Topic Overview

Background and suggested aims

Aims

- To develop an understanding of colour vision;
- To appreciate which aspects of the behaviour of light and colour are a matter of physics and which are a matter of the biology of the eye and brain;
- To develop an understanding of the technology behind colour printing and colour TV;
- To link the physics of light and sound to music and art;
- To develop, in a very tentative way, some questions about the nature of perception if some colours are synthetic.

Lesson summary

Lesson	Content summary	National Curriculum links	Activities
Lesson 1: *What are colours?*	The frequency of a wave related to sound, water waves and light.	**Waves:** waves on water as undulations that travel through water with transverse motion; these waves can be reflected, and add or cancel – superposition. Frequencies of sound waves, measured in Hertz (Hz); echoes, reflection and absorption of sound. auditory range of humans and animals. Colours and the different frequencies of light, white light and prisms (qualitative only); differential colour effects in absorption and diffuse reflection.	Demonstrate Newton's experiment with a prism and white light. Demonstrate tuning forks. Demonstrate a ripple tank. Demonstrate the range of human hearing.
Lesson 2: *Emitting and reflecting light.*	Difference between objects that produce and reflect light. Colour mixing in light and missing colours.	**Waves:** colours and the different frequencies of light, white light and prisms (qualitative only); differential colour effects in absorption and diffuse reflection.	Demonstrate the flame test. Demonstrate colour mixing in light.
Lesson 3: *Is an object always the same colour?*	Properties of coloured filters. The colour of an object is determined by the light that it reflects.	**Experimental skills and strategies:** ask questions and develop a line of enquiry based on observations of the real world, alongside prior knowledge and experience; make and record observations and measurements; select, plan and carry out the most appropriate types of scientific enquiries to test predictions.	Viewing coloured objects through filters.
Lesson 4: *An artist's palette.*	Colour mixing using pigments or paints.		Demonstrate mixing colour pigments or paints.
Lesson 5: *Colour vision.*	Structure and operation of the eye. Relevance to colour mixing in light.		Demonstrate structure of the eye. Access web site simulation. Demonstrate mixing of coloured lights.

Background

This topic is appropriate for students who have studied optics in Year 8. Some familiarity with waves would be helpful, but the resources provided develop the necessary understanding. Students who are already familiar with the notion of primary colours in pigments (perhaps through painting in junior school) often find this topic confusing as they attempt to apply what they have learned to every context, appropriate or not. Some 'unlearning' or at least refinement of understanding is needed. Generally, this aspect of the syllabus challenges many Year 8 students. The resources available with this topic suggest an approach that helps to make the subject of colour vision and its complexities more accessible to students. Some simplifications have been made. Specifically, the model assumes that the cones in the retina are sensitive to red, green and blue light respectively, whereas there is some overlap in the frequency bands to which the different types of cone respond.

Teacher background knowledge

Teachers should be familiar with the structure of the eye, its optics, the nature of the cells in the retina and the optical nerve. They should also be confident with the wave theory of light, the spectrum of colours and the different frequencies corresponding to the visible spectrum (although specific numerical values are not used). The content does not extend to other aspects of the electromagnetic spectrum. Teachers should be familiar with the theory of colour mixing in light and in pigments. It would be helpful to speak to teachers in the art and music departments before starting this topic, in order to be familiar with the relevant content from their syllabuses as well as their perspective on the themes raised.

Cross-curricular links

This topic explicitly develops ideas from music and art and makes reference to topics that would most likely be covered in those subject areas. It is also possible to make some reference to philosophy, especially in regard to the subjective aspects of colour vision.

Student background knowledge

Some familiarity with the nature of sound and water waves with an appreciation that sounds have pitch and volume is helpful. If students have already covered the frequency and wavelength of waves, they will be able to access the early material more readily. Additionally, it would be useful if students had studied the structure of the eye and were familiar with the optical processing inside the eye. This will allow teachers to focus on the role of the retina, rather than being drawn into a conversation about how the light is focused with the eye.

Useful internet sites

https://www.colormatters.com/color-and-design/are-black-and-white-colors – an article discussing the issue of black and white as colours.

http://headforart.com/2016/12/16/how-artists-use-colour/ – an interesting article on the use of colour in painting..

https://artclasscurator.com/color-in-art-examples/ – examples of the use of colour in painting with some downloadable resources.

https://www.telegraph.co.uk/culture/photography/10758308/Why-Picassos-palettes-were-a-work-of-art-in-themselves.html – Picasso's palettes.

https://faculty.washington.edu/chudler/retina.html – some information about the cells in the retina and the working of the eye.

https://phet.colorado.edu/sims/html/color-vision/latest/color-vision_en.html
– an interactive simulation of colour vision.

Resources

The resources for teachers are the student materials with appropriate answers provided to the questions posed.

For teachers

Teacher Resource 1 – What Are Colours?
Teacher Resource 2 – Emitting And Reflecting Light
Teacher Resource 3 – Is An Object Always The Same Colour?
Teacher Resource 4 – An Artist's Palette
Teacher Resource 5 – Colour Vision

For students

Student Resource 1 – What Are Colours?
Student Resource 2 – Emitting And Reflecting Light?
Student Resource 3 – Is An Object Always The Same Colour?
Student Resource 4 – An Artist's Palette
Student Resource 5 – Colour Vision

Activities

Lesson 1: What are Colours?

In this lesson we are building the idea that waves have frequency and that the frequency of a wave corresponds to a physical property: in sound, frequency is pitch; in light, frequency is colour. It helps to be able to demonstrate these ideas practically. The following should be carried out, or at least demonstrated:

- Newton's experiment using a prism to split white light into the component colours;
- A range of different tuning forks so that students can see the difference between forks of different pitch;
- If possible, show the notes produced by a tuning fork on an oscilloscope so that the waves can be 'visualised';
- If possible, show a ripple tank with a 'dipper' bobbing at different frequencies so that the water waves (ripples) can be observed;
- Demonstrate the range of human hearing using a signal generator and a loudspeaker.

By the time you get to this topic, these experiments and demonstrations may already have been done, but it is advantageous to do them again in this new context.

Lesson 2: Emitting and Reflecting Light

The key concept in this lesson is the difference between objects that produce light and those that reflect light. Demonstrating the flame test makes the point that the colour of an object can be different depending on the light that it reflects vs the light that it produces (if hot). Technically speaking, the light in the flame test is produced by the material vapour in the flame but, if asked you can point out that it is still the material emitting the light, just as individual atoms.

In the lesson, we also recap the idea that colours of light correspond to different frequencies of light wave. Now, however, we are pointing out that this cannot be the whole story, at least from a visual perspective, as certain colours that we see in the world are not present in the rainbow and so are not single frequencies of light. Some students will be confused by this, so develop the point slowly and reassure them that, as the topic develops, we will revisit this idea several times.

Aside from black and white, the most obvious 'missing colour' (not present in the rainbow) is brown. The point that we are stressing here is that brown is not a single frequency of light. For the moment, we are leaving the nature of the missing colours as slightly mysterious.

Some students may come up with the idea that a TV produces light and can produce the missing colours. They should be congratulated for their thinking. This is then an excellent opportunity to develop the idea that is going to come into a later lesson. Point out to them (with an image if possible) that the TVs are actually only producing red, green and

blue lights very close to each other. As they are so close, the eye and the brain cannot see them as separate lights, so what we see is then 'made up' by the brain. So, a combination of lights can be any colour, but no individual pure light can be brown.

Lesson 3: Is an Object Always the Same Colour?

The intention is to provide students with coloured filters to look through. Student Resource 3 describes a technique where they are given standard lab safety goggles / spectacles and then asked to tape sheets of coloured film over these. The sheet can be adapted if other approaches are used. Initially, provide them with red, green and blue films, trying to ensure that they are of roughly equal density. For their observations, students also need cards of different colours and lights to match. An anglepoise lamp with coloured film in front would be appropriate, provided that it does not get too hot in the process. Leave an air gap at the top of the film coverage. Also, warn the students about the issue. Alternatively, it might be possible to use the LED lights on their mobile phones, with coloured films being held in front.

Students should quickly establish that a red film (for example) only lets red light through. Hence it can be used to examine the amount of red light being reflected from a surface. The same, of course, is also true of the other coloured films.

The series of observations made during this lesson should confirm that the colour of an object is determined by the light that it reflects. Hence, a red object predominantly reflects red light. If white light shines on a red object, it will absorb all other colours and reflect red. If red light shines, then it will appear red. However, if illuminated by blue light, the previously red object will appear black as there is no red to reflect.

For the final part of the lesson, provide students with a card that is not a primary colour (the example suggested is orange). Between viewing this card through coloured films in white light and viewing it in different coloured lights (without film), the students should establish that the orange is reflecting a combination of colours.

Lesson 4: An Artist's Palette

This lesson introduces the idea of colour mixing, using pigments or paints. It would be useful to borrow a genuine art palette from the art department if possible. If the students can have access to some appropriate paints, so that they can try mixing for themselves, that would also be beneficial. However, it would be wise to try the paints beforehand to see if the results are predictable. Colour mixing is complicated by the saturation and consistency of the pigment, never mind the chemical details.

The lesson builds on the previous idea that the colour of an object depends on the light that it reflects. Mixing two different paints will result in a colour determined by the combination of colours that both pigments will reflect at the same time. The appeal of the content can be extended by pointing out that a variety of professions (including make-up artists) need to understand the basics of colour pigment mixing.

Lesson 5: Colour Vision

This crucial lesson discusses the structure of the eye and the rods and cones that can be found in the retina. It is obviously helpful if the basics of this topic have been covered before, in either physics or biology. The most important learning objective is an understanding that the primary colours of light are a function of the biology of the cones, not the physics of light. The mixing of primary-coloured lights to make any other colour is a subjective phenomenon to do with brain and eye function, not a physical effect due to the superposition of waves.

The website https://phet.colorado.edu/sims/html/color-vision/latest/color-vision_en.html is strongly recommended, as the simulations allow students to pass pure light into an eye and then create the same colour by a careful mixture of red, green and blue.

Teachers with an appropriate ability group might like to raise the philosophical issues relating to 'fooling' the brain into seeing any colour from a combination of red, green, blue. If red and green light creates an image of yellow, even though there is no yellow light present, then how do we know the extent to which the brain has 'invented' anything that we see? This is especially pertinent when it comes to the missing colours, such as brown.