanings in conversation. These activities are not 'tricks', but are interesting questions designed to engage students with the different meanings of the word 'light', and clarify how light and vision are related. They are appropriate for upper primary and lower secondary school students, if not adults.

A conversation about the candle will usually bring up three senses of the word 'light': the flame itself ('the light stays on the candle'), the effects on the wall ('I can see the light out to about a metre, but maybe it would be further in the dark') and the light that travels ('I know it comes as far as me because I can see the candle').

The light from the candle travels in straight lines until it hits an object. We see the candle because light from it enters our eye and is focused by the eye lens on our retina. The retinal image is then processed by our brain. Therefore, if we can see a luminous object then light travels at least to our eyes. A scientific understanding of the vision process then allows us to use the eye as a light detector.

If we walked backwards from a candle, how far could we go and still see the flame? Perhaps a kilometre if it was dark. Is that as far as the light travels? Perhaps if we had a really powerful telescope we could see it from the moon!

(A telescope concentrates the light.) There is no theoretical limit on how far that light will travel. It spreads out as it goes, of course, and becomes increasingly difficult to detect.

ACTIVITY: CANDLELIGHT

Key ideas: Light from luminous objects keeps travelling until it hits something. Daylight does not affect the amount of light produced from a luminous object nor does it affect how far light will travel from the object.

You will need:

- **a stick of incense**
- **a candle**
- **matches.**

A stick of incense glows dully. Does it give out light? How far do you think the light travels, if it is given off?

How would the answer to these questions differ for a candle, or for a light globe?

Candlelight can be seen flickering on the walls of a room at night, but cannot be seen by day. Why do you think this is so?

Where is there light in this room at this moment? (This question may be asked in situations where there are no light sources operating in the room, or situations where the candle is burning and/or fluorescent lights in the room are operating.)

ACTIVITY: WHAT GIVES OFF LIGHT?

Key ideas: Luminous objects give off light. Light from luminous objects keeps travelling until it hits something.

You will need:

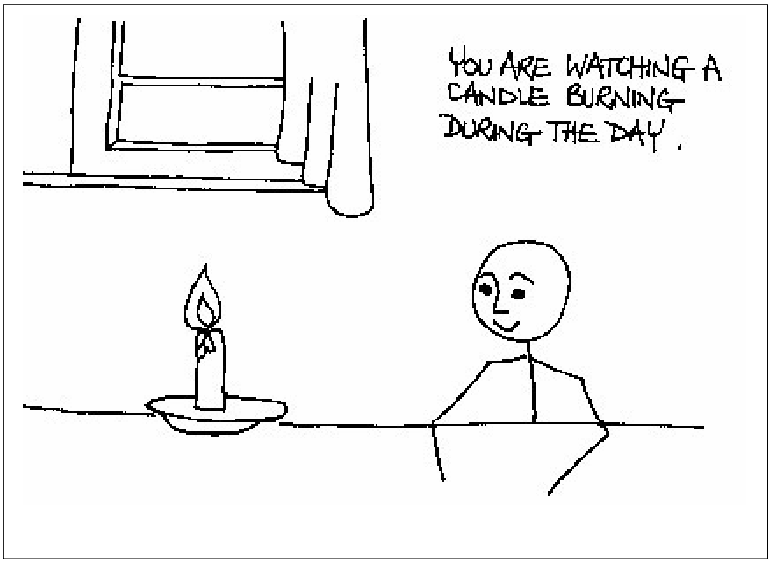
- **a series of cards that show a luminous object, or supposed luminous object, in daylight and night-time situations.**

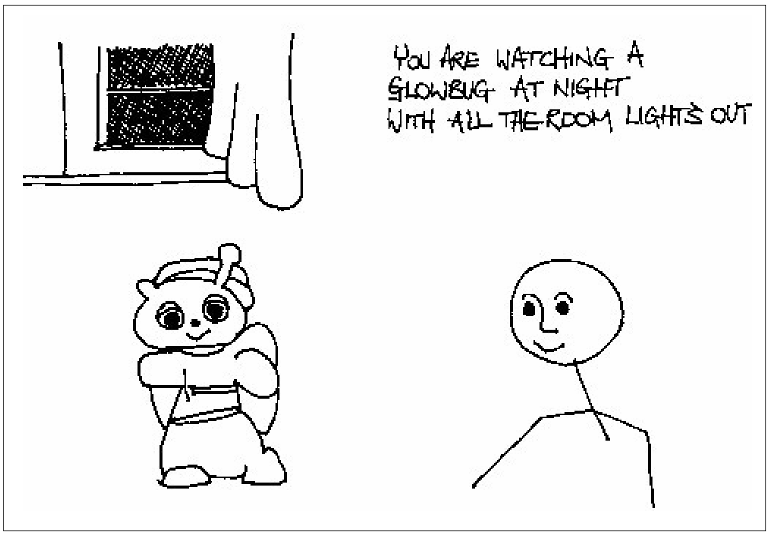
Make up some cards (like those shown below) that show a luminous object, or supposed luminous object, in daylight and night-time situations. The objects should include bright and dim luminous objects, as well as non-luminous objects. Also have situations where the object is in daylight and night-time conditions.

The objects could include:

- **a candle (night and day)**
- **a television (night and day)**
- **a mirror**
- **a light bulb (night and day)**
- **a moon**

- **glowing coals (night and day)**
- **a glow-in-the-dark sticker**
- **a glowbug toy (night and day)**
- **a movie screen.**





Present these cards, in turn, to the students. Explore the students' ideas through asking: Does the object make light? If so, how far from the object does the light travel? (Does light reach the person? Any further?)

ACTIVITY: SHADOW SHAPES

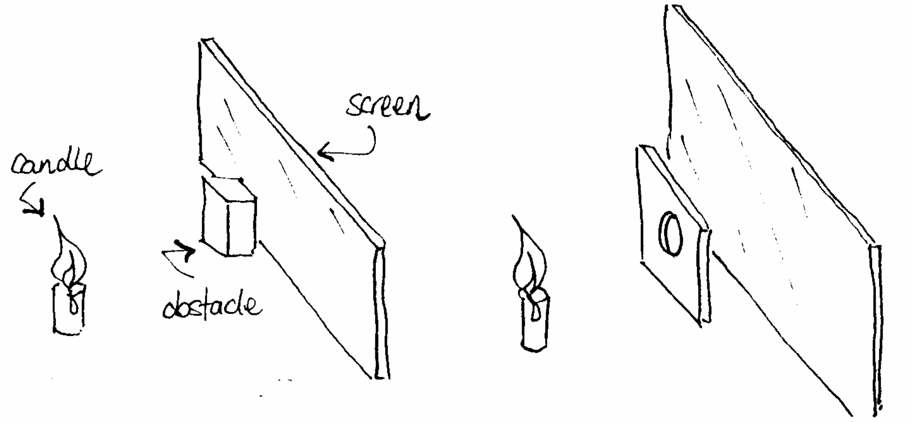
Key ideas: Light travels in straight lines. Shadows are areas that have less illumination than surrounding areas.

You will need:

- **a candle or torch**
- **matches or a lighter**
- **various objects of different shapes (e.g. a glue stick)**
- **cards that have cut-out shapes**
- **a screen.**

Arrange an object, say a glue stick, between a screen and an unlit candle or a torch. Predict the size and shape of the shadow produced when the candle is lit or the torch is turned on. Predict the size and shape of shadows when the screen is moved (forward or back), and/or the object is placed at a different level to the light source. How is the shadow formed?

As well as using different-shaped objects, include cards with a cut-out shape. These cards will produce an illuminated shape.



ACTIVITY: HOW DOES LIGHT TRAVEL?

Key ideas: Light travels in straight lines. More light reflects off light-coloured objects than dark-coloured objects. Light reflects in a regular way from mirrors and in all directions from non-mirrored surfaces.

You will need:

- **a torch or slide projector with a slit**
- **white and black sheets of paper**
- **a mirror.**

In a darkened room, shine the torch, or a slide projector with a slit, onto a sheet of white paper. Explain how the light is travelling. What will happen if we replace the white paper with black? Try it. What will happen if we replace the paper with a mirror? Try it.

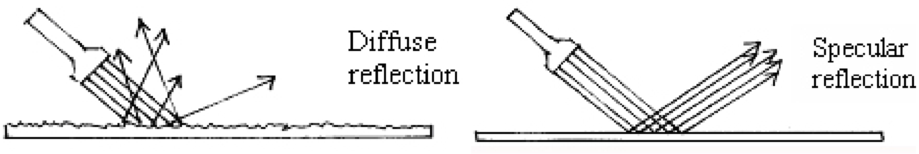
Explanatory note: If the room is quite dark, it is surprising how much more the room lights up when light is shone onto white paper when compared with black paper. When a light beam is shone onto the mirror the beam reflects in only one direction so unless the students are in the path of the reflected beam the mirror will appear dark.

Reflection from a mirror surface (called ‘specular reflection’) and a non-mirrored surface (called ‘diffuse reflection’) is shown in the figure below.

The non-mirrored surface reflects light in all directions because it has a rougher surface than the mirror.

Black paper doesn’t reflect as much light as white paper, as most of the light gets absorbed by the paper. When an object absorbs light it tends to heat up slightly. Have you ever wondered why people wear light-coloured clothing in hot countries?

FIGURE: SPECULAR AND DIFFUSE REFLECTION



ACTIVITY: LET THE LIGHT SHINE THROUGH

Teaching note: Students will have to record how well the light shone through (e.g. a lot, some, none). These words (or symbols if you prefer) should be agreed upon beforehand and written on the board for students to refer to. Discuss the results as a class.

Key ideas: Light passes through transparent objects. Light does not pass through opaque objects.

You will need:

- **coloured and clear glass and plastic containers**
- **tea cups or mugs**
- **fabric pieces**
- **coloured and white paper**
- **opaque containers**
- **cardboard boxes**
- **torches.**

Which of the items will let light shine through? Write down your prediction and draw a picture of the item beside it. Discuss why you predicted this way.

Working in pairs, test your predictions, first with sunlight, then with the torch. (Make sure to turn the torches off when not in use!) When testing for sunlight, hold the item up to the window. When testing for torchlight, hold the torch about 5 cm away from the item you are testing.

What items let the most light through? Was there a difference between sunlight and torchlight going through an item? When would you use material that let light pass through? What materials would you use for a window blind, for example?

ACTIVITY: SHADOW PUPPETS

Key ideas: Light travels in straight lines. Shadows are areas that have less illumination than surrounding areas.

You will need:

- **a slide projector**
- **a screen.**

Make shadow puppets with a slide projector. How does it happen?

ACTIVITY: SHADOW PLAY

Key ideas: Light travels in straight lines. Shadows are areas that have less illumination than surrounding areas.

You will need:

- **a cardboard box**
- **greaseproof paper**

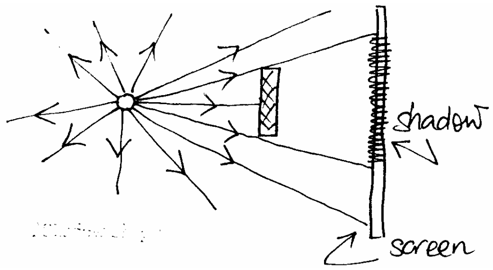
- **glue**
- **scissors**
- **torches**
- **cardboard**
- **skewers, sticks or straws**
- **sticky tape**
- **a screen.**

Make a shadow play. Cut a square hole in the bottom of the box and cover it with greaseproof paper, using sticky tape to hold the paper. Choose a short story (e.g. 'Three Little Pigs', 'Goldilocks') for your puppet show or make one up. Cut out cardboard shapes to match the characters in the story and attach a skewer, stick or straw to the back of the character with the tape or glue. By shining the torch to the back of the screen you can cast a shadow onto the cardboard figures and enact the play.

Explanatory note: In this activity, the production of shadows that have the same shape as the object is due to the key idea that light travels in straight lines. As light streams out from the torch, or candle, it continues until it hits something. See the figure below.

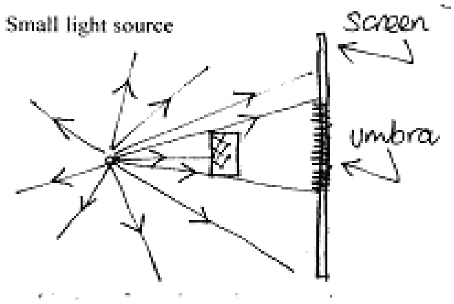
The arrows in the figure represent the direction of the light streaming out from the source. It gets stopped by the obstacle and the screen. Notice how this diagram shows that the shadow will be the same shape as the object but larger.

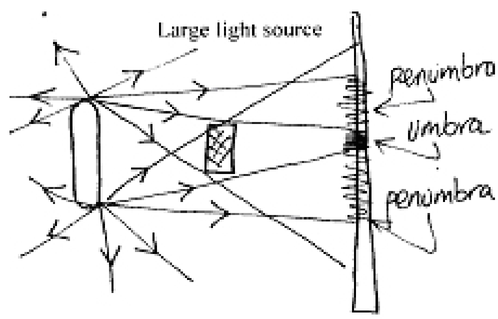
FIGURE: LIGHT STREAMING FROM THE SOURCE



A shadow will form in an illuminated area if the surrounding area is more brightly illuminated. Also, if the light source is large, or long, as in a fluorescent tube, any shadows formed by placing objects in front of it will have fuzzy edges. The fuzzy areas, called 'penumbras', are due to some, but not all, of the light reaching the screen. The figure below illustrates how areas of no light (umbra) and partial light (penumbra) may be formed.

FIGURE: SHADOW SHAPES





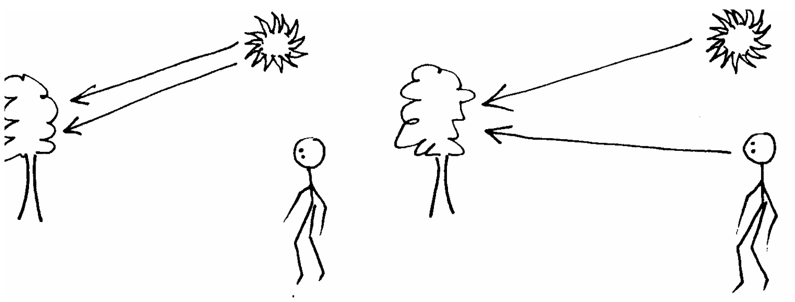
The vision process

The following activities explore students' ideas of the vision process. You may find through these activities that few students have an idea that light needs to enter the eye of the observer to be able to 'see'.

Teaching note: Students have difficulty with the idea of the eye as a passive receiver, and this is supported by the everyday language associated with 'seeing': 'cast your eye on that', 'her icy stare pierced his defence'. Even 'look over there' has an active ring to it that acknowledges the way we attend to objects, but misrepresents the physical nature of the visual process.

You may find that very few of the students have a scientific understanding that light needs to enter the eye for vision to occur. Common alternative conceptions are shown in the figure below.

FIGURE: ALTERNATIVE CONCEPTIONS OF VISION



ACTIVITY: EXPLORING OBJECTS

Key idea: The sense of sight is the most important sense for people.

You will need:

- **a series of interestingly shaped objects.**

Explore several of the objects provided and, for each observation, list the sense that you used. Consider your data and discuss with your group the conclusions you have drawn. For example, which sense gave you the most information? Which sense gave you the least information? Is the dominant sense item-related?

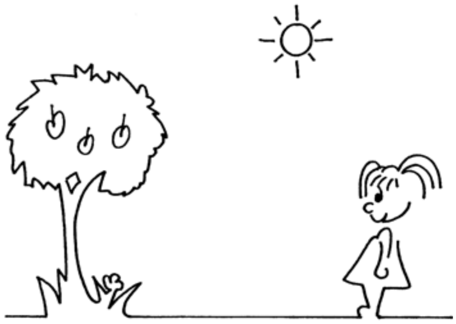
ACTIVITY: ABBIE AND THE TREE

Key idea: To see a non-luminous object, light needs to reflect off the object and enter the eye of the observer.

You will need:

- **a drawing like that shown below**
- **a darkened room**
- **a torch.**

In the figure opposite, Abbie is able to see the tree. Draw arrows to show how light from the sun enables her to see the tree.



Abbie is in bed at night. The curtains are drawn and the lamps in the room are off so there is no light in the room at all. Will Abbie be able to see objects in her room without any light? Why? Her cat is also in the room. Can her cat see objects without any light present? Why?

Allow your eyes to adjust to darkened room conditions. Pair up, so you are looking into each other's eyes. Turn on the lights—observe the changing size of the pupils.

Explanatory note: Light must enter the eye of the observer for vision to occur; this applies to all animals, including nocturnal animals. For humans, improved vision at night occurs when our pupils dilate to allow more light to enter our eyes. Nocturnal animals are better able to dilate their pupils, allowing more light to enter their eyes. Notice that cats' eyes are slits during the day and circles at night. Note that nocturnal animals still require light to see; if there is no light they will not be able to see. Cats' eyes have an added feature to allow them to see well in dim light conditions. When light enters cats' eyes, some of it will be absorbed by the vision cells at the back of the eye. If the light doesn't hit a vision cell it gets reflected inside the eye; some of this reflected light may be absorbed by a vision cell.

ACTIVITY: CAN YOU FEEL A STARE?

Teaching note: These activities should expose the students' thinking in relation to the vision process. The staring activity exposes the alternative conception that something emanates from the eye in the vision process. The figure below illustrates the vision concept. The direction of the light is shown by arrows, which in scientific circles we call 'rays'.

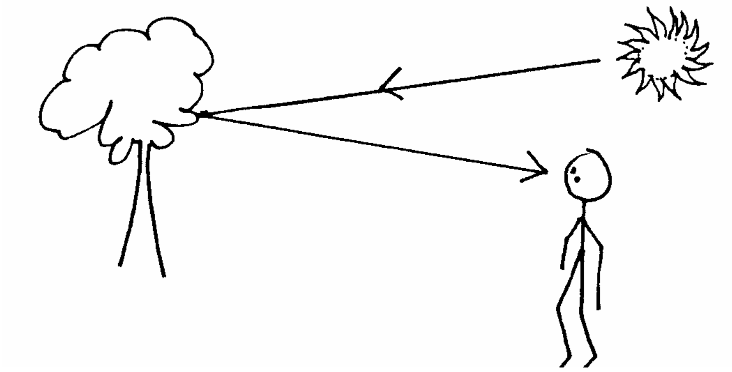
Key idea: Nothing emanates from the eye in the vision process.

Think up an experiment to test whether a person is able to 'feel' someone who is staring at them.

For example: Blindfold three students and place them at different positions at the front of the classroom. On the command of the teacher, the rest of the class will stare at one of the students (the blindfolded students will not be told which one of them is being stared at). Can this student 'feel' the stares? If so, he or she should raise their hand.

When looking at a particular object we often notice other objects to the side of our direct vision: this is our peripheral vision. While looking straight ahead, test your peripheral vision for each eye separately and for both eyes together.

FIGURE:
THE VISION
CONCEPT



Explanatory note: If we accept that light needs to enter the eye before vision can occur, if there is no light then vision of anything is not possible. Therefore, we can't see in the absence of light. Many students will say they can. This is probably due to the fact that few people experience nil-light conditions. Even on the darkest of nights, there is still some light that allows some vision to occur. When you step outside on a dark night it is difficult to see, at least initially. However, after a short time our eyes adjust to the light conditions and our vision of objects returns. This is because our pupils dilate in dim conditions to allow more light to enter our eyes. Nocturnal animals see well in dim conditions as their pupils dilate very well.

Effects of two eyes and a brain on the vision process

With two eyes we receive two different views of the world, and this helps our judgment of depth and allows us to move about effectively. The brain interprets the two images with some surprising results. A number of the following activities emphasise that we see a different perspective with each eye.

Teaching note: The idea of vision as a passive process does extreme injustice to the role of the eye–brain system in interpreting the light signals falling on the retina. While the physics can be described in terms of the eye as a receptor, what the brain does with the signal is highly interpretive and active, and is the subject of much ongoing research. Knowledge of how we perceive colour, for instance, has changed radically in the last twenty years, and many optical illusions illustrate the way the brain actively interprets, enhances and suppresses aspects of what is seen. In these illusions, when faced with seemingly contradictory information, the brain flips from one interpretation to another.

The secret of having two eyes is that the stereo effect enables us to judge distance. Humans have in common with other primates a fully frontal set of eyes, which enables overlapping frontal views of the world and accurate depth perceptions. This is crucial for the hand–eye coordination that is so important for making and using tools. With both mammals and birds, whether the animal is a carnivore or herbivore (i.e. predator or prey) is reflected in eye position. Thus, rabbits and cows and pigeons have eyes at the sides of their heads that enable an almost a 360-degree view (why is this helpful?), while cats and foxes and owls have eyes placed much more forward. A hunter needs a good sense of depth for the chase!

Humans have a number of mechanisms to judge depth, in fact. The main mechanism involves two eyes. With two eyes we are able to judge the angle at which an object must be looked at (greater for closer objects … have a friend stare at his or her finger while bringing the hand from outstretched to close up, and watch carefully what happens to the eyes. They angle in as they follow the finger). We can also judge how an object sits against the background from each eye: information which also allows depth judgment. Even with one eye we can make some depth judgment, based on the placement of objects in front or behind each other, or their relative size. We also have information from how we focus on an object. All this is achieved without our conscious awareness, since we do it constantly!

The early activities in this section demonstrate that we have two views of the world—one from each eye—that the brain puts together to make sense. In the case of the *Hole in the hand* and *Merging images* activities, the sense is in fact nonsense. *Jumping fingers!* illustrates that the information that helps us judge depth concerns the way an object appears at different positions against the background, depending on how far away it is. *Judging depth* illustrates that our judgment of distance is much reduced with only one eye open.

Other physical effects can be demonstrated to affect our vision. In *Eye-fooling flipper,* the fish appears to be in the bowl if the flipper is twirled quickly, because the image of each lasts a sufficient time on our retina to allow the other side to appear before it has faded. The images coexist. This ‘persistence-of-vision’ effect is critical to make sense of a movie, since without the effect we would be aware of a series of disjointed still images. If the film moves too slowly, we get a jumping sensation, as happened with early film technology.

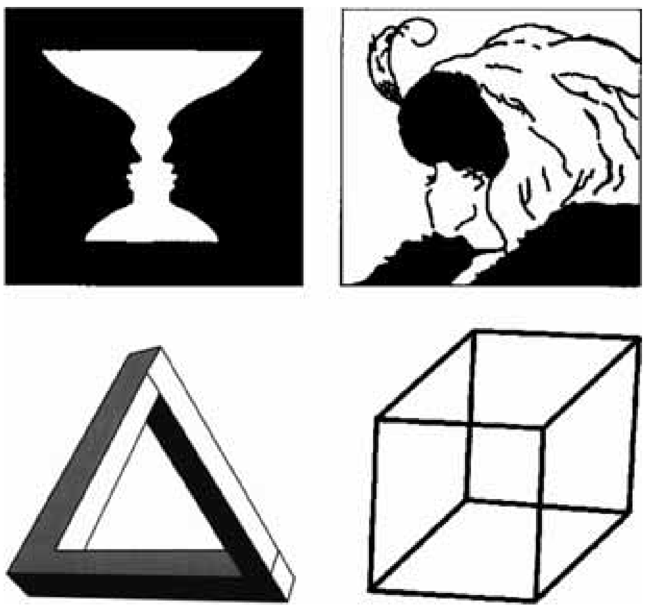
ACTIVITY: SEEING IS BELIEVING

Key idea: Our eyes and brain can be misled.

You will need:

- **a set of optical illusions such as those shown below.**

Look at the illustrations below. Does what you see make sense?



ACTIVITY: HOLE IN THE HAND

Key ideas: Our brain puts together the stereo view we have of the world. Our eyes and brain can be misled.

You will need:

- **an A4 sheet of paper.**

Roll the sheet of paper into a tube with a diameter of 3 to 4 cm. Hold it in your right hand and look through it with your right eye, with both eyes open and staring straight ahead. Arrange your left hand beside the tube so that your left eye is staring at it.

You can arrange to view a hole in your friend's head instead!

Does the position of the left hand matter?

Why does the illusion require you to stare into the distance?

ACTIVITY: MERGING IMAGES

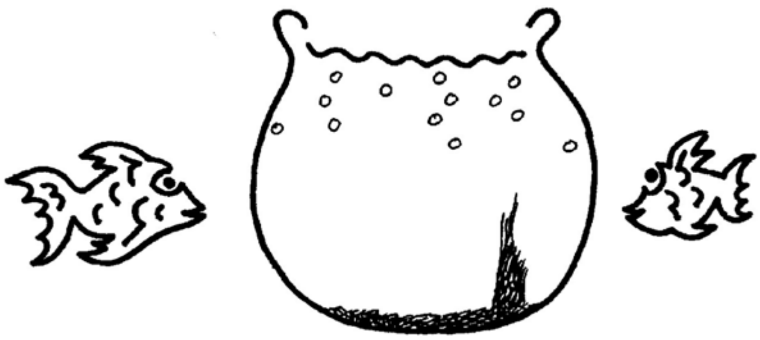
Key idea: Our brain puts together the stereo view we have of the world.

You will need:

- **a picture of a bowl and fish such as the figure shown below.**

Hold your eyes 20 cm from the page and stare at the fish and empty bowl.

Can you put the fish in the bowl?



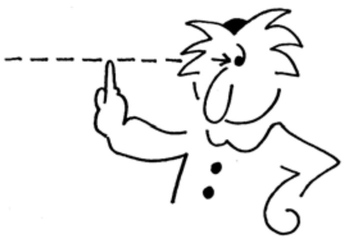
Explanatory note: In the first instance, the brain uses the image from just one eye, the dominant eye, to interpret what the person sees as each eye 'sees' a different perspective of the fish and bowl. By staring at the page, the brain begins to combine the images from each eye into one—the fish appears to be in the bowl.

ACTIVITY: JUMPING FINGERS!

Key ideas: Each eye gives a different perspective of the world. Our brain puts together the stereo view we have of the world.

Hold your finger in front of you, at arm's length, in front of a distant set of objects, perhaps at the other end of a room, or across the road.

Close first one eye, then the other. Your finger should jump from one part of the background scene to another.



Your finger jumps because each eye is looking at it from a slightly different position and lining it up differently.

Can you arrange your finger and eyes so that your finger can cover both ‘buttons’ below without moving, but only by opening and closing your eyes?

Push me
with your
right eye

Push me
with your
left eye

Why does the position of your finger affect the amount by which it apparently jumps?

ACTIVITY: DETERMINING YOUR DOMINANT EYE

Key ideas: Our brain puts together the stereo view we have of the world. Our brain most often ‘sees’ mainly the image from our dominant eye.

Line up your finger at arm’s length, against an object in the background, with both eyes open. Holding it there, close first one eye, then the other.

Which eye did you use to line your finger up? We tend to favour one eye over the other when our eyes are sending confusing messages to our brain.

Explanatory note: The brain doesn’t always superimpose the images from both eyes equally. It uses the image from one eye, the dominant eye, and then fills out the scene we ‘see’ with parts of the image from the non-dominant eye.

ACTIVITY: JUDGING DEPTH

Key idea: Having two eyes is necessary for judgment of depth.

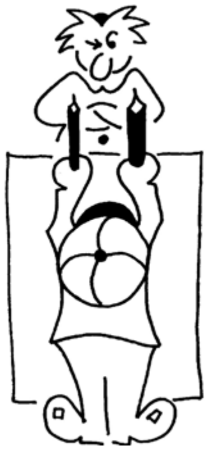
You will need:

- **three pencils of different size and colour**
- **a blank screen**
- **a room full of objects.**

Our two eyes are useful for judging depth.

Use a pen held at arm’s length to touch an object (the corner of a box, for instance, or a particular pencil in a case), moving the pen in from the side.

Now try it with one eye closed. Is it easier or harder?



Devise a game to challenge your friends!

Hold two different-sized pencils up against a blank screen, at slightly different distances from your friend.

Have your friend close one eye and tell which is closer. Does opening both eyes help?

Walking around a room full of objects is easy.

Try it with one eye closed. Can you explain the difference?

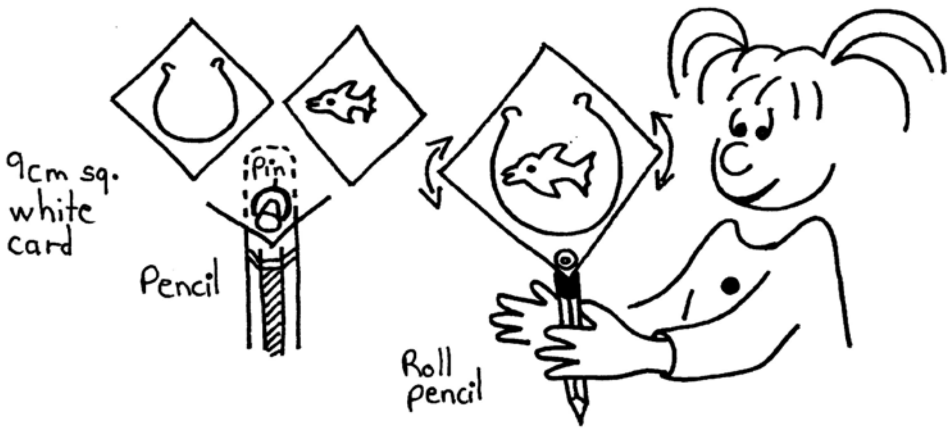
ACTIVITY: EYE-FOOLING FLIPPER

Key idea: The brain can interpret quickly changing scenes as one merged image.

You will need:

- **white card about 9 cm square**
- **pencil**
- **a tack**
- **Blu-Tack.**

Draw a bowl on one side of the square of white card and a fish on the other side.



Attach the card to a pencil using a tack and Blu-Tack. Roll the pencil in your hand so the card spins. When you spin it fast enough, the fish will appear to be happily in the bowl.

Images in mirrors

The following activities relate to the concept that the image in a mirror is inverted and symmetrical with the object. The activities are appropriate for early and middle years students. Students will tend to think that what we see in a mirror lies on the shiny surface. In fact the image appears to exist behind the mirror, in a 'mirror world' symmetrical with ours. Images in a mirror appear inverted. Multiple images, using two mirrors, suffer alternate inversion. Investigating mirror images can be fascinating.

Teaching note: Younger students can have fun exploring mirrors and their uses without needing to engage with the subtleties of light travel and reflection angles. There is a lot to explore with the inversion of images in mirrors, and the symmetry that exists between an object and its image.

There is quite a bit of useful mathematics that can be explored in symmetry, and the idea can also be used to explore the natural world, by looking with mirrors at flowers, leaves, insects, etcetera—either the real thing or photographs. Axes of symmetry can be found by ruling lines at positions where a mirror can be put to reproduce the object faithfully.

The symmetry aspects of these activities are straightforward, and can be extended to many objects and shapes. In terms of the optics, these activities provide a good opportunity to encourage children to refer to what they see in mirrors as images, and to point out they are back to front compared to the object, and perhaps that they appear to lie behind the surface of the mirror. The idea that the objects are reflected in the mirror could be extended to the notion that light is reflected by mirrors.

ACTIVITY: WINK, WINK

Key idea: The image in a mirror is inverted, and symmetrical with the object.

You will need:

- **a plane mirror.**

Look into the mirror and wink. Which eye winks back?

ACTIVITY: MIRROR MESSAGES

Key idea: The image in a mirror is inverted, and symmetrical with the object.

You will need:

- **a plane mirror and a stand to hold the mirror vertical**
- **a sheet of paper and a pen**
- **a piece of carbon paper.**

Write your name on a sheet of paper and look at it in a mirror. What do you notice? Can you make your name read back to front? Upside down?

Can you think of a word that reads correctly when viewed as an image in a mirror? Write it down and test it out.

With a mirror standing up in front of you, write your name so it appears the right way round in the mirror. Don't look at your hand while you are doing this; look only in the mirror. How do things look in a mirror?

Write your name in the normal way, but with a piece of carbon paper underneath, the wrong way up. Look at the writing that appears on the underside of the paper. It looks like mirror writing! Is it? How can you test? Can you use a mirror to read this writing?

ACTIVITY: MIRROR MAZES

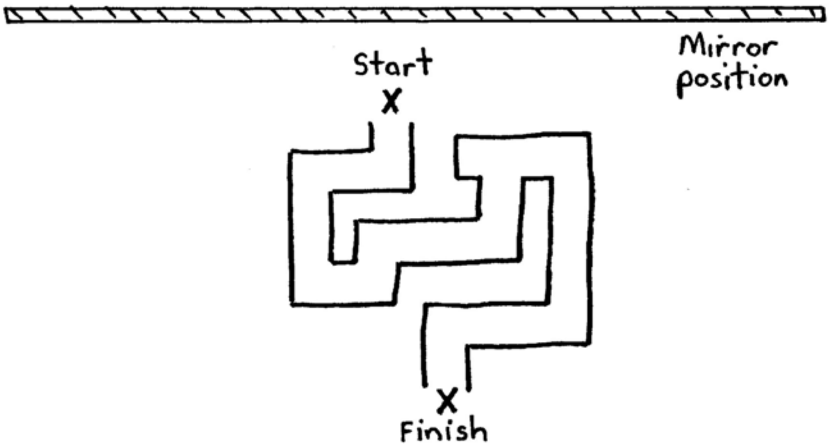
Key idea: The image in a mirror is inverted, and symmetrical with the object.

You will need:

- **a plane mirror and a stand to hold the mirror vertical**
- **a maze like that shown in the figure below**
- **a pencil.**

Make a maze that has to be followed with a pencil from one end to the other. Get a friend to try to follow the maze, using a mirror standing up in front, and looking in the mirror only.

When the pencil moves towards you, what does its image in the mirror do? When the pencil turns left, what does its image do?



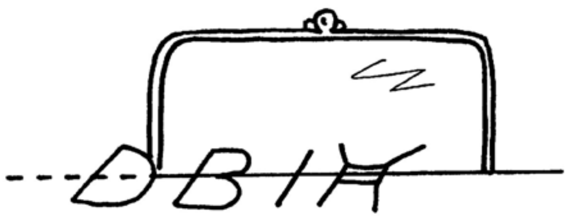
ACTIVITY: SILLY SYMMETRIES

Key idea: The image in a mirror is inverted, and symmetrical with the object.

You will need:

- **a plane mirror and a stand to hold the mirror vertical.**

A mirror can be used as a decoder for secret messages. It can also be used to test symmetry. 'Symmetry' is a word we use to describe when things are the same on different sides. The letter B, for instance, is symmetrical about a horizontal line through its middle, and that can be tested by placing a mirror along the line and seeing if the letter still looks the same. The letter A has a different symmetry line (axis of symmetry). Can you find it? The axis of symmetry is the imaginary line dividing the parts that are the same. Use a mirror to try to make sense of the following words:



BOB	**DID**	**TAT**	**BED**	**BOD**	**OMO**	**MAT**	**GENE**

Can you find any axes of symmetry? Make up some longer words that make sense in a mirror. Make up some symmetrical numbers! Use your mirror to test for symmetry in other objects.

ACTIVITY: FACE IT!

Key idea: The image in a mirror is inverted, and symmetrical with the object.

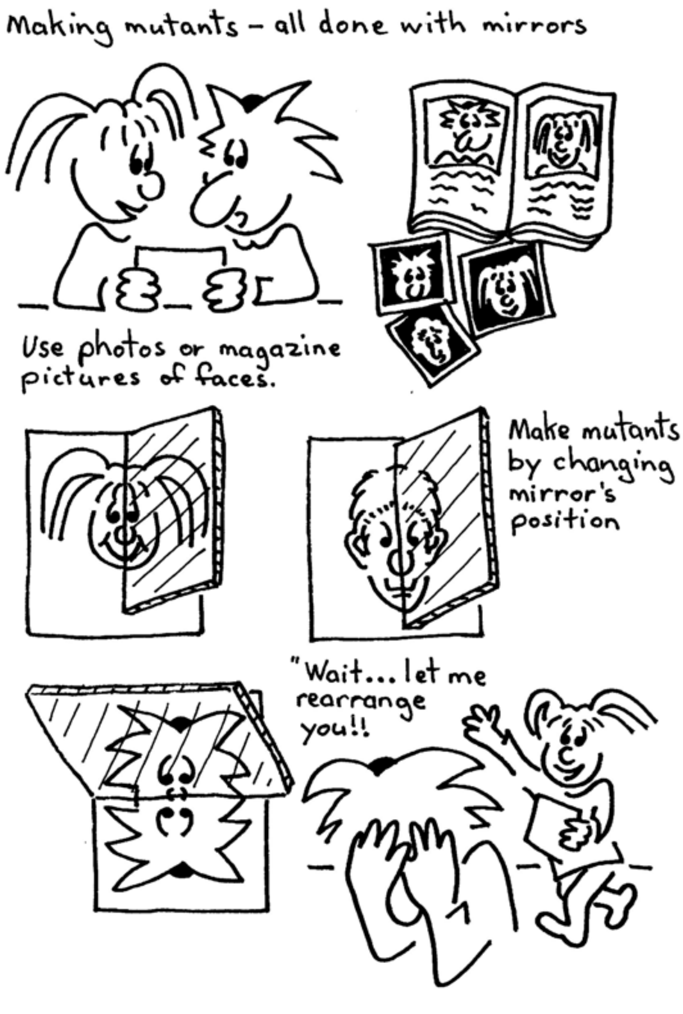
You will need:

- **a plane mirror**
- **photographs of yourself and faces of people in magazines.**

We humans are supposed to be symmetrical about a line down our middle. But are we really?

Find a full-faced photograph of yourself and test, using a mirror, whether you look the same on the right and left sides. You could test for symmetry in full-face photographs of people in magazines. You will notice that eyebrows—or wrinkles, or mouth shape—can be different on either side of the face, , and this can make people appear to have different personalities on each side of their face.

You can make some weird face shapes using a mirror with magazine photographs.



If you hold your mirror upright to check for symmetry in the photograph of a face, where does the image of the half-face in the mirror seem to be? What is happening to the light to make the image?

Multiple mirrors, light and vision

These activities explore mirrors further to include the concepts that light reflects off mirrors at equal angles. Multiple reflections of light from mirrors can create interesting images.

Teaching note: The *Lighting system* and *Seeing around corners* activities work quite well with a piece of card laid out with the box taped down, and circles drawn to mark A and B positions, and mirrors taped to a rectangular block of wood.

Students do not have difficulty explaining what happens to torch beams hitting mirrors, and conversations using a bouncing-ball analogy can bring out the idea of equal in–out angles. There's no real need for younger students to talk about formal angles of incidence of reflection. Younger children, however, are much more likely to use language that ignores the idea of light ('the torch bounces off this mirror onto that and then shines here'). For students of all ages it is difficult to reconcile the idea of torchlight, and the process of looking in the mirror. Thus, in talking of the statue in the box, they tend to draw and talk about seeing along a line into mirror B, which 'looks at' A, which then enables the statue to be seen. The order of activity is reversed from the science view, as the mirrors become a looking device, rather than reflectors of light from the statue.

Similarly, with the *Periscope* activity, students will explain that the scene (not necessarily the light from the scene) is reflected by the top mirror down to the second mirror, and then we look in the second mirror to see it! The science view—that light is reflected down the periscope and then out to our eyes—competes with the strong sensation of actively looking in the mirror. Negotiating or modelling the language of seeing is an important aspect of teaching about light.

In the *Periscope* activity, it is only partly convincing to replace the statue with a torch, and the eye with a screen. The light from the torch that reaches the screen is exactly the light that enters your eye if you look from where the screen is placed. With the torch is turned off, this is exactly where you need to be to see the unlit torch, since light scattered from the torch rim is reflected exactly as the torchlight was. Does that make sense?

The *Candle in a jar* illusion uses glass or perspex rather than a mirror and allows the position of the image to be directly perceived in relation to the real objects behind. A common mistake is to imagine that a mirror image lies on the surface of the mirror, almost as if it is acting as a screen.

This trick can be done by placing an unlit candle on the other side of the perspex. From the lit-candle side, it will look like the candle is alight behind the screen. If you have an audience in front of the screen you can fool them by:

- asking whether the (unlit) candle will go out when a glass jar is put over it
- attempting to light a piece of paper with the apparently lit candle, or
- casually leaving your finger in the 'flame' while discussing it.

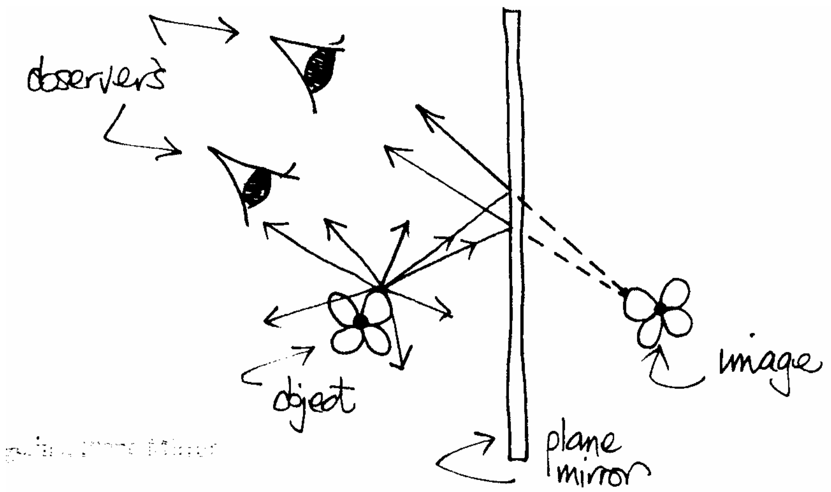
Two mirrors allow some fun with reversed symmetries and multiple images. These effects can be explained by tracing the path of light as it bounces off one mirror, onto another and into your eyes. In the case where many images are seen, the light will reflect back and forth a number of times, each time reflecting some to the eye to create an image. It is probably easier to think in terms of images—the image in one mirror acts as an object to be reflected in the second mirror. This can happen many times over if the mirrors are angled correctly—an infinite number of times with two parallel mirrors, or three mirrors forming a triangle, as with the kaleidoscope.

In *Multiple images*, each successive image will have been reflected once more, and so each alternate image will be reversed, or the right way round. Thus, every second image of a written word will be readable!

One way of looking at this is to regard the 'V' between the mirrors as an object world, which is reflected many times to create image worlds in the mirrors. Thus, for a given angle for the V, the pen will be seen as many times as that angle fits into 360 degrees. If the angle is 90 degrees (try it), then that is the situation with the corner mirror, and the non-inversion of the image is because it involves a double reflection. This is also the explanation for the periscope image being the right way round.

Explanatory note: When you look into a plane mirror, do you see your face or do you see an image of your face? Everyday language would suggest that you would see your face, but from a scientific perspective you are seeing an image of your face. We need to make the distinction between an object and its plane mirror image because, while they are the same size and shape, they are in different locations. The figure below illustrates this point.

FIGURE:
AN OBJECT AND
ITS PLANE MIRROR
IMAGE



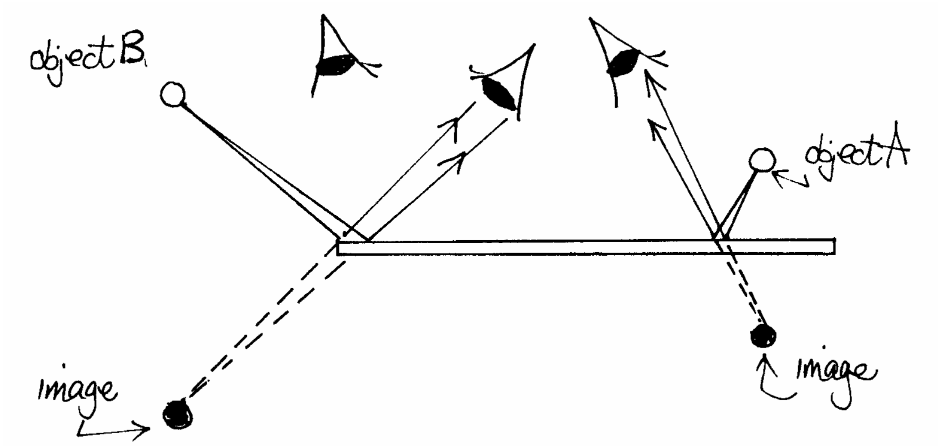
There are two observers, represented by eyes, where one observer is looking at the top of a flower and the other observer is looking at an image of the top of the flower.

Light from a luminous source, presumably the sun, reflects off the top of the flower in all directions. Some of this light goes directly into one observer's eyes. Some of the light also gets reflected off the mirror and enters the eyes of the other observer.

The observer who sees the flower will get the perception that light is diverging from one particular point in space (the location of the flower), whereas the observer who sees the image will get the perception that light is diverging from another point in space (the location of the image). The significance of the eye in image formation is important as the image is created when the light enters the observer's eye.

When directly observing an object, light from the object travels in a straight path to the eye. However, if the light from the object is redirected by reflection off a mirror (plane or curved) or after passing through a transparent material, then an image is formed and the observer will perceive its location to be different to that of the actual object. If the redirected light only appears to come from points in space then the image formed is called a virtual image. In the case of the plane mirror, the reflected light appears to come from an image located behind the mirror; light doesn't originate from behind the mirror. The distance from the image to the mirror is equal to the distance from the object to the mirror. The line between the object and image cuts the mirror axis at right angles. This is illustrated in the figure below.

FIGURE:
THE LINE BETWEEN OBJECT AND IMAGE CUTS MIRROR AXIS AT RIGHT ANGLES



In the figure above, the observer on the left will not see an image of object B but will be able to see an image of object A. Can you explain why?

The light from the object must reflect off the mirror according to the reflection rule and enter the eye of the observer before an image can be seen.

Where an object is placed in front of multiple mirrors, light from the object undergoes multiple reflections. Reflected light from the first reflection appears to come from an image; if this light is reflected from another mirror it will appear to come from somewhere else, a second image. As each new light reflection appears to come from another point in space, multiple images can be produced from the one object.

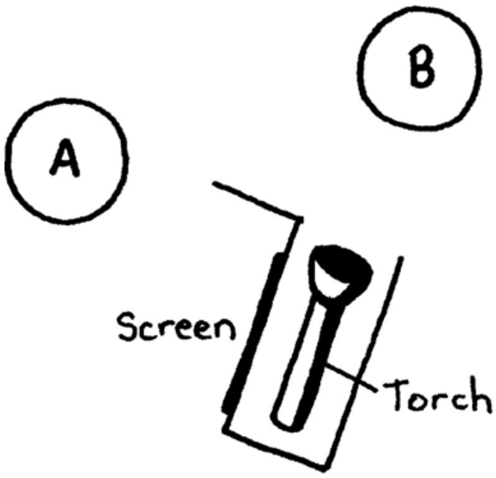
ACTIVITY: LIGHTING SYSTEM

Key idea: Mirrors reflect light at an equal angle to the incoming light.

You will need:

- **a torch**
- **a small cardboard box with a screen glued to its side**
- **two small (10 cm square) mirrors taped to wooden blocks to enable them to stand**
- **an A3 sheet of paper with two circles marked A and B as shown in the figure below.**

Can you use two mirrors so the torch lights up the screen on the side of the box?



Where do you have to put the two mirrors? How do the mirrors have to be angled? Can you explain what is happening to make the torch light up the screen?

ACTIVITY: SEEING AROUND CORNERS

Key idea: Mirrors reflect light at an equal angle to the incoming light.

You will need:

- **a toy figure or statuette**
- **a small box**
- **two small mirrors as previous**
- **an A3 sheet of paper with circles marked A and B.**

Mirrors can be tricky things. They are used often in shops to give a view of customers hidden down aisles, or on 'blind' corners so that motorists or pedestrians can see what is coming. They can be used by magicians to create illusions.

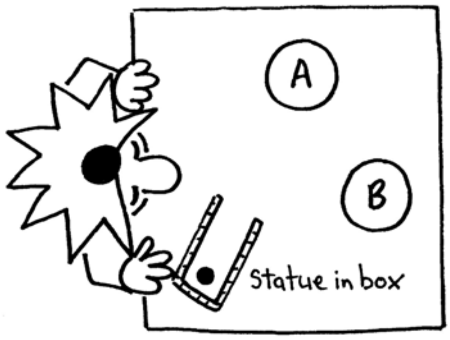
Place a small 'treasure' behind an upright screen. Why can't you see it directly? (You might say 'You can't see around corners'. But can you explain why, by talking about what happens to the light reaching our eyes?)

Here's a challenge: place a mirror in a position so you can see the treasure behind the screen. How many positions can you find? How does the mirror have to be angled in each case?

A small statue or figure sits in a box.

Arrange two mirrors, placed on the circles A and B, so you can see the statue in the mirror at B, from the marked position.

How are the mirrors allowing you to see the statue round the corner?



ACTIVITY: SEEING A FIGURE IN A MAZE

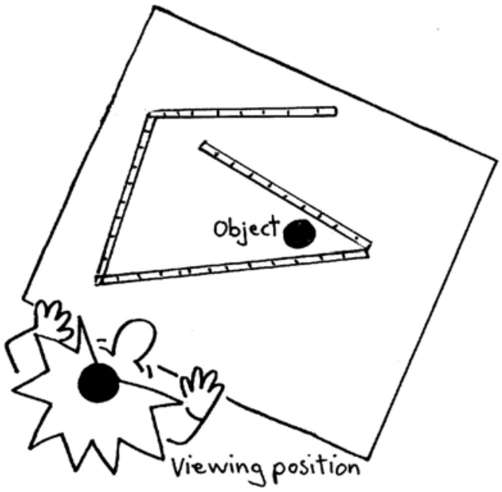
Key idea: Mirrors reflect light at an equal angle to the incoming light.

You will need:

- **a small statue or figure**
- **a set of cardboard screens and tape**
- **three small mirrors taped together.**

Here's a bigger challenge: use three or four screens to hide the figure in a maze. Challenge your friend to design a system of mirrors that will enable the figure to be seen. What is the rule for placing the mirrors?

You could use a secret message instead of a figure. Is the writing 'inverted' when mirrors are used? Does that depend on the number of mirrors?



ACTIVITY: CANDLE IN A JAR

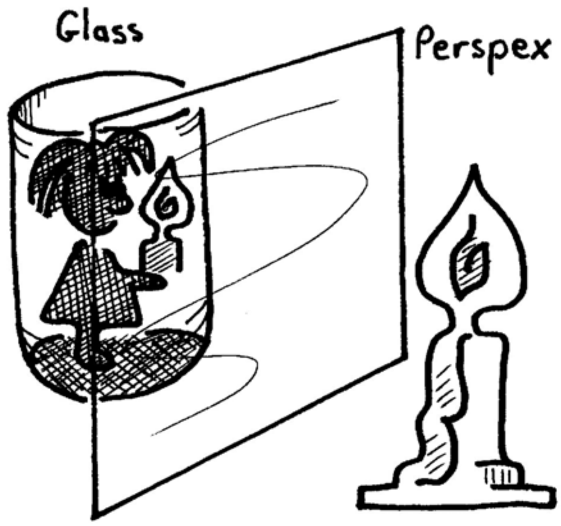
Key idea: The image in a mirror is equally far behind the mirror as the object is in front of the mirror.

You will need:

- **two birthday candles**
- **a glass jar with small toy figure**
- **a perspex or glass screen at least 30 cm × 20 cm held vertically by two large, inverted, bulldog clips.**

Place a vertical piece of perspex or glass between a birthday candle and a small figure in a glass jar. Light the birthday candle and look from its side of the perspex.

Can you see its reflection in the perspex? What is happening to allow you to see the reflection?



The figure in the jar is on the other side of the perspex. Can you move the candle around so its reflection seems to be being held by the figure in the jar?

Can you explain why the candle seems to be in the jar?

ACTIVITY: MULTIPLE IMAGES

Key ideas: Light from an object that gets reflected by a mirror appears to come from an image that is located behind the mirror. Multiple reflections create multiple images.

You will need:

- **two mirrors (15 cm × 15 cm, taped together along one edge)**
- **a pen, paper and a ruler.**

Perhaps you have been in the changing rooms in a clothing shop, and seen yourself a number of times, from the back and side, in the two mirrors supplied. Well, here's a way to multiply your pens (a handy thing to be able to do, if you keep losing them) or even your 10c coins!

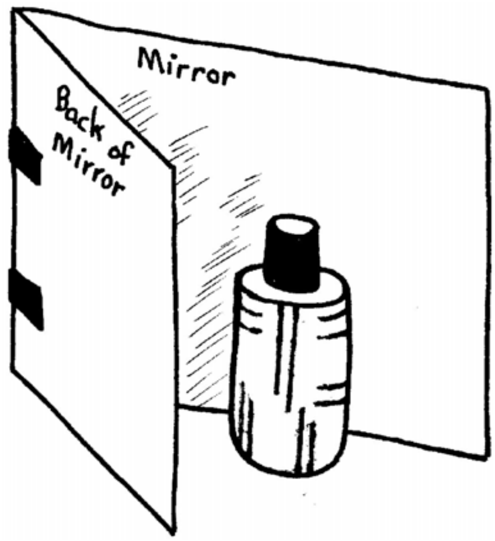
Join two upright mirrors together at the edge using tape, and stand a pen or a small bottle or statue in between. How many images can you see in the mirror?

Change the angle between the mirrors. How many images can you make? What is happening to the light scattered from your pen, to make so many images?

Rule some lines on your page, or draw some shapes or a word, and look what happens when the two joined mirrors are placed over them. You should be able to arrange some interesting and complicated shapes.

Use pictures and words from a book or magazine to create some mirror artwork.

If you use words, can their images be read? Can you work out a pattern?



As you bring the mirrors together, so that the angle between them gets smaller and smaller, you would expect to get an ever-increasing number of images. Of course, as the angle approaches zero, you can't see what is happening, but if you unstick the mirrors and stand them up facing each other with your pen in between, and peek over the top, you will see the effect. What would you expect to see?

ACTIVITY: AN INFINITY OF IMAGES

Key ideas: Light from an object that gets reflected by a mirror appears to come from an image that is located behind the mirror. Multiple reflections create multiple images.

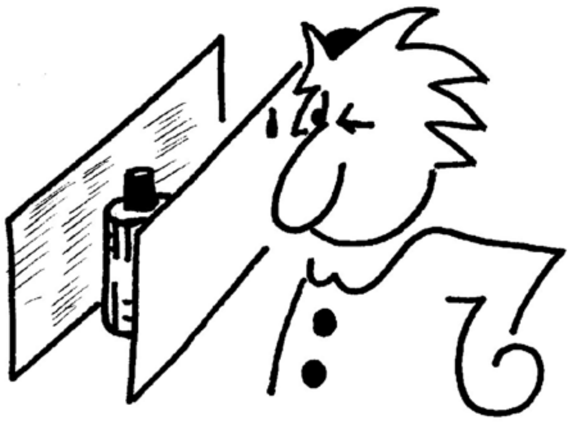
You will need:

- **two mirrors (15 cm × 15 cm) supported to stand vertically, one with a small hole scratched in the back**
- **a small object such as a figurine.**

Look through the small hole scratched in the backing of one of the mirrors facing each other.

This mirror arrangement was used in a Chinese description of what 'infinity' means.

Can you see an infinity of images? Why do you see so many? What are the mirrors doing?



ACTIVITY: CORNER MIRRORS: THE SURPRISING WINK

Key ideas: The image produced from a single reflection from a mirror is inverted. The image produced from a second reflection from a mirror is inverted twice.

You will need:

- **two mirrors as described in the *An infinity of images* activity above.**

Look at your own image in the two joined mirrors, and change the angle until you can see your face clearly. (If the angle is wrong, you will have a 'mutant' face, perhaps without a nose, or perhaps with one, three or four eyes. Don't be shocked—it's all done with mirrors!)

Move your head about. Your image always remains in the centre! Wink your right eye. Which eye winks back?

ACTIVITY: KALEIDOSCOPES

Key idea: Multiple images are produced from an object placed within a triangular arrangement of three mirrors.

You will need:

- **three mirrors, each approx. 2.5 cm × 12 cm**
- **coloured paper and white paper**
- **scissors.**

Kaleidoscopes have provided an endless source of fascination over the years. They come in various sizes, sometimes with moving attachments to add interest, or lenses to give a kaleidoscopic view of the world. A basic kaleidoscope is very easy to make.

Tape three long, thin mirrors together to form a triangle. Put a small object (a word, or pieces of coloured paper) on white paper and look at it through the kaleidoscope. How many images can you see? What shape are they? Are the images upside down (can you read the word)? How are the mirrors in the kaleidoscope causing these effects?

Make a drawing of the effects you see, to show how the images form. What is happening to the light through the kaleidoscope to create these effects?

You can use the kaleidoscope to create some wonderful effects. Here are some ideas to try:

- **Produce coloured patterns that look particularly good through the kaleidoscope.**
- **Draw one or two straight lines across the page. What shapes can you make from them in the kaleidoscope?**
- **Look at something moving, like a fan or a toy helicopter blade. Perhaps you could arrange for a disk of different coloured cellophane shapes to rotate in front of the kaleidoscope.**

- **Put a clear glass marble or a thick lens in front of the kaleidoscope and see the world in a new light!**
- **Put a piece of paper with a slit in front of your kaleidoscope.**
- **Predict what would happen if you inserted a pencil inside your kaleidoscope. Try it! (Be careful of your eye.)**

ACTIVITY: PERISCOPE

Key ideas: The image produced from a single reflection from a mirror is inverted. The image produced from a second reflection from a mirror is inverted twice.

You will need:

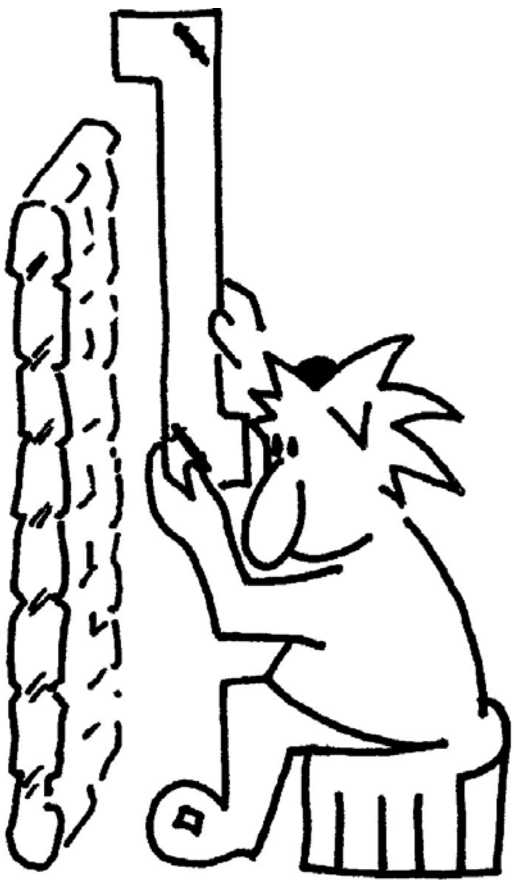
- **two small 8 cm mirrors**
- **a long cardboard tube or cereal box**
- **scissors or a knife**
- **sticky tape.**

A periscope is useful if you are in a submarine, or if you want to look over a tall wall, or even if you are in a crowd of tall people and want to see over their heads.

Use a long tube, or cardboard box, to make the periscope. Cut slits and use tape to fix two mirrors at the right angle to make your periscope. You may have to find a way to get the mirror angles right. What angles should they be at?

Would you expect the image to be upside down or the right way up? Is it back to front? If you use the periscope to look around a corner, is the image back to front?

Draw lines to show the path of light through the periscope.



Images and rays of light

ACTIVITY: PINHOLE CAMERA

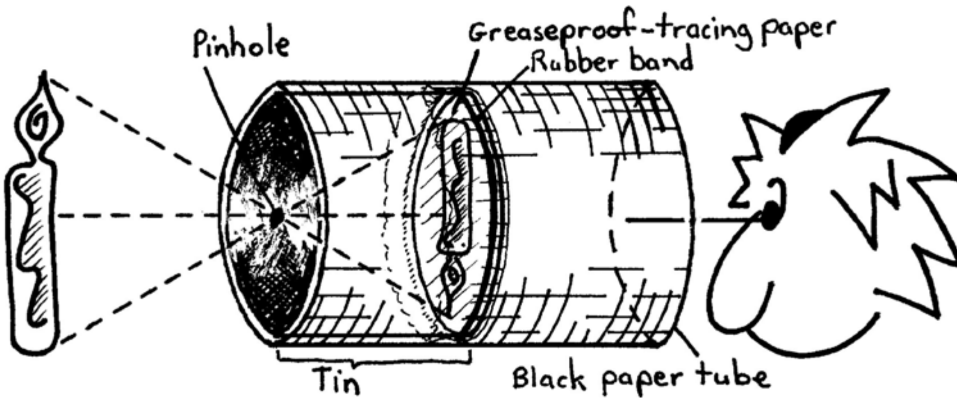
Key idea: A pinhole camera creates an image of an object on a screen by light passing through a small hole.

You will need:

- **a cardboard box (long and thin) or black paper tube, or a cylindrical tin**
- **a pin**
- **a rubber band**

- **scissors**
- **greaseproof tracing paper**
- **a candle**
- **matches.**

Make a pinhole camera, as shown in the figure below. It is best used in a darkened room to create an image of a bright scene outside. Any paper would allow an image to fall on it due to light coming through the pinhole, but the onion skin, or tracing paper, will allow the image to be seen from the other side. It helps to wrap some dark paper round to make a 'tunnel' in which the screen can be seen.



Where would light from the candle tip fall on the paper, if it passes through the pinhole? Where would light from the bottom of the candle fall onto the paper? Would the image be the right way up or upside down? Try out the camera. What would happen to the image of a candle if it was moved downwards? Try it. What would happen to the image of a candle as it is brought closer to the camera? Try it. What would happen if the hole was made larger? Try it.

Explanatory note: Both the *Pinhole camera,* and *How big is a mirror?* activities require the idea of 'ray tracing' to explain them fully. For the pinhole camera, light from any point of the scene below the horizon will pass through the pinhole to fall on the upper part of the image screen, and vice versa. The image is inverted. The camera design involves a compromise between sharpness and brightness. If the hole is small, within reason, the light from each point in the scene creates an equivalent point on the screen leading to a sharp, but dull image. If the hole is too large, the brightness is improved, but each object point becomes a patch of light in the image, which becomes blurred.

ACTIVITY: HOW BIG IS A MIRROR?

Key idea: To see a full image of yourself, you do not require a 'head-to-toe' length mirror.

You will need:

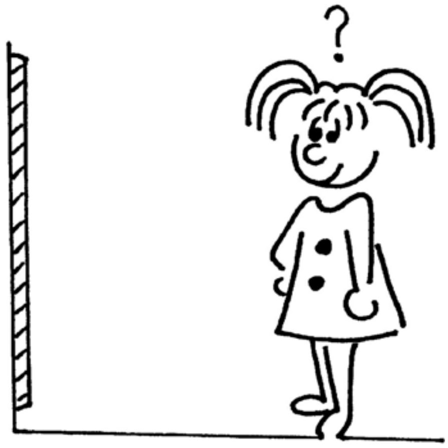
- **a mirror at least as large as the size of a head**
- **masking tape.**

How big does a mirror need to be for you to see all of yourself in it? How much of a mirror is needed to see your face?

Use two pieces of tape stuck across a mirror to mark the portion of the mirror needed to see from the top of your head down to your chin.

How does the distance between the pieces of tape compare with the length of your head from top to chin?

Perhaps you could try this with a full-length mirror, to see which part of the mirror is needed to see from the top of your head to the tip of your toes. Would you expect the same result?



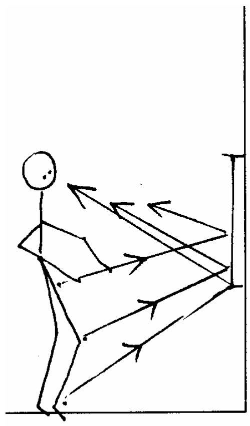
You should find that the mirror needs to be half the length of your head, or body. This is because you are looking at an image of yourself on the other side of the mirror. Looking into a mirror is like looking through a window at an image world.

Another way of understanding this is to consider light coming from your toes, reflecting from the mirror to your eye. The part of the mirror from which the light reflects is where you look to see your toes, and this is at half the height of your eyes, because of the way light reflects.

Explanatory note: The mirror size can be worked out by tracing a ray from the foot, reflecting off the mirror to the eye. This is the point on the mirror at which the foot can be seen. Any mirror section below this halfway point is not needed to see the reflection. Refer to the figure below.

Another way of looking at this is to imagine the mirror as a window through which an image world is viewed. Drawing lines from the eye to the image will show that this 'window' must be half the size of the person.

FIGURE:
MIRROR SIZE



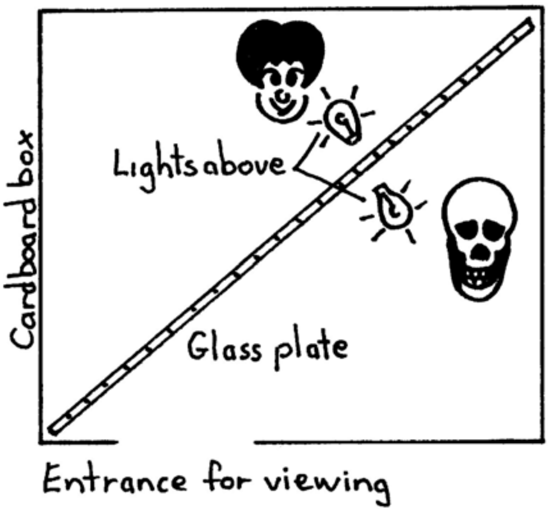
ACTIVITY: MAGICIAN'S ILLUSION

Key idea: Part of the light incident on plane glass will pass through; the rest is reflected.

You will need:

- **two dolls (one dressed as a skeleton)**
- **black paint**
- **cardboard box**
- **glass plate**
- **two shaded lights.**

Some famous illusions performed by magicians depend on the use of mirrors. In one illusion a man sitting at a table gradually disappears to be replaced by his skeleton! You can make your own version of this illusion using a plate of glass diagonally across a box painted black. The two dolls (one dressed as a skeleton) are lit by two separate, shaded lights.



Why is a plate of glass used, rather than a mirror?

The position of the dolls is important. Where must they be? Each light must illuminate only one doll, and not the other. Why?

Why is the inside of the box painted black?

Explanatory note: If you illuminate the doll the glass plate will act like a window. From the viewing entrance only the doll will be seen. However, if the doll's light is turned off and the light to the skeleton is turned on, the glass plate will act like a mirror (as do your windows at night). From the entrance one will now be able to see the image of the skeleton, located behind the mirror at the same position as the doll.

Bending light

While a proper consideration of the way refracted light creates distorted images is beyond primary school treatment, the powerful notions of light bending and images distorting can be readily observed in a range of everyday phenomena.

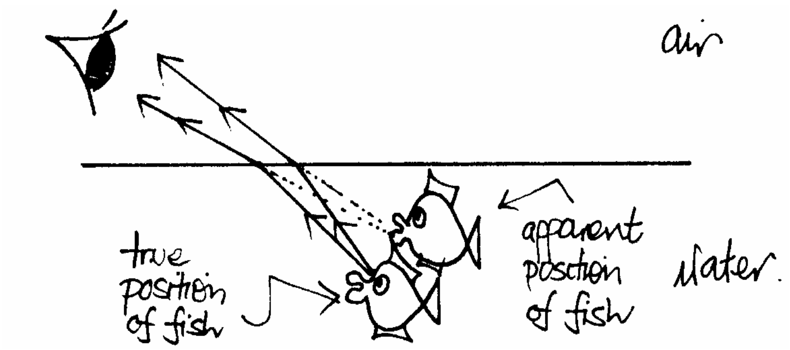
Explanatory note: Refraction of light is a phenomenon associated with light passing from one transparent medium into another. For example, refraction occurs when light passes from air into water. Quite often the light changes direction when passing from one transparent medium into another. Similarly to images in plane and curved mirrors, each time light gets redirected an image is formed.

The effects in each of the activities in this section can be explained by the redirection of light that comes from the object we are looking at. The redirected light appears to come from other points in space than the position of the object, and so we see images of the object. Whereas in plane mirrors we observe exact copies of the object, when we observe objects through transparent material such as glass or water we observe distorted copies of the object. The underlying reason for the effects is that light has changed direction in passing through transparent materials. The phenomenon where light passes through transparent materials is called ‘refraction’.

The reason light changes direction in passing from one transparent material into another is because it changes speed. Light is fastest in space and slows slightly when it enters our atmosphere. There is a significant drop in speed when light enters water. Light is slowest in diamond (it is responsible for diamonds sparkling).

An example of a refraction effect is observing fish in a tank. Because the light from the fish changes direction at the surface of the water, when it enters the eye of the observer, the light appears to come from another place than where the fish actually is. The observer will see an image of the fish.

FIGURE: A REFRACTION EFFECT



ACTIVITY: DISAPPEARING COIN

Key ideas: Light may change direction when passing into or out of transparent objects. Light from an object that changes direction after passing through a transparent object will create an image.

You will need:

- **a clear round glass full of water**
- **a small coin**
- **a sheet of paper**
- **a saucer.**

Your friends won’t like it when you make their money disappear but, on the other hand, you should be popular when you make it magically reappear!

The coin can still be seen through the top surface of the water, but you might like to place a saucer on top to stop this being seen.

Place a 5c coin on a sheet of paper. Place a glass full of water over the top. The coin cannot be seen, looking through the sides of the glass!

ACTIVITY: APPEARING COIN

Key ideas: Light may change direction when passing into or out of transparent objects. Light from an object that changes direction after passing through a transparent object will create an image.

You will need:

- **an opaque cup (china or plastic)**
- **a small coin**
- **a jug for water.**

Place your 5c coin at the bottom of an opaque (china or plastic) cup, and move your eye down so that the coin is just hidden by the rim of the cup.

Keeping your head steady, pour water into the glass. The coin comes into view!

ACTIVITY: ENCASED IN GLASS

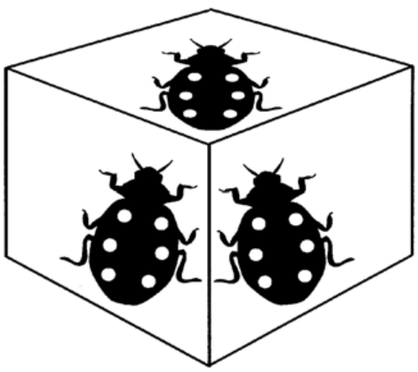
Key ideas: Light may change direction when passing into or out of transparent objects. Light from an object that changes direction after passing through a transparent object will create an image.

You will need:

- **biological specimens encased in perspex or glass.**

A block of glass or perspex is a wonderful thing! If you look through it from different directions you will notice some strange effects and distortions. Sides act as mirrors, if you look through at an angle. Objects appear in strange places.

Ask a friend to hold the block up in front of their eye. It appears to float out from their face! That is because the block appears thinner than it is, due to the bending of light (refraction).



Look at and through the block. How many observations can you make?

A biological specimen encased in perspex can be seen a number of times, because of the bending of light coming out of the sides of the block. The specimen seems to be closer to the surfaces than it really is, and its position seems to shift as you move the block around. You notice the same thing if you look at fish in a tank. Water and perspex and glass all bend light as it enters or leaves the surface. Light is wonderful for creating illusions!

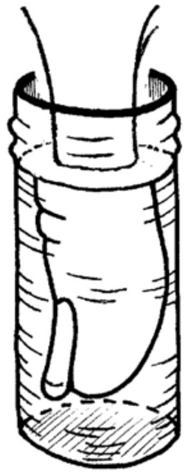
ACTIVITY:
THICK THUMB

Key ideas: Light may change direction when passing into or out of transparent objects. Light from an object that changes direction after passing through a transparent object will create an image.

You will need:

- **a narrow, cylindrical jar large enough for a finger (3 to 4 cm wide and 6 cm tall)**
- **water.**

Partly fill a small round jar with water. The jar should be slightly larger than your finger or thumb. An olive jar or spice jar is a good size. Stick your finger in the jar. It blows up!



But before you call the doctor, think about what you are seeing. Where is the light being bent?

Move your finger around in the jar. Is the distortion always the same?

You can create a similar effect in a glass of water, using a tube of toothpaste, a carrot, or something of similar shape.

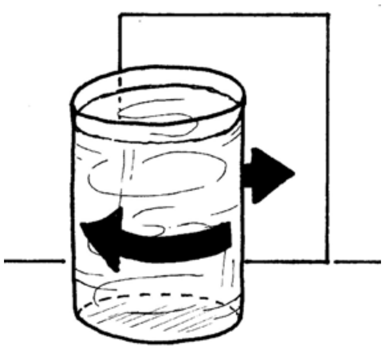
ACTIVITY:
CHANGE
DIRECTION!

Key ideas: Light may change direction when passing into or out of transparent objects. Light from an object that changes direction after passing through a transparent object will create an image.

You will need:

- **a clear round glass**
- **water**
- **a sheet of paper and a pencil**
- **an upright screen.**

Draw an arrow pointing left, on a piece of paper attached to an upright screen. Place a full glass of water in front of the arrow. If you get the position right, the arrow changes direction!



Could you use this glass to decode mirror writing?

ACTIVITY:
GLASS ROD
READING AID

Key ideas: Light may change direction when passing into or out of transparent objects. Light from an object that changes direction after passing through a transparent object will create an image.

You will need:

- **a glass rod**
- **a line of writing.**

A glass rod, sitting over the top of a line of writing, can give a magnified image. The light from the page is bent as it passes into the glass and out again.

Is the image magnified or shrunk? Is it the right way up?

ACTIVITY: MULTIPLYING MEASURER

Key ideas: Light may change direction when passing into or out of transparent objects. Light from an object that changes direction after passing through a transparent object will create an image.

You will need:

- **a perspex ruler with trapezoidal cross-section**
- **a pen.**

Do you have a problem with losing pens? Here is a possible answer to your problems! Place a pen down on the table. Take a perspex ruler, of the type with two angled sides and a flat centre section, and hold it between the pen and your eye. If you get the position right, you should see not one but three pens: one in each section of the ruler!

ACTIVITY: WATER DROPLET LENSES

Key ideas: Light may change direction when passing into or out of transparent objects. Light from an object that changes direction after passing through a transparent object will create an image.

You will need:

- **thin, pliable wire**
- **water**
- **a large nail**
- **scissors to cut the wire.**

Take a thin wire and twist it around a nail to form a small loop. If you dip the loop in water, a small round drop should form inside it. (If it doesn't, your loop is probably too large.)

If you hold this loop close to the writing on this page, you should see it has a magnifying effect. Very early microscopes used drops of liquid, such as honey or water, for lenses. Some of these were capable of high magnification.

Explanatory note: The phenomenon of refraction, in which light is bent in going from air to water or glass, gives rise to distortions. If the glass or light surface is straight, then the image is not distorted in shape but appears closer to the surface than it really is. This is the effect we notice when we look down, standing in waist-deep water. Our legs look fat and dumpy (certainly not true in real life!) and our feet look closer than they should be. That is, any pool of water looks shallower than it really is.

In the *Disappearing coin* activity, the reason the coin cannot be seen is that light from the coin that hits the side of the glass cannot get out to be seen. It is ‘totally internally reflected’, and so is trapped inside the glass. This reflected light can be seen if you look from the top. You will see an upside-down, distorted coin reflected in the walls of the glass, as well as the coin viewed directly through the bottom.

In the *Appearing coin*, the coin can be seen over the rim of the glass because the light is bent by the water surface. The image of the coin hovers above the actual coin position, making the water appear shallower than it actually is. This is related to the swimming-pool effect described above.

Encased in glass involves the glass acting in a similar way to a water surface, with the glass appearing shallower than it really is, and the insect likewise appearing close to the surface. The effect increases with the angle of view. Extra effects are noticed because of the reflections that occur from the inside surfaces.

When the surface is curved, distortions and inversions can occur, as the surface acts like a lens. This is true of the *Thick thumb*, in which the curved surface acts like a magnifier, and also in *Change direction*. The glass acts as a lens, forming a back-to-front image of the arrow. The image is formed between the glass and your eye!

Colour

ACTIVITY: COLOUR PUZZLE

Key idea: Coloured cellophane only allows certain colours of light to pass through it.

You will need:

- **various coloured sheets of cellophane**
- **coloured paper**
- **torches.**

Look through the coloured cellophane at different coloured paper. What colour do you see?

Design a method of recording and presenting your results that includes the colour of the cellophane, colour of the paper without cellophane, and colour of the paper looking through cellophane.

Create a ‘colour puzzle’ page by arranging coloured cellophane over coloured sheets. Other members of the group are to identify the colour of the sheet.

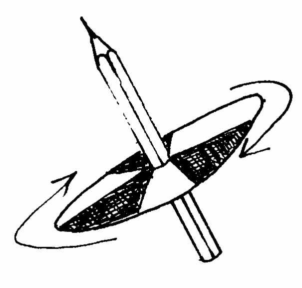
ACTIVITY: COLOUR WHEEL

Key idea: Lights of different colour mix differently to coloured pigments in paints, pencils and crayons.

You will need:

- **circular sheets of coloured cardboard, or textas**
- **circular sheets of white cardboard**
- **pencil**
- **scissors**
- **glue.**

Cut out circular sheets of coloured cardboard and divide the circles into segments.



On the white circular cardboard glue segments of two different colours, say green and red. Alternatively, colour-in segments on the white circular cardboard with textas.

Put a hole in the centre of the wheel and spin it on a pencil. Observe the coloured mixture.

Construct a colour wheel which:

- **looks brown when spun even though there is no brown on the wheel**
- **looks green when spun even though there is no green on the wheel.**

ACTIVITY: COLOURED PICTURES

Key idea: Coloured paints can be mixed to create lots of different colours.

You will need:

- **red, blue and yellow tubs of paint**
- **white paper**
- **a brush, and water for cleaning it between colours.**

Use red, blue and yellow paints to create multicoloured squares on the white paper. How many colours can you create? Take a note of the colours and amounts of paints you mixed for each coloured square made.

ACTIVITY: MIXING COLOURED LIGHTS AND PIGMENTS

Key ideas: The primary colours of light are red, green and blue. These primary colours produce all the colours we see on television or on computer screens. The primary colours of pigments are cyan, magenta and yellow; these primary colours produce all the colours we see in magazine pictures and books.

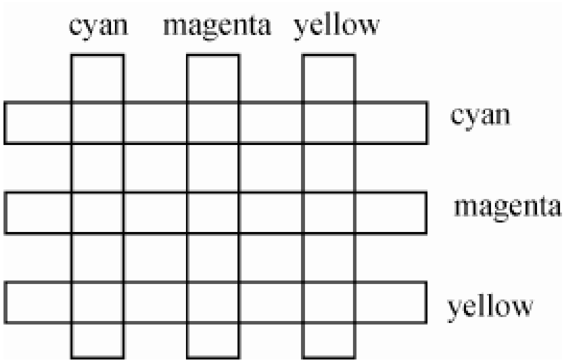
You will need:

- **a computer**
- **a colour printer.**

Coloured lights can mixed very effectively using a computer. To do this open a Word document. Create a rectangle or circle using one of the autoshapes on the toolbar. Now colour your shape (fill colour) using the palette on the toolbar. You have a choice of colours or you have a choice of 'more fill colours'. Enter 'more fill colours' and then enter 'custom'. This will allow you to create your own colour by adding various intensities of red, green and blue. Try just mixing red and green.

What mixture do you get? Mix all the colours equally. Try different shades of colours. Any colour is possible by mixing the right proportions of red, green and blue.

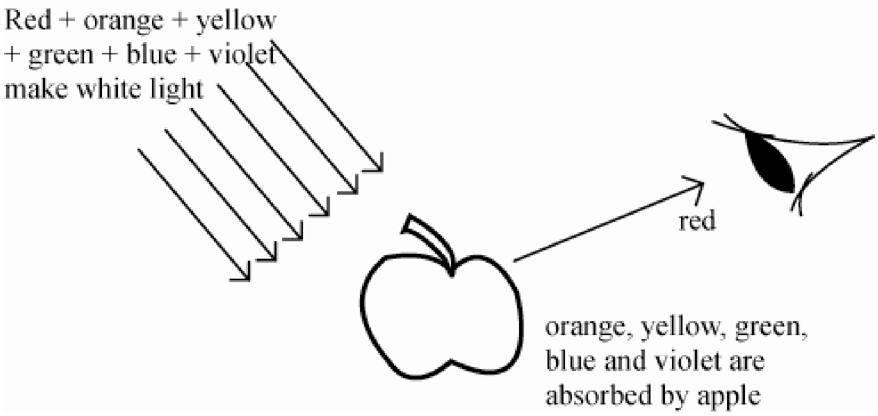
If you can get access to a coloured printer, try mixing the primary coloured pigments. This can be done by first printing off a series of coloured strips horizontally and over the top of this sheet reprint a series of vertical coloured strips. The intersections of the strips coincide with the coloured mixtures. If you mixed magenta ink with green ink what colour would you perceive when white light is shone onto the mixture?



Explanatory note: We know that to see an object, light must reflect off it and enter our eyes. We also know that we don't get blinded when we look at most objects, which means that some of the light from luminous objects, such as the sun, gets absorbed by the object. From a scientific perspective, the colour of an object is the colour of the light that is reflected into our eyes. All the other colours in the light from the sun gets absorbed by the object (light from the sun is composed of different coloured light: these are the rainbow colours—red, orange, yellow, green, blue and violet).

This view contrasts with most people's understanding of coloured objects. That is, objects are composed of particles that are coloured. This misconception is reinforced often in our everyday speech. For example, to say 'I'm wearing a red jumper' implies that the jumper is made of red particles. To be scientifically accurate one should say 'I'm wearing a jumper that will reflect red light'. Objects are not composed of coloured particles. They just reflect certain colours of light and absorb other colours. The figure below indicates how we perceive the colour of an apple.

FIGURE: COLOUR OF AN APPLE



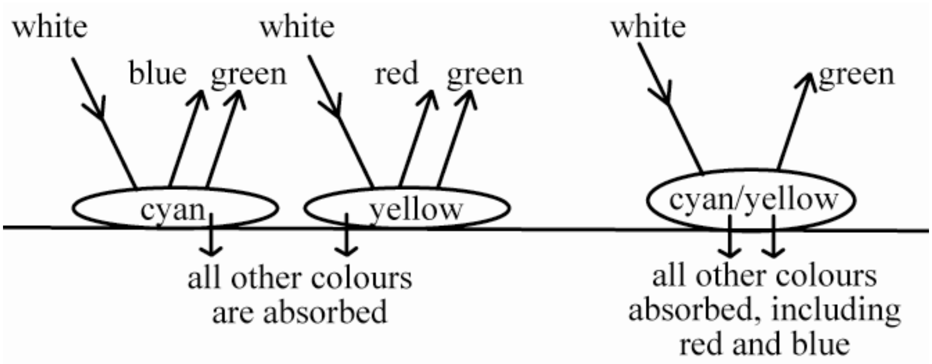
Just as white light can be split into the colours of the visible spectrum, coloured light can be recombined to form white light. However, all the colours are not needed for humans to perceive white light. Three colours are required: red, blue and green. These are the primary colours for light. A colour television uses these three colours. Mixing paired combinations of these colours produces the secondary colours for light. For example, mixing red and green produces yellow. Then mixing yellow and blue will produce white light. Thus yellow and blue are said to be complimentary colours of light. Two primary colours add together to produce the complementary colour of the third primary colour. Refer to the table below.

TABLE: MIXING THE PRIMARY COLOURS OF LIGHT

Colour mixture	**Resultant colour**	**Complimentary colour**
Red + Green	Yellow	Blue
Blue + Green	Cyan (aqua)	Red
Red + Blue	Magenta (crimson)	Green

The primary colours for pigments (ink colours in printers) differ from the primary colours of light. The primary colours of pigments are cyan, magenta and yellow. Newspapers, magazine and book printers use just these coloured inks in their printing. In producing colours such as red, blue and green, consider the following example. A cyan ink will reflect both blue and green light when white light is incident upon it (as suggested by the table above) and absorb red light. Similarly, yellow ink will reflect both red and green light but absorb blue light if white light is incident. Therefore, by mixing cyan and yellow inks, both blue and red light will be absorbed, leaving only green light to be reflected. Cyan plus yellow pigments make a green pigment. By mixing all the coloured pigments we should achieve black, as none of the primary colours of light are reflected if white light were to be shone onto the mixture.

FIGURE: PIGMENTS



The table below gives all the resultant colours from mixtures of the primary colours of pigments.

TABLE:
MIXING THE PRIMARY COLOURS OF PIGMENTS

Colour mixture	**Resultant colour**
cyan + yellow	green
yellow + magenta	red
magenta + cyan	blue

This colour theory only uses six colours, but the human eye can perceive an almost limitless number of different colours. However, televisions employ just the three primary colours of light and printing uses just the three primary colours of pigments in inks. (Printers also use black ink to reproduce colours.) Therefore, various strengths and combinations of colour mixtures can produce the variation in colours that we perceive.