



### To study

Colour vision depends on receptor cells in the retina, called *cones*. Each type of cone responds to the stimulus of a different colour of light. There are blue, red and green cones.

Other receptor cells, also in the retina, respond to light as a general stimulus but not to different colours.

### To do

#### Make a prediction

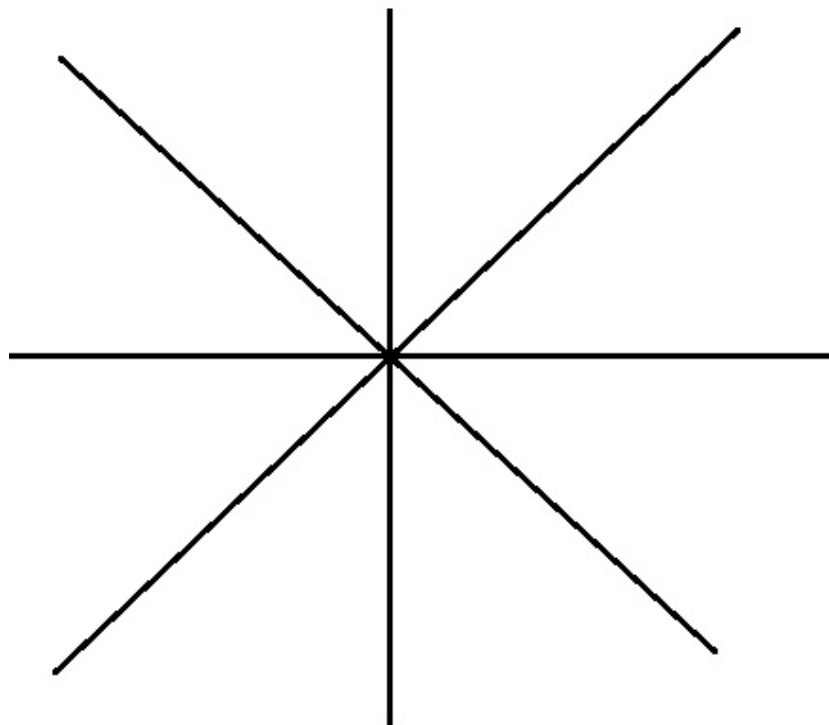
You will make a model for red and blue colour vision.

Your model will be a colour vision map. It will show the outer limit of where you can see blue and red in your field of view.

**1** Imagine you are facing the grid below, and are looking straight ahead at the centre of the grid using one eye. The centre of your field of view is where the lines cross.

Coloured objects will be moved along the lines across your field of view from the edge to the centre. On each line mark with a cross where you think you will first see:

- a** an object in your field of view
- b** the colour red
- c** the colour blue.



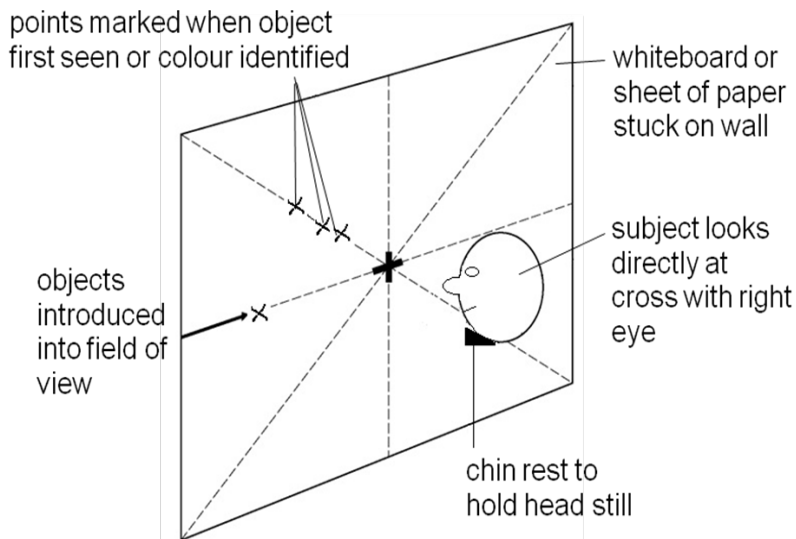
**2** Explain why you have predicted this pattern.



## Gathering evidence to test models of colour vision – Student sheet

### Collect evidence

3 Use the experiment set-up shown in the diagram below to test your predicted model.

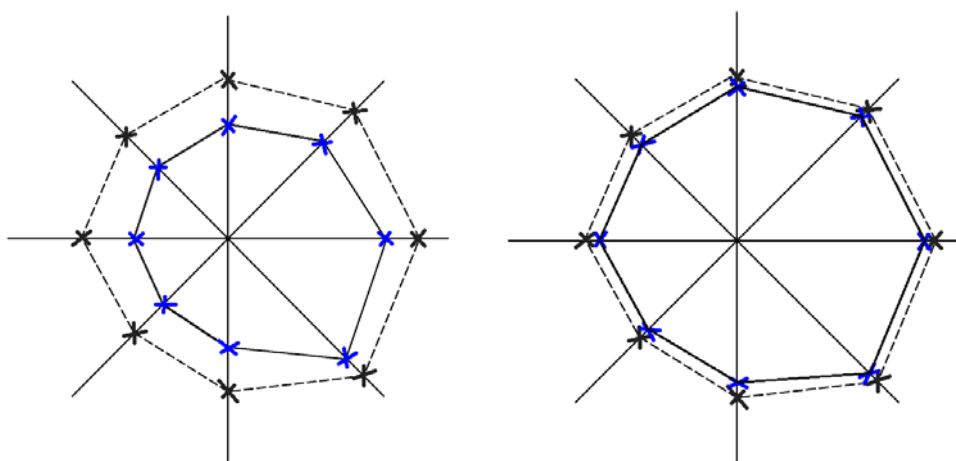


4 Draw straight lines to join the crosses which map where you first see an object.

Draw straight lines to join the crosses for where you are first sure of the colour of a blue object.

Draw straight lines to join the crosses for where you are first sure of the colour of a red object.

The examples below have a line for 'first see object' and 'first see blue' only. Your model should also have a line for 'first see red'.



#### Map key

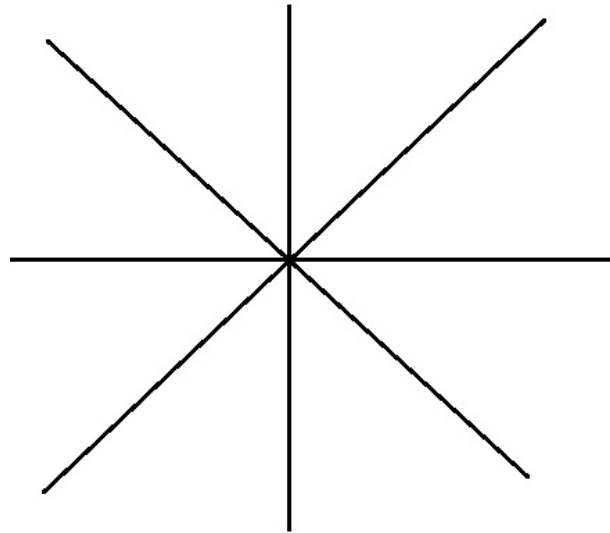
First see object - - - - -  
First see 'blue' ————



**Colour vision: Assessing learning**

**To answer or to discuss**

**1** Sketch the model you drew from the experimental data. Use the grid provided.



**2** Summarise your evidence in a series of short statements. For example:

‘The person tested has exactly the same field of view for the colours red and blue.’

.....

.....

.....

.....

**3** Summarise the similarities and differences between your predicted model and the one you produced from the data. Use the table below.



Prediction	Data supporting or contradicting the predicted model
My first model predicted that .....	

#### 4 Read this information about colour vision.

Scientists have studied the cells in the retina.

They have found that there are around seven million cones in the retina.

64% of these are red cones, sensitive to red light.

34% are green cones and 2% are blue cones.

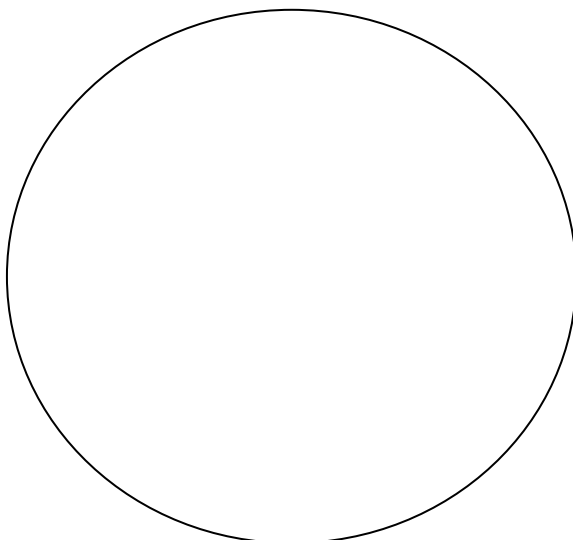
The blue cones are mainly outside the central area of the retina.

The red and green cones are concentrated in the centre of the retina.

Outside the central region of the retina there are few cone cells.

Other receptor cells in the outer regions of the retina detect light, but do not detect different colours.

- a** Use this information to draw a simple sketch showing the position of cones on the retina. Use the outline provided. Add notes and labels to explain what your sketch shows



Outline of the retina



**b** Write a short statement linking:

- the model produced in your experiment
- your sketch of the retina
- the information about cones in the retina.

.....

.....

.....

**c** Compare your answer with the model answer provided. Suggest how your answer could be improved.



## Gathering evidence to test models of colour vision – Teacher guidance

### Learning structure of the lesson

<p><b>The big picture</b></p> <p>This lesson is designed to exemplify a model-based inquiry approach to practical work. It is based around a model for human colour perception which describes colour-sensitive receptors (cones) in the retina.</p> <p>Students use their own ideas to make a prediction about the outcomes of an experiment to test colour vision. By gathering evidence of colour perception in the field of view, students build a model in the form of a map to help them understand what is happening on the retina. They then relate their map to the distribution of receptors (cones) in the retina, for different colours of light. They use the collected data to critique both their predicted model and the consensus model.</p>		<p><b>Age range:</b> 14–16 or 16–18</p> <p><b>Timing:</b> 50 minutes</p>
<p><b>Learning episode 1 (teacher-led) 10 mins</b></p> <p>Share the learning outcomes with students, then use the interactive to help students organise what they already know.</p> <p>Present the context for the activity and ask students whether they see all colours just as well across their whole field of view.</p> <p style="text-align: center;">↓</p>	<p><b>Learning outcomes</b></p> <p>Students will be able to:</p> <ul style="list-style-type: none"> <li>recall that different kinds of receptors in the retina are stimulated by different colours</li> <li>predict a model for colour vision</li> </ul>	<p><b>Equipment and materials</b></p> <p>Teacher guidance Practical guidance Slide presentation Interactive Video 1 Video 2 Student sheet Practical sheet</p> <p><b>Per group</b> Ruler, 1 metre long Coloured pens or pencils, one red, one blue (or coloured spot on a long strip of white card)</p> <p>Blu-tack A3 paper, one or two sheets</p> <p style="text-align: center;"></p> <p>Refer to the health and safety advice and practical guidance</p>
<p><b>Learning episode 2 (student-led) 20 mins</b></p> <p>Introduce the method to map the ability to see in colour across the field of view.</p> <p>Students work in small groups to make a prediction in the form of a map of colour vision for their field of view. They explain their reasoning for their prediction.</p> <p style="text-align: center;">↓</p>		
<p><b>Learning episode 3 (student-led) 10 mins</b></p> <p>Students carry out the practical activity and collect evidence of their ability to discriminate colours in different areas of their field of view.</p> <p style="text-align: center;">↓</p>	<ul style="list-style-type: none"> <li>evaluate and refine the predicted model using experimental evidence</li> <li>describe the arrangement in the eye of receptors for different colours of light</li> </ul>	
<p><b>Learning episode 4 (student-led) 10 mins</b></p> <p>Students work in small groups to discuss the evidence they have collected and what it shows. Does it match their prediction? How might their model for colour vision need to be revised?</p> <p><i>Homework:</i> Complete the assessment questions which provide an opportunity for students to relate their model to the distribution of cones in the retina.</p>		
<p><b>Key words</b></p> <p>Cone, light-sensitive cells in the retina, retina, field of view, model</p>		



## Gathering evidence to test models of colour vision – Teacher guidance

### Prior knowledge

It is assumed that students know the following.

- Cells called receptors detect stimuli (changes in the environment).
- Receptors in the eyes are sensitive to light.
- When light reflected from an object (a stimulus) hits the receptors in the retina, impulses are sent to the brain.
- The brain interprets the impulses from the eye and builds a picture of the world around us.

### Background information

Colour vision relies on three types of light-detecting cells (cones). These are concentrated in the central area of the retina. One type of cone is sensitive to red light, another to blue light, and a third to green light. This set of colours might be counter-intuitive to students who are used to mixing pigment colours, but it matches the colours of LEDs in television screens and the RGB mix for colours on computer desktop software.

Red light entering the eye falls on the retina and stimulates 'red' cones. Red cones then send a signal to the brain, which is interpreted as 'seeing' the colour red. Blue light falling on the retina results in the brain 'seeing' the colour blue. Stimulation of green cones by green light results in 'seeing' the colour green.

Colours such as purple and yellow are 'seen' when different combinations of cones are stimulated. For example, seeing purple relies on blue and red cones being stimulated at the same time.

The distribution of the three types of cones on the retina affects people's ability to see different colours in each area of their field of view. For example, imagine that there were only red cones on one side of the retina of the left eye. It would not be possible to see blue or green on the opposite side of the field of view.

This lesson focuses on just blue and red cones for simplicity. The activity allows students to gather evidence to support or reject their predicted model.

Students might predict that blue-sensitive receptors and red-sensitive receptors will be evenly distributed across their retina. Or they might think that the receptors are arranged in clusters on the retina or in some other pattern. If they think they see all colours equally well across their whole field of view, they should predict an even spread of each type of receptor. Any pattern a student predicts is also a model that can be tested by the practical investigation.

### Colour-blindness

Most humans can see in colour, although 8% of males and 0.5% of females have some form of colour-blindness.

One or more students in a class may have a degree of colour-blindness. This will affect the results of this experiment, so be aware that it may arise in the



## Gathering evidence to test models of colour vision – Teacher guidance

course of the activity. Some students will be interested in the opportunity to explore differences between their vision and that of others, but be aware that some students may be uncomfortable about discussing it and unwilling to draw attention to their unusual perception.

### Terminology

The terms which students need to understand and use in this lesson are:

**cone** – light-sensitive cells in the retina of the eye. Cones are concentrated in the central area of the retina and function best in relatively bright light. Three types of cone cell are sensitive to different wavelengths of light, roughly equivalent to the colours red, blue and green. Different colours of light entering the eye stimulate different combinations of cone cells. This allows us to perceive colour as our brains interpret the information from several receptors.

**retina** – a layer of light-sensitive tissue lining the inner surface of the eye.

**field of view** – the extent of someone’s surroundings which can be seen at any moment.

**model** – a mentally visualisable way of linking theory with experiment. Models enable predictions to be formulated and tested by experiment.

### Optional extension activities

Students could devise a method for assessing the fine detail of the distribution of cones on the retina. An example would be a machine flashing points of light of different colours on and off in the field of view; the subject has to signal that they have seen the light and identify the colour correctly. Some students may have experienced this (without colours) for peripheral vision determination at an optician. Issues of experimental design can be discussed.

Research how images from MRI scans provide information about activity in different parts of the brain: vision centre, sound centre, and so on.

### Related practical activities on Practical Biology / Practical Physics

Colour vision:

[www.nuffieldfoundation.org/practical-biology/investigating-how-we-see-colour](http://www.nuffieldfoundation.org/practical-biology/investigating-how-we-see-colour)

Receptors and stimuli:

[www.nuffieldfoundation.org/practical-biology/assessing-skin-sensitivity-%E2%80%93-touch-discrimination](http://www.nuffieldfoundation.org/practical-biology/assessing-skin-sensitivity-%E2%80%93-touch-discrimination)

[www.nuffieldfoundation.org/practical-biology/assessing-skin-sensitivity-%E2%80%93-locating-different-receptors](http://www.nuffieldfoundation.org/practical-biology/assessing-skin-sensitivity-%E2%80%93-locating-different-receptors)

How the brain interprets our surroundings:

[www.nuffieldfoundation.org/practical-biology/practice-makes-perfect](http://www.nuffieldfoundation.org/practical-biology/practice-makes-perfect)

The physics of the eye:

[www.nuffieldfoundation.org/practical-physics/eye](http://www.nuffieldfoundation.org/practical-physics/eye)





## Lesson details

### Slide 2

#### Learning outcomes

You will be able to ...

- predict a model for colour vision
- evaluate and refine the predicted model using experimental evidence.



**Task:** Use **slide 2** to present the learning outcomes for the lesson.

### Interactive



**Task:** Use the **interactive** to check/revise students' understanding of the parts of the eye and their function.

Emphasise the parts of the eye that are relevant to this activity:

- where the cones are in relation to the retina
- how the retina sends signals to the brain via the optic nerve.

Make sure students understand the terms model, retina, cone, and field of view.

### Video 1



**Task:** Students discuss the question at the end of the interactive: 'Can you see all colours just as well across your whole field of view?'

They are likely to answer 'yes' to the question – they might never have noticed any situation where the variation in colour perception across the field of view is obvious.

The question sets the challenge for the inquiry. Students are asked to make a prediction and give reasons for their prediction. In this case their reasons might include evidence from their own experience.

**Task:** Play **video 1** to show students how to test this out and then get them to do this for themselves.



# Gathering evidence to test models of colour vision – Teacher guidance

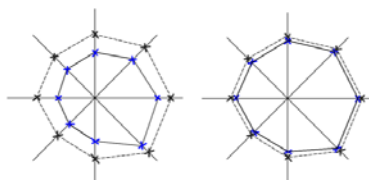
## Slides 3-4

### Mapping the retina: a model for the arrangement of cones

points marked when first seen or colour identified

objects introduced into field of view

### Modelling the retina



Map key  
First see object - - - - -  
First see 'blue' - - - - -



## Video 2



**Task:** Use slides 3 and 4 and video 2 to introduce the method used to map the ability to see in colour across the field of view.

## Student sheet

Gathering evidence to test models of colour vision: Student sheet



### To study

Colour vision depends on receptor cells in the retina, called cones. Each type of cone responds to the stimulus of a different colour of light. There are blue, red and green cones.

Other receptor cells, also in the retina, respond to light as a general stimulus but not to different colours.

### To do

#### Make a prediction

You will make a model for red and blue colour vision.

**Task:** Students work in small groups and using the Student sheet and slide 5 make a prediction in the form of a map of colour vision for their field of view. They explain their reasoning for their prediction.

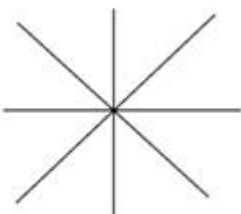
Discussing their results in small groups gives students the opportunity to organise their ideas. They compare their results with their prediction. If the two do not match they need to consider whether their model needs to be revised, and if so, how.

## Slides 5

### Predict your model to test

Draw a grid like this one.

Sketch a map which predicts how you think you see red and blue across your field of view.

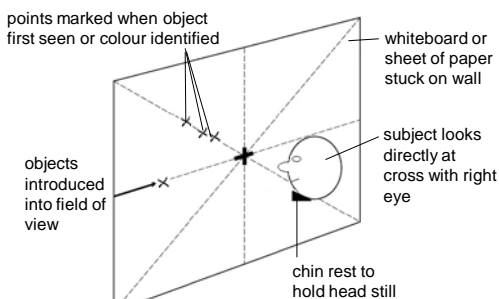




# Gathering evidence to test models of colour vision – Teacher guidance

## Slides 6

### Collecting the data



**Task:** Students work through the protocol on the **Student sheet**, thinking how it relates to model. See also **slide 6**.

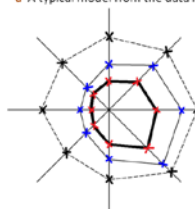
**Differentiation:** Assist students if the protocol is not understood. If students are confident of the method, they could introduce blue and red pens randomly, rather than recording results for red followed by blue, reducing errors as a result of students knowing what the colour is.

**Task:** Students work in small groups to discuss the evidence they have collected and what it shows. Does it match their prediction? How might their model for colour vision need to be revised?

## Slide 7 –12

### Assessing learning

a A typical model from the data might look similar to this one



Map key  
First see object - - - - -

### Assessing learning

b Statements might include:

- ✓ The person tested has a larger field of view for blue than for red.
- ✓ The field of view for colours is smaller than the total field of view.
- ✓ The field of view is larger to the right of the right eye.

**Task:** Students complete the assessment questions. Peer- or self-assessment can use the model answers provided on **slides 10–15** or at the end of this guidance.

The emphasis should be on discussing students' ideas.

### Assessing learning

c The similarities and differences between your predicted model and the one you produced from the data might include:

#### Prediction

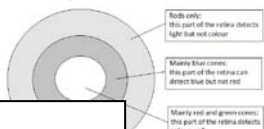
My first model predicted that, at the edges of your field of view you would be able to see the objects before you can see what colour they are.  
I predicted that there is no difference between the field of view for red and blue.

#### Data which supports or contradicts the predicted model

The line joining the points where the person could see the objects before they could see what colour they are.  
The sketch shows that the field of view for red and blue is the same.

### Assessing learning

d Your sketch might be similar to this.



### Assessing learning

e Your statement might include:

The data shows that you can see objects at the edge of your field of view before you can see what colour these are. This suggests that there are no cones in the outer regions of the retina.

As objects move towards the centre you detect the colour blue before the colour red. This suggests that 'blue' cones are more numerous in the inner retina, but red cones are even more numerous in the inner retina.

Continued...

### Assessing learning

e Your statement might include:

Continued...

The sketch of the retina shows these rings of different types of cells in the retina.

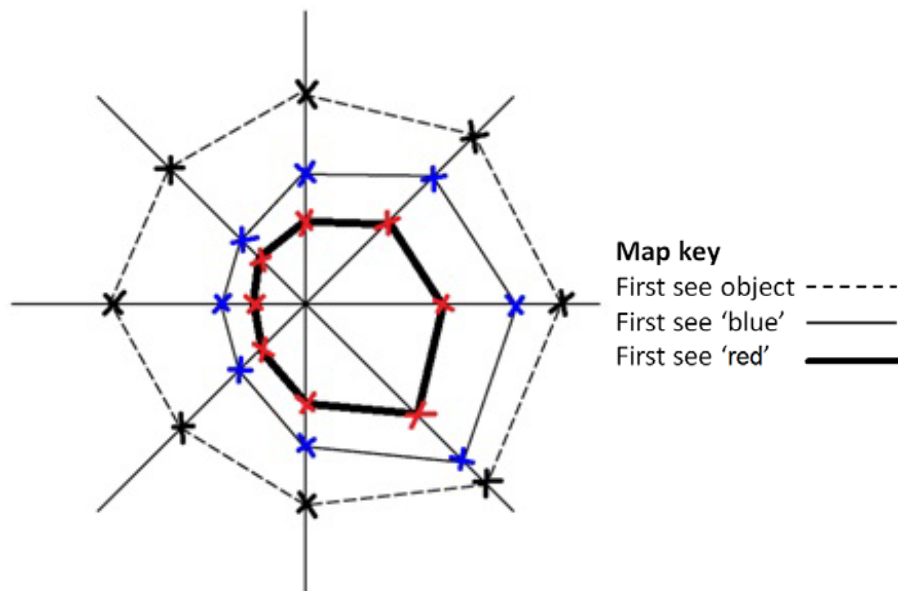
The information from scientists studying the retina supports the model produced from the data and the model sketch of the retina.



## Gathering evidence to test models of colour vision – Teacher guidance

### Assessing learning: Answers

- a A typical model from the data might look similar to this one.



- b Statements might include:

The person tested has a larger field of view for blue than for red.

The field of view for colours is smaller than the total field of view.

The field of view is larger to the right of the right eye.

- c The similarities and differences between your predicted model and the one you produced from the data might include:

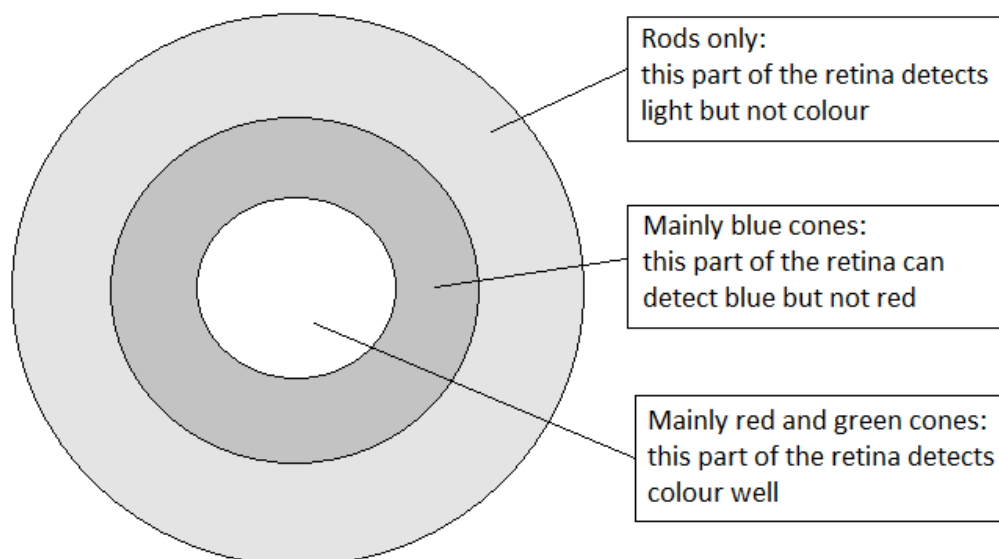
Prediction	Data which supports or contradicts the predicted model
My first model predicted that, at the edges of your field of view you would be able to see the objects before you can see what colour they are.	The line joining the points where the person could first see an object is outside the line showing where they could first see a colour.
I predicted that there is no difference between the field of view for red and blue.	The map produced from the data shows that the field of view for red is smaller than the field of view for blue.



## Gathering evidence to test models of colour vision – Teacher guidance

d Your sketch might be similar to this.

### Outline of the retina



e Your statement might include:

The data shows that you can see objects at the edge of your field of view before you can see what colour these are.

This suggests that there are no cones in the outer regions of the retina.

As objects move towards the centre of your field of view, you can detect the colour blue before the colour red.

This suggests that 'blue' cones are spread over the centre of the retina, but red cones are even more central.

The sketch of the retina shows these rings of different types of cells in the retina.

The information from scientists studying the retina supports the model produced from the data and the model sketch of the retina.



Students work in pairs or small groups, to collect information with which to produce a map of the receptors present in the eye.

### Equipment and materials

#### *Per group of students*

Ruler, 1 m long

Coloured pens or pencils, one red, one blue (or a coloured spot on a long strip of white card)

Blu-tack

A3 paper, one or two sheets

### Health and safety and technical notes

Before carrying out this practical, users are reminded that it is their responsibility to carry out a risk assessment in accordance with their employer's requirements, making use of up-to-date information.

[Read our standard health & safety guidance.](#)

- 1 The room will need to be well lit for the students to be able to discern the colours, particularly if they have dark irises.
- 2 The teacher will need to be very sensitive to the issue of colour blindness. Students should volunteer to be the participant, rather than it being assumed.
- 3 The extension activity describes using flashing lights. You must ensure that no one with epileptic tendencies is exposed to the flashing lights.

### Procedure

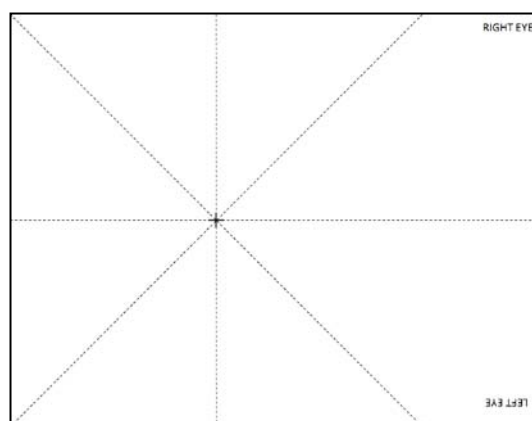
1 By printing the attached document, or making photocopies, produce an A3 sheet for each working group as shown in the diagram here.

2 Use Blu-tack to fix the piece of paper to a wall or safety screen, or to a bench.

3 Choose one person from your pair or group to be the subject of the investigation. Sit them so that the distance between their right eye and the cross in the centre of the paper is about 15 cm, so that when they look at the cross, they cannot see the edges of the paper.

4 Get the subject to cover or close their left eye, and to look at the cross in the centre of the paper with their right eye. **They must keep their head still and their eye focussed on the spot where the lines cross.**

5 Keeping their head still, the subject keeps looking at the cross. Meanwhile another member of the group brings either a red or blue object – such as a coloured spot on a long strip of white card **slowly** along each of the lines on the paper in turn, starting from the edge of the paper and moving to the centre. Do not tell the subject which colour is being used.



- 6 Mark on the paper the place on **each** dotted line where:
- the subject **first** sees the item (mark this in black)
  - the subject can tell its colour (mark this in red or blue, whichever is the colour of the item).

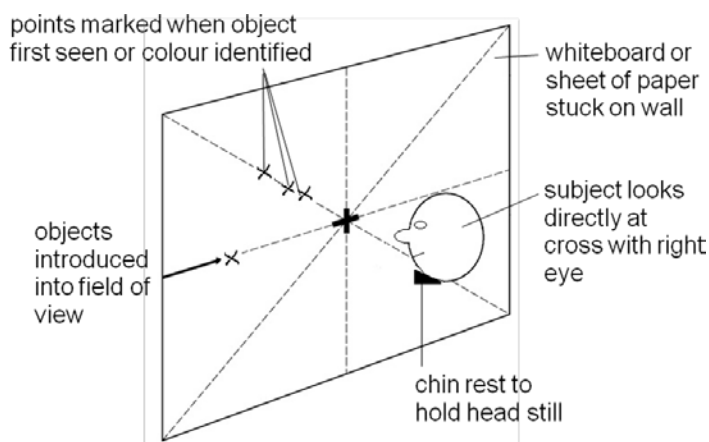
Repeat with the red and blue items at random until the point where you can first see any item and each colour has been identified on **all** of the eight lines.

7 Make a scale drawing of your results.

Join in **pencil** the points where the item was first seen.

Join in **blue** the points where the item was first seen as blue.

Join in **red** the points where the item was first seen as red.



## Teaching notes

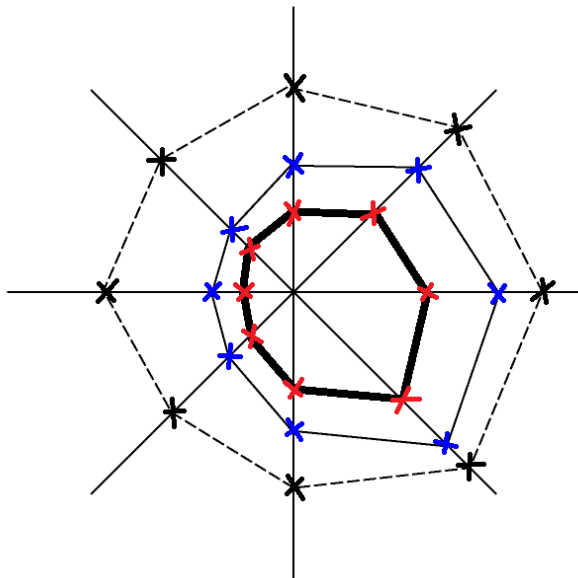
The method is straightforward, but some improvisation will be necessary.

You could use a clean plastic measuring cylinder to keep the distance from the subject's head to the paper constant at around 15 cm.

If space is limited, find a way to involve more students with fewer subjects.

Use class discussion and demonstration to ensure that students understand the basic technique.

The results will look something like this.



**Map key**

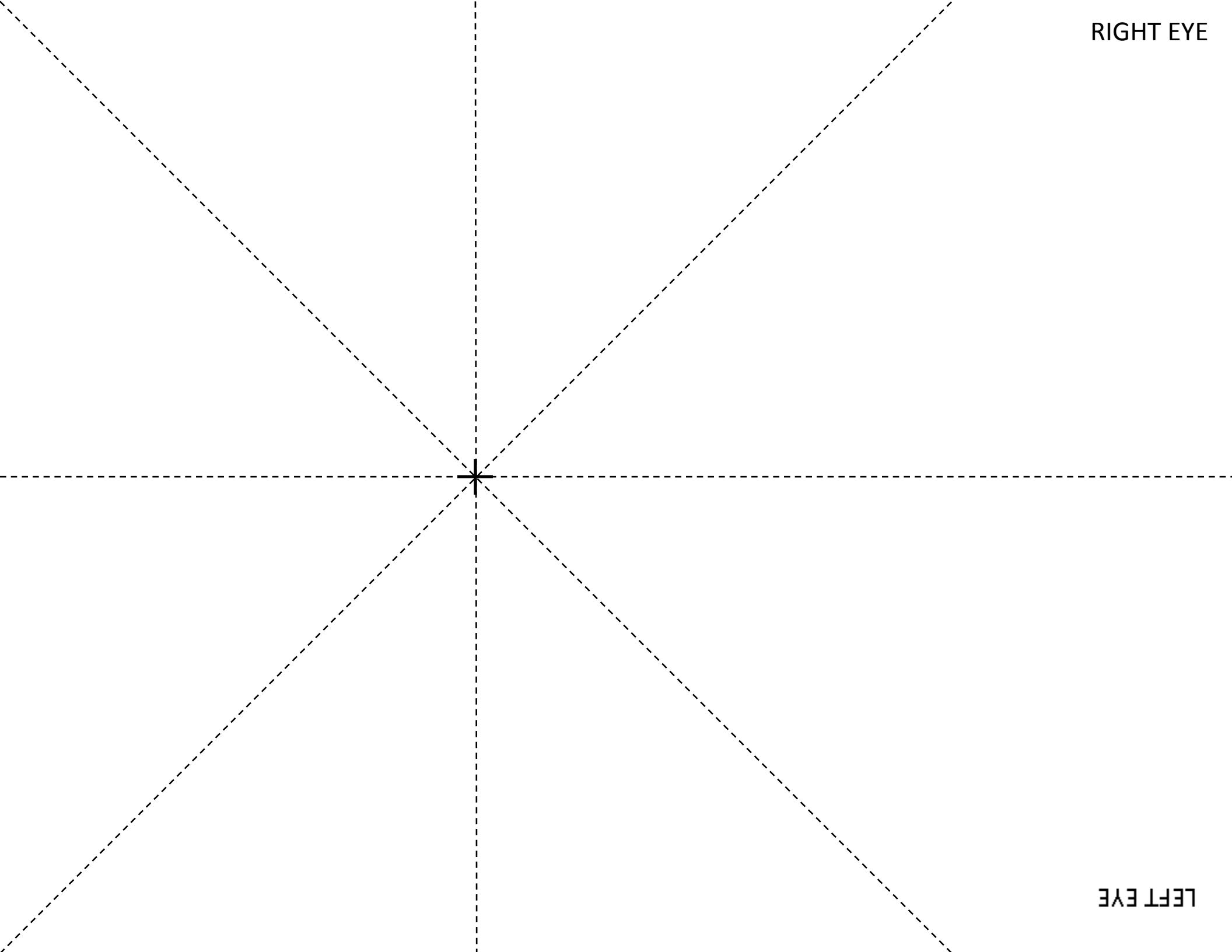
First see object - - - - -

First see 'blue' ————

First see 'red'      **—————**



RIGHT EYE



LEFT EYE