*Physics > Big idea PSL: Sound, light and waves > Topic PSL2: How we see*

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| **Key concept (age 11-14)** |
| **PSL2.2: Seeing in colour** |

**What’s the big idea?**

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

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

This key concept helps to develop the big idea by building on the idea that non-luminous objects are seen by the light that they scatter, in order to help develop students’ understanding of colour formation by the selective scattering and absorption of different colours of light by coloured objects.

****The conceptual progression starts by checking understanding that different colours of light mix to make light of a different colour. It then supports the development of the idea that daylight and sunlight are made from all the colours of the spectrum, which together we see as ‘white light’, in order to enable understanding that the colour an object is perceived to be is determined by the colours of light that it reflects.

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

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

**Progression toolkit: White light**

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| **Learning focus** | Daylight and sunlight are made from all the colours of the spectrum, which together we see as ‘white light’. | | | | |
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| **As students’ conceptual understanding progresses they can:** | **C o n c e p t u a l p r o g r e s s I o n** | | | | |
| Give an example of how coloured lights mix to make light of another colour. | Explain how adding coloured lights together affects brightness. | Describe how sunlight and daylight are different to yellow light. | Explain how daylight / sunlight can be split into colours of the spectrum, whereas yellow light cannot. | Explain how colours of light combine to make light similar to daylight, which is called white light. |
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| **Diagnostic questions** | Colour TV | Bright lights | Light and day | Rainbow | Three into one |
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| **Response**  **activities** | Mixing coloured light | |  | Yellow light | Newton’s prisms |

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

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| **Colour TV** | **Bright lights** | **Light and day** | **Rainbow** | **Three into one** |
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| Confidence grid | Two-tier multiple choice | Simple multiple choice | Simple multiple choice | Confidence grid |
| **Mixing coloured light** | **Yellow light** | **Newton’s prisms** |  |  |
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| Application and practice | Predict, explain, observe, explain | Predict, explain, observe, explain |  |  |

**Progression toolkit: Colours we see**

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| **Learning focus** | Light has colours that are seen when reflected by bodies. | | | | |
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| **As students’ conceptual understanding progresses they can:** | **C o n c e p t u a l p r o g r e s s I o n** | | | | |
| Describe how white objects reflect all the colours in white light. | Describe how coloured objects selectively reflect particular colours in white light. | Describe how coloured objects selectively absorb or reflect particular colours of light. | Work out the colour a coloured object looks in light that is a different colour to the object (primary colours). | Work out the colour of an object that is a secondary colour, in red, green or blue light.  **B** |
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| **Diagnostic questions** | White stuff | Football kit | Blue bottle | TARDIS | Flag of Guyana |
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| **Response**  **activities** | Red fridge light |  | White king | | Flag colours |

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

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| **White stuff** | **Football kit** | **Blue bottle** | **TARDIS** | **Flag of Guyana** |
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| Confidence grid | Confidence grid | Focused cloze | Two-tier multiple choice | Confidence grid |
| **Red fridge light** | **White king** | **Flag colours** |  |  |
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| Talking heads | Predict, explain, observe, explain | Predict, explain, observe, explain |  |  |

**What’s the science story?**

*White light is a mixture of lights of different colours*

When a beam of white light is passed through a prism, the emerging light beam has the colours of the spectrum (ROYGBIV). A second prism can recombine this coloured light beam into a beam of white light. This suggests that the colours are in the light rather than being caused by the material of the prism. We can think of white light as a mixture of lights of all the colours of the spectrum.

A coloured filter works by allowing light of one or more spectrum colours through (transmission) and absorbing light of the other colours.

An object appears white if it scatters all the colours of light that fall on it, and black if it scatters none (and absorbs all). It appears coloured if it scatters light of some colours and absorbs light of other colours. Its observed colour is that of the light it scatters.

*The ‘three primary colours’ model of human colour vision*

The human eye has three types of colour sensor, which detect red, green and blue light respectively. These are called the primary colours. If beams of red, green and blue light are shone on a white screen, the area on which all three beams fall appears white. Areas on which two primary colours fall show the three secondary colours: yellow (R+G), cyan (turquoise) (G+B), and magenta (R+B). Any colour can be produced by combining the three primary colours.

This model can be used to explain and predict the effect of filters, and the appearance of coloured objects when illuminated by lights of different colours. It can also explain the effects of mixing pigments (paints) of different colours.

**What does the research say?**

Only a tiny minority of students hold the scientific understanding of how we observe colour and ‘standard teaching techniques’ do not seem to improve this very much (Martinez-Borreguero et al., 2013).

When an object is observed its colour is determined by the colours of light that it reflects. For example, an object looks red because it reflects red light and absorbs the other colours falling on it. This is the process that underlies colour formation, and a physically adequate concept of white light is crucial to understand it fully (Haagen-Schutzenhofer, 2017).

In a study of 13-year-olds (n=150), 72% did not think that white light was a mixture of different colours (Zylbersztajn and Watts, 1982; Driver et al., 1994). In fact, before encountering ‘white light’ in science lessons fewer than 10% of 13- to 15-year-olds (n=22) understood what ‘white light’ was (Haagen-Schutzenhofer, 2017). 95% of these students described sunlight as yellowish or with a yellow tint. Over half described daylight in a similar way and fewer than one-in-six described daylight as ‘white light’ (ibid.). It does not help that most school textbooks draw rays of white light as red or yellow lines.

For a physicist, sunlight and daylight are both examples of white light. Each consists of all the colours of the spectrum which combine to be seen as white. Students often regard white light as ‘pure light’ that is free of any tinge. More than half of a sample of 13- to 16-year-olds (n=166) considered colour to be different to light and something that is added to light (Galili and Hazan, 2000).

Haagen-Schutzenhofer (2017) suggests avoiding the term ‘white light’ in the initial stages of instruction and to develop a scientifically sound concept of white light which is related to everyday experiences. She developed a teaching sequence that starts with coloured lights and shows how they can be mixed to produce another colour of light. Next she compares sunlight/daylight with a yellow light to show they are different, before using a prism to split daylight into a spectrum, and another prism to recombine the spectrum into light similar to daylight (specifically not ‘white light’). It is at this stage that the term white light is introduced, along with the idea that it does not exist physically, but is an interpretation of our brain like every colour sensation. Once students have an adequate understanding of white light, ideas of how colour is seen become more straightforward.

The more common views of colour formation are shown in the table below:

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| **View held about colour** | **Primary**  **(n=74)** | **Secondary**  **(n=86)** | **Secondary teachers – mostly science specialists (n=64)** |
| The correct scientific understanding | 0.0 % | 1.2 % | 17.2 % |
| Misunderstanding that the colour perceived is the sum of the colour of the light plus the colour of the object (both ‘emit’ their own colour, which the eye then adds together) | 62.2 % | 60.5 % | 46.9% |
| Misunderstanding that the colour perceived is always the colour of the object (the colour of a body is an intrinsic property) | 8.1 % | 8.1 % | 12.5 % |
| Misunderstanding that the colour perceived is the colour of the illuminating light, because it is the only colour emitted | 6.8 % | 9.3 % | 14.1 % |
| Misunderstanding that if the colour of the object is the same as the colour of the light, then the object is not seen as it appears the same colour as its surroundings | 4.1 % | 2.3 % | 6.3 % |
| Misunderstandings that do not fit into a consistent framework (a mixture of some of the above) | 18.9 % | 18.6 % | 3.1 % |

Table showing the results of a study of the different misunderstandings about colour (Martinez-Borreguero et al., 2013).

Martinez-Borreguero et al. (2013) found that students’ explanations of colour formation were most often of the form: ‘bodies have colours that are seen when they reflect light’. They reformulated this explanation to: ‘light has colours that are seen when it is reflected by bodies’ and asked students to consider which statement they found most useful. They found that a shift in focus to the latter made the origin of misunderstandings more explicit and resulted in a significant improvement in students’ longer term conceptual change.

The progression toolkit for ‘white light’ begins by reminding students of how a television makes a full range of different colours by mixing just three. By comparing sunlight and daylight with yellow light students confront the common misunderstanding that sunlight is yellow. Through investigation they find out that daylight can be split into all the colours of the spectrum and that yellow light, because it is made of just one colour of the spectrum, cannot be split into different colours. Two further activities challenge students to explain how colours of the spectrum combine to make light similar to daylight, which is called white light.

Once students understand that white light is actually a mixture of all the colours of the spectrum, the progression toolkit ‘colours we see’ challenges students to explain colour formation. It begins by reminding students that objects are seen by the light that reflects off them into our eyes. They first consider the colours that objects reflect into the eye, before working out which colours of white light must have been absorbed in order not to have been reflected. Further activities challenge students to apply this understanding to new situations and to explain the colours that objects will be perceived to be when they are viewed in coloured light.

**Guidance notes**

*Yellow light*

Yellow light is a pure colour in the spectrum of light. It is a part of the electromagnetic spectrum that has a wavelength within a range that we always see as yellow. In the eye we don’t have a particular sensor to detect yellow light, instead it is detected by both the red and the green colour sensors. The brain combines signals from both of these to produce the perception of yellow. This is why yellow is seen when a red light and a green light are mixed. It also explains why yellow can be ‘perceived’ by mixing red and green light, but yellow light cannot be split into red and green. Red light has a lower frequency than yellow light and green has a higher frequency.

A short video by the Royal Institute called “Colour Mixing: The Mystery of Magenta” explains this very clearly, and can be easily found on the internet.

*Observing colour effects in a school science laboratory*

In the laboratory it is challenging to accurately observe the colour that a coloured object looks in coloured light. This is because a blackout needs to be perfect if all daylight is to be excluded and even small amounts of daylight give objects a tinge of the colour that they have when viewed in daylight. A common misunderstanding is that colour is intrinsic to an object and viewing an object under coloured light that has a slight tinge of its original colour can be enough to convince students that this view is correct.

An alternative is to observe objects through coloured filters. A blue filter, for example, allows only blue light into the eye. If an object were viewed with only blue light present then only blue light could enter the eye. Viewing the object through a blue filter gives a very accurate picture of what an object looks like when bathed only in the colour of light that matches the colour of the filter.

It should be noted that a coloured filter lets through the colour(s) of light that combine to make the colour of light that matches the colour of the filter. A blue filter lets through only blue light, a yellow filter lets through both red and green light which combine to make yellow. For this reason filters cannot be added: a red filter will stop all colours except red, adding a blue filter will additionally stop all colours except blue. The blue filter stops the red light and no light will pass through the two filters when they are combined.

**References**

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