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RESOURCES FOR SCHOOL TEACHERS

THE ATLAS OF COLOUR

Colour sits at the intersection of physics, perception, nature, biology, aesthetics and culture. From the early optical experiments of Alhazen a thousand years ago, to the quantum insights of Max Planck a century ago, colour begins as a property of light itself. Yet it is never purely physical. Through the perceptual theories of Johann Wolfgang von Goethe and Thomas Young, and the evolutionary thinking of Charles Darwin, colour becomes something we see, experience, interpret and even inherit through DNA. In art, from Johannes Vermeer to Vincent van Gogh, colour transforms again – this time into emotion, atmosphere and meaning.

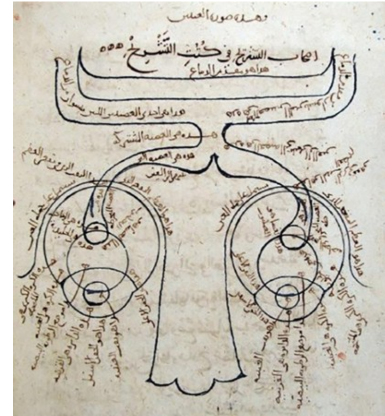
The 'Atlas of Colour' forms one branch of the wider *Atlas of Human Imagination*, tracing how a phenomenon such as colour can be understood across many disciplines and centuries. Like other domains in the Atlas, colour reveals a pattern: ideas move from observation, to explanation, to expression and finally to systematisation. The pioneers gathered here are not only contributors to colour theory, but participants in a larger human project – to make sense of the world through light.

This unique document helps guide students and teachers through some of the **crucial, colourful concepts of 40 pioneering thinkers, scientists and artists** from the *Atlas of Human Imagination,* and beyond. In the following pages, we trace the conceptual chronology of colour, spanning millennia. First, we look at the physics and chemistry of colour, then we look at how colour has appeared and evolved in nature, as well as how we perceive it psychologically. Finally, we explore some of the ways that colour has been used imaginatively by artists and architects in famous artworks and buildings across the world.

Colour is where light becomes experience

1) The Physics & Chemistry of Colour

Theory of Vision

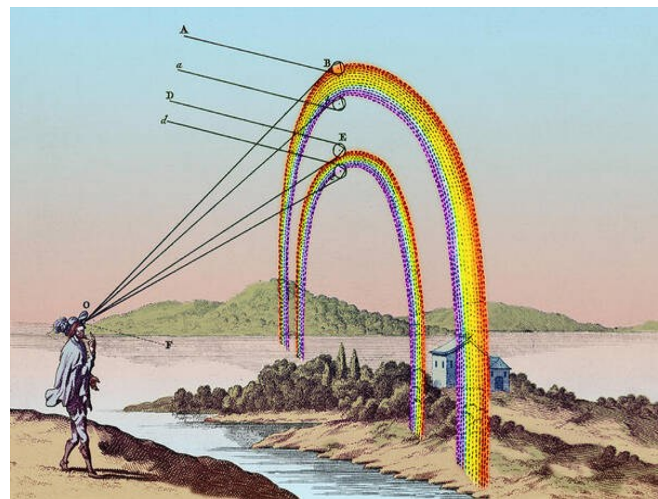


(Alhazen)

Alhazen (1011)
The Islamic scientist Alhazen (or *Ibn al-Haytham*) established the first rigorous experimental *theory of vision*, showing that light enters the eye rather than being emitted from it (see sketch, right). Alhazen's work in optics laid the foundation for understanding colour as a property of light interacting with the eye. He transformed vision from philosophy into an empirical science.

Refraction and Rainbows

René Descartes (1637)
In France, Descartes contributed to early mechanical explanations of light and *refraction*, including studies of rainbows (see image, right). He treated colour as a physical phenomenon governed by laws of optics. This work helped shift colour understanding towards mathematical science.



(Descartes)

Christiaan Huygens (1656)
In Holland, Huygens proposed the *wave theory of light*, opposing particle-based models dominant in his time. This framework helped explain reflection, refraction and later colour behaviour in waves. His ideas became central to modern optical physics.

Synthetic Rainbows through Glass Prisms

Sir Isaac Newton (1704)
The English scientist Newton demonstrated that white light splits into a *visible spectrum of colours*, establishing colour as a property of light. His prism experiments formed the basis of spectral theory (see image, right), realising for the first time that white light (or sunlight) comprised the seven colours: red, orange, yellow, green, blue, indigo, violet (ROYGBIV) – the same as what we see in a rainbow.

(Getty Images)

In his 1704 book *Opticks*, Newton also correctly explained how an object derives its colour. If white light falls on a red object (say a tomato), then the surface of the tomato is absorbing yellow, green, blue, indigo and violet and reflecting mainly red (which is what we see with our eyes). Likewise, the flowers of lavender absorb red, orange, yellow and green, but reflect blue, indigo and violet, giving a lavender colour. Newton thus systematised colour, turning it into a measurable physical phenomenon.

Chemicals Creating Colours

Jöns Jacob Berzelius (1820)
The Swedish chemist Berzelius was a founding father of modern chemistry. He used his massive *mineralogy* collection to categorise substances based on their chemical composition rather than just their outward appearance. By analysing specimens like malachite (copper ore), amethyst (silica with iron impurities) and cinnabar (mercury ore), he demonstrated that the vibrant colours of minerals were direct indicators of the specific elements within them (see minerals, below).

This helped shift the study of colour from description to measurement, laying the groundwork for our understanding of how chemical bonding and atomic structure create the visible spectrum.

Malachite

Amethyst

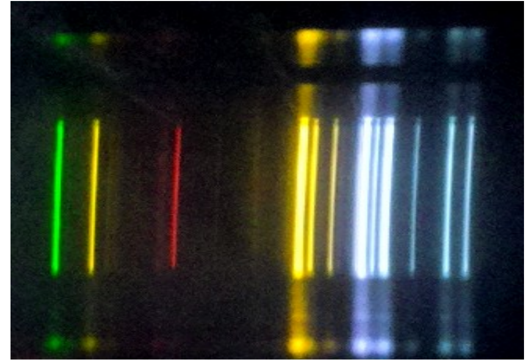
Cinnabar

Michael Faraday (1831)
Amongst many other topics, Faraday investigated the interaction between light and matter, including the behaviour of *colloids* which scatter light and produce colour effects (see image, right). This image is of very fine particles of gold in solution that become bright red, instead of the usual golden colour.

He also discovered the *Faraday effect*, showing that magnetism can influence light. This revealed that colour can arise from physical interactions beyond simple reflection.

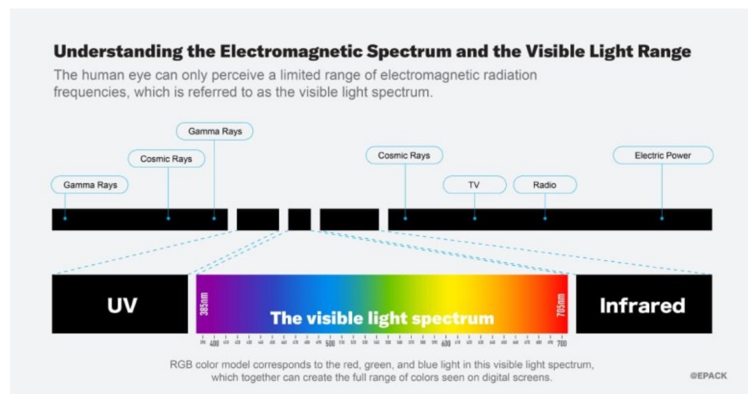
(Royal Institution)

Gustav Kirchhoff (1859)
The German physicist Gustav Kirchhoff developed the laws of thermal radiation, linking emitted light to temperature and material properties. His work, alongside *spectroscopy*, showed how specific elements produce characteristic colours. This made colour a tool for understanding the composition of matter. Kirchhoff and his collaborator, Robert Bunsen, were the first to ascertain the chemistry of the Sun, based on the colour of its light spectra (see image, right).



Colours as Part of a Spectrum

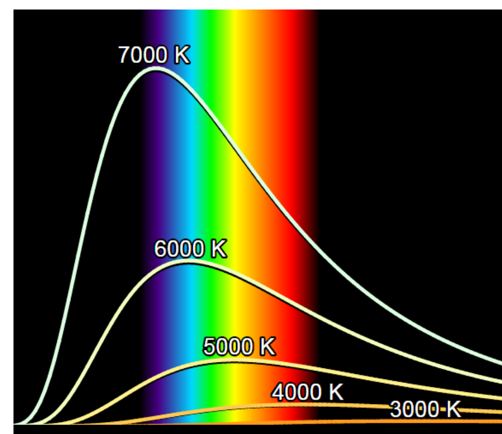
James Clerk Maxwell (1873)
Building on Faraday's work, Maxwell unified *electromagnetism,* and demonstrated that visible light is an electromagnetic wave and just a tiny part of a much larger electromagnetic spectrum (see image, right).



(Epack)

He also developed the first mathematical colour system and created the first durable *colour photograph*. Maxwell's work bridged physics and colour reproduction technology.

Max Planck (1900)
The German physicist Planck introduced *quantum theory*, showing that light is emitted in discrete energy packets. This laid the groundwork for understanding how light of different wavelengths – and thus colours – is generated. The groundbreaking work that Planck did in the early 1900s underpins modern physics of radiation and colour temperature (see image, right).



Sir David Brewster (1816)

The Scottish physicist Sir David Brewster invented the *kaleidoscope*, demonstrating how simple optical reflections can generate complex and shifting colour patterns (see image, right). He also studied polarisation and optical properties of materials. Brewster therefore highlighted the aesthetic and perceptual richness of light through various optical devices.

(Brewster Kaleidoscope Society)

Claude Shannon (1948)

The American computer scientist Claude Shannon developed *information theory,* including the concept of entropy as a measure of variation and complexity (see equation, right). In the digital age, Shannon shows that colour is no longer just physical or biological—it is also data.

Later applied to digital images, this *entropy equation* can describe the richness or diversity of colour distributions in photos and videos. A completely black image would have zero entropy, whilst a colourful image of, say, an iridescent butterfly wing would have very high entropy. His ideas underpin modern digital imaging, compression and colour encoding.

$$H = -\sum p(x) \cdot log_2 p(x)$$

p(x) is the probability of a specific colour appearing

Physics **→ Colour begins as light**

Having understood colour as a physical property, we now turn to how it evolves in nature and living systems.

2) Colours in Nature

Natural Observations

Leonardo da Vinci (1510)
Da Vinci closely studied how light, atmosphere and distance affect the way we perceive colour in nature. Through careful observation, he described how colours become softer, cooler and less distinct as they recede into the distance – a phenomenon now known as *atmospheric perspective*. He also explored how shadows are not simply black, but contain subtle variations of colour depending on surrounding light. Da Vinci's experiments on smoke revealed how light scattering could create a blue tinge (see image, right). His notebooks combine artistic practice with scientific thinking, anticipating later developments in optics and visual perception.

Colours in the Sky

John Tyndall (1859)
The Irish scientist Tyndall explained how *light scatters* through particles and molecules in the atmosphere, accounting for phenomena like red sunsets and the blue sky itself (see image, right). His experiments connected environmental conditions to perceived colour. Tyndall expanded colour theory into nature and atmosphere.

Fridtjof Nansen (1895)
While Nansen is best known as a polar explorer, his scientific observations of the *aurora borealis* (see images, right) during the Fram Expedition helped advance European understanding of the aurora phenomenon. Since high-speed cameras were not yet available, Nansen used his artistic skill to produce detailed drawings capturing the complex forms and shifting colours of the northern lights (mainly green, red and purple).

(Nansen)

Evolution of Colour

Charles Darwin (1859)
The British naturalist Darwin studied colour in animals as part of *evolutionary processes*, particularly through sexual selection and natural selection. He showed that vivid colours can function as signals for attraction, warning or camouflage (see image, right). This reframed colour as an adaptive trait shaped by survival and reproduction.

Alfred Russel Wallace (1867)
Wallace was another British pioneer of evolutionary biology who proposed that vibrant animal colours often serve as a warning signal to predators that a species is unpalatable or dangerous, a phenomenon now known as *aposematism.* He argued that such conspicuous displays benefit both the prey and the predator by preventing costly or fatal mistakes. Wallace laid the foundation for our modern understanding of adaptive colouration, shifting the scientific focus from purely aesthetic views to the role of survival.

Gregor Mendel (1866)
Mendel's experiments on *plant hybridisation*, particularly with pea plants (see image, right), revealed how traits such as flower colour are inherited through discrete units – now known as genes. His seminal research showed that colour in living organisms follows underlying biological rules rather than blending continuously. This established colour as a measurable, heritable property shaped by genetic structure. After Mendel, this was then attributed to the fact that colour could be encoded in DNA – life's instruction manual.

(John Innes Centre)

Marianne North (1870)
North travelled extensively to document plant life, producing highly detailed paintings that captured the vivid *colours of botanical species* from around the world (see image, right). Her work combined scientific observation with artistic precision, preserving colour as a record of biodiversity before colour photography was well established. She demonstrated how colour could function as both aesthetic expression and scientific documentation of nature.

(North/RBG Kew)

Abbot Handerson Thayer (1909)

The American painter and naturalist Thayer took a strong interest in nature and the patterns that animals adopted to blend into their surroundings (see peacock, right). Like Darwin and Wallace before him, Thayer realised that concealing colouration or *camouflage* was ubiquitous. Birds, insects, reptiles, fish and mammals all made use of coloured patterns to avoid being preyed upon. Thayer also saw uses of camouflage for concealing soldiers, vehicles and navy ships, proposing it in military operations in 1915.

(Thayer)

***Nature* → Colour becomes information**

Having explored how colour appears and evolves in the natural world, we now turn to a deeper question: how do we actually perceive it? Colour is not only something that exists ‘out there’ in light and living systems – it is also constructed by the brain, shaped by biology and interpreted through experience.

3) Perception of Colour

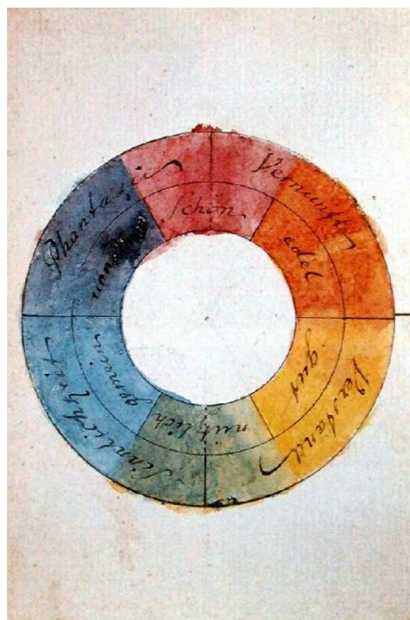
Synesthesia

(Suarez)

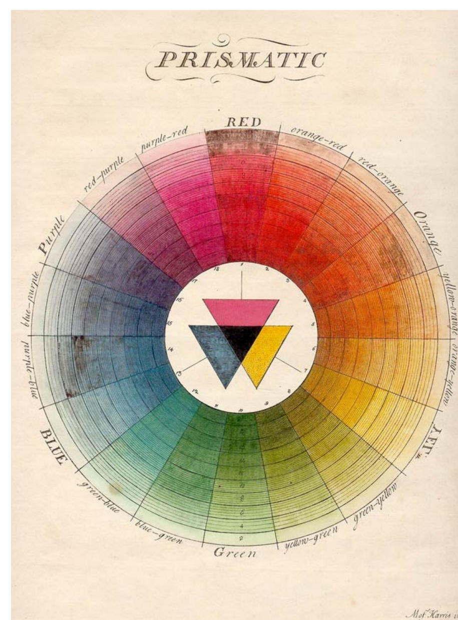
Pythagoras (500 BC)
Pythagoras is associated with early ideas linking sensory experience to mathematical harmony, including speculative connections between colour, sound and proportion. Later traditions attribute to him proto-concepts related to *synesthesia*, where human senses intermingle (see image, right). His legacy reflects an early attempt to systematise perception across domains. Intuitively, Pythagoras knew that colour exists in the interaction between light, eye and mind.

Perceptual Colour

Johann Wolfgang von Goethe (1790)
The German polymath Goethe argued that colour arises from the interaction of light and darkness as perceived by the human eye. He challenged Newton's purely physical model by emphasising *subjective experience* too. Based on colour wheels (see images, below), Goethe established colour not only as a physical feature but also as a psychological phenomenon.



(von Goethe)



(Harris)

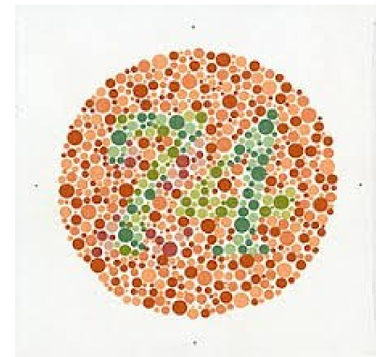
Thomas Young (1802)
Young proposed the trichromatic theory of vision, suggesting that the eye has three types of colour receptors detecting red, green and blue (RGB). This explained how all visible colours can be produced from three primary stimuli (see image, right). His *RGB theory* became foundational for modern vision science.

(Epack)

Hermann von Helmholtz (1850)
Helmholtz expanded Young's theory into a physiological model of human vision. He linked colour perception directly to neural processing in the eye and brain. Helmholtz helped establish modern *neuroscience of vision*.

Colour Blindness

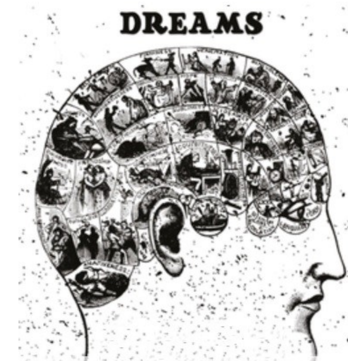
Shinobu Ishihara (1917)
The Japanese ophthalmologist Ishihara devised a colour test to detect *colour blindness* – a condition that affects almost 5% of humans. Patients are asked to stare at the Ishihara plate (see image, right) and say which numerals they can see. Viewers with normal vision would see the number '74' straight away. Those with different forms of colour blindness would see other numbers – including no numbers in the case of monochromacy.



(Ishihara)

Psychology

Sigmund Freud (1900)
The Austrian psychologist Freud explored how unconscious processes shape perception and symbolic meaning, including visual experience. While not a colour theorist himself, his ideas influenced later interpretations of how colour may carry emotional and *psychological associations*, such as red for anger or blue for depression. Freud and later psychologists (notably Carl Jung and Max Lüscher) helped provide a contextual psychological layer to the perception of colour.



(Freud)

***Perception* → Colour becomes experience**

If colour is shaped by perception, then it can also be shaped deliberately. Artists and architects have long explored how colour can influence emotion, meaning and space. In the final section, we will explore how artists over millennia have used colour as a powerful tool of human expression.

4) Colour in Art & Architecture

Exiting the Medieval Times

Hieronymus Bosch (1500)
In Holland, Bosch used vivid, often surreal colour palettes to construct moral and psychological narratives. His numerous triptychs employ colour symbolically to depict sin, heaven and chaos. He represents one of the earliest highly expressive uses of colour in northern European painting, at a time when most medieval artwork was much darker and sombre.

(Bosch)

Johannes Vermeer (1665)
The Dutch painter Vermeer mastered subtle tonal relationships and light effects to create highly realistic spatial perception. His controlled palette emphasises how light transforms colour in everyday scenes. For example, in his *Girl with a Pearl Earring*, the vibrant ultramarine of the turban – crafted from the rare and costly pigment lapis lazuli – creates a striking contrast against her luminous skin and the deep, dark background (see image, right).

(Vermeer)

Entering the Industrial Revolution

J. M. W. Turner (1804)
Turner dissolved form into *atmospheric colour*, prioritising light and emotion over structure. His work anticipates *Impressionism* through dynamic, luminous palettes. He transformed colour into movement and energy, as seen in many of his seascape paintings (see image, right).

(Turner)

Katsushika Hokusai (1831)
In Japan, Hokusai helped popularise the use of *Prussian blue* in Japanese woodblock prints, a newly imported synthetic pigment. This vivid, stable blue transformed the visual language of prints such as *The Great Wave* (see image, right). Hokusai showed how material innovation could also reshape colour aesthetics across cultures.

(Hokusai)

Claude Monet (1877)
The French artist Monet focused on capturing fleeting light conditions and their effect on *colour perception*. His series of paintings, like waterlilies, show how colour changes with time, atmosphere and observation (see image, right). He made perception itself the subject of painting.

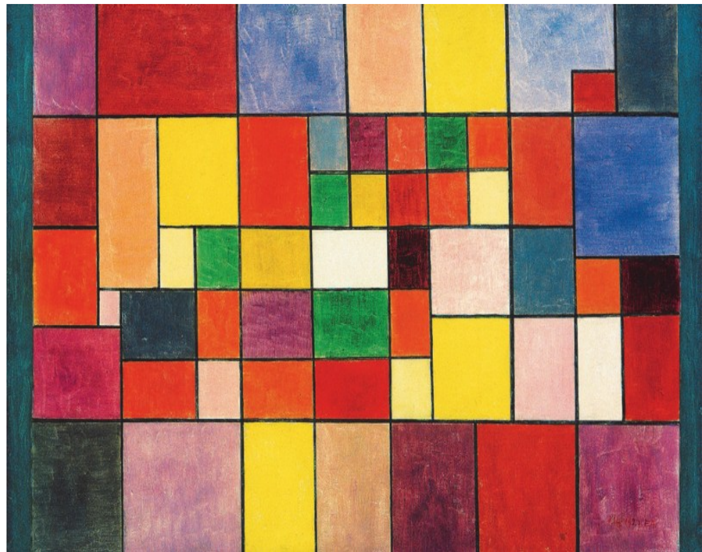
(Monet)

Vincent van Gogh (1889)
The Dutch painter Van Gogh used colour as a *direct expression of emotion,* often intensifying or distorting natural hues to convey inner states. His bold contrasts – especially complementary colours like blue and orange or yellow and violet (see image, right) – create visual tension and energy. He transformed colour from a descriptive tool into a primary vehicle of feeling and psychological depth.

(Van Gogh)

Entering the Modern Era

Walter Gropius (1920)
In Germany, Gropius founded the *Bauhaus*, integrating art, design and industrial production. While not a colour theorist himself, he created the institutional framework that enabled systematic colour education. His legacy therefore shaped modern design thinking.



(Klee)

Paul Klee (1930)
Klee developed deeply analytical yet poetic approaches to colour relationships (see image, right). At the *Bauhaus*, he taught colour as a living system of balance, rhythm and tension, bridging artistic intuition and structural theory.

Pablo Picasso (1937)
The Spanish artist Picasso used colour symbolically and structurally across different artistic phases of his career. From the emotional blues of his early period to his vivid, analytical *Cubism*, colour becomes a tool for *conceptual expression* (see images, below). In Cubism, Picasso redefined colour as an element of intellectual structure.

(Picasso Foundation)

Emily Kame Kngwarreye (1978)
The Australian Aboriginal artist Kngwarreye developed a distinctive visual language of layered dots and sweeping colour fields rooted in *Aboriginal knowledge systems* and connection to land (see images, below). Her use of colour encodes seasonal change, ecological patterns and cultural meaning rather than purely visual representation. Her artwork expands colour into a form of mapping, memory and ancestral knowledge.

(Emily Kame Kngwarreye)

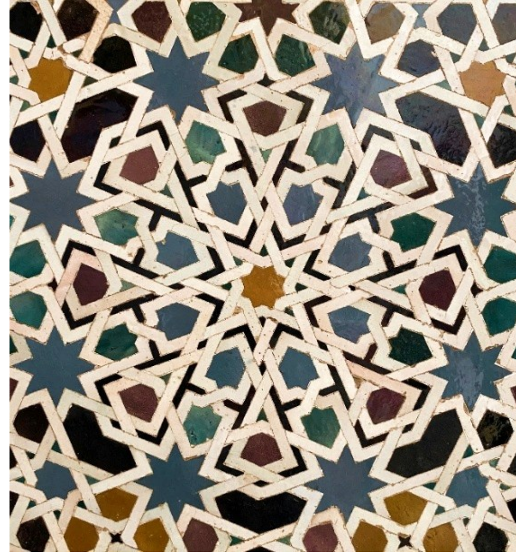
Colourful Architecture

Alhambra (13th-15th Century)
Perhaps one of the most spectacular uses of colour in architecture can be seen at the Nasrid palaces in Granada, Spain – collectively known as the *Alhambra*. Built during the Nasrid dynasty (c. 1230–1492), these palaces exemplify the sophisticated decorative arts of medieval Islamic Spain.

Islamic craftsmen in al-Andalus developed and refined an advanced form of ceramic chemistry, tile-making and architectural style that was unprecedented in Europe in the 1300s. Through manual skill and materials knowledge, they were able to make intricate coloured tiles '*azulejos'* that adorned the walls of their palaces (see images, below and overleaf). These tiles were typically formed from baked terracotta clay and coated with a glaze composed of silica, fluxes and opacifying agents, then fired in furnaces at temperatures approaching 900-1000 °C.

The base colour was an opaque white glaze made from a careful mineral recipe of lead oxide (PbO), tin oxide (SnO_2) and silicon dioxide (SiO_2). After centuries of trial-and-error, they discovered that adding a small amount of other minerals (known as *chromophores*) to the glaze mixture would yield a vivid colour palette. Cobalt oxide (CoO) produced dark blue; copper oxide (CuO) produced turquoise and green tones; manganese oxide (MnO_2) produced dark browns and blacks; and iron oxide (Fe_2O_3) and lead antimonate ($Pb_2Sb_2O_7$) produced a honey-yellow colour. These special recipes became standardised over hundreds of years and are now increasingly understood through sophisticated, modern archaeometric analysis. [*]

* C. Cardell et al. "*Archaeometric analysis of Nasrid glazed architectural ceramics from the Alhambra and Generalife Monument, Granada, Spain"*, Boletín de la Sociedad Española de Cerámica y Vidrio, Volume 65, Issue 1, January–February 2026, 100477.



Antoni Gaudí (1914)

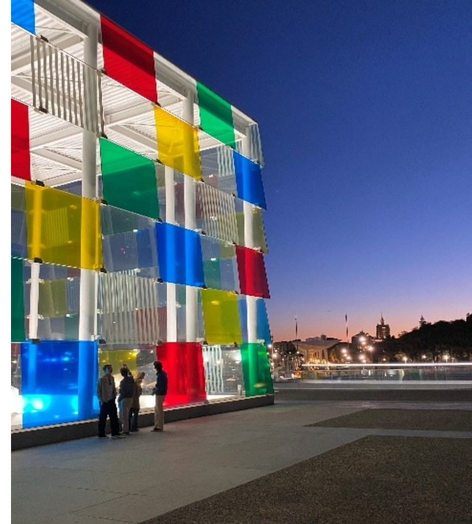
Park Güell in Barcelona was built by the Spanish architect Gaudí at the turn of the 20th century. Originally intended as a luxury residential estate, it is now a UNESCO World Heritage site and park showcasing Gaudí's unique style of flowing forms and bright colours. Similar to the previous Alhambra example, the park is brought to life by vivid, coloured tiles – employing a new technique called *trencadís*.

In this case, the tiles were in fact broken and damaged crockery collected from the local tile factories outside Barcelona. Using recycled fragments of these cups, vases, plates and glasses, Gaudí cemented them into the curved walls and seats of the park to create an imaginative explosion of colour – one of the first examples of sustainable upcycling in architecture.

(Gaudí)

Daniel Buren (2015)

In 2015, French artist Daniel Buren transformed the glass structure known as *El Cubo* (The Cube) into a vibrant landmark by adorning its panels with a multi-coloured geometric pattern. The primary colours – red, yellow, blue and green – were chosen to act as a living sunlit skylight, projecting shifting hues into the subterranean Centre Pompidou Málaga (see image, right). This design, created in collaboration with architects Javier Pérez de la Fuente and Juan Antonio Marín Malavé, serves as a bold modern beacon that reconnects the historic city centre of Málaga with its revitalised port area.



(Buren, Fuente, Malavé)

Zaha Hadid (2016)

At the London Science Museum, The Winton Gallery is a masterclass in using shape and colour to visualise the invisible. The gallery's fluid, sweeping forms – crafted from curved fabric and steel – are designed to mimic the mathematical equations of airflow generated by an aircraft. This sense of movement is dramatically enhanced by a bold, atmospheric lighting scheme of pink, mauve and deep purple that glows from within the "eddies" and "vortices." Hadid's choice of colour does more than provide a futuristic aesthetic; it highlights the complex geometry of the turbulence, transforming a rigid museum space into a vibrant environment where maths feels tangible and alive.

(Hadid/London Science Museum)

***Art* → Colour becomes expression**

Conclusion

As we have seen in this document, colour has many different facets. It is a feature of materials chemistry and optical physics. It also appears in nature, where it is encoded and inherited in the form of DNA. Colour also depends somewhat on our perception of it; and when turned into art form, it can be used to express powerful human emotions.

In simple terms: colour is not a single phenomenon, but a concept that changes depending on whether we study light, life, mind or culture.

Taken together, these perspectives show that colour is profoundly cross-disciplinary, sitting at the intersection of physics, chemistry, biology, neuroscience, art and architecture. It moves seamlessly from measurable wavelengths to lived human experience, and from natural evolution to cultural meaning.

This interconnectedness is echoed in the *Atlas of Human Imagination*, which similarly explores how ideas, perception and creativity span across domains to form a unified landscape of human understanding.

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FOR TEACHERS

Using the *Atlas of Human Imagination* in Lessons

Some Classroom Ideas exploring the concepts behind colour (16-19 Yrs):

Discussion Points

- *Colour in Art*: Get students to think about how colour evolved in art over time. What are the most colourful works of art in *early history* (cave paintings, Aboriginal art, Alhambra, Bosch, medieval art)? What are the most colourful works of *modern art* (Picasso, Klee, Kandinsky, Warhol, Pollock, Hirst)? What is the colour difference between ancient and modern art? How did availability of pigments play a role?

- *The Subjective vs. Objective Debate*: Use the contrast between Newton (page 2) and Goethe (page 9) to spark a debate. Newton saw colour as a measurable physical property of light, while Goethe saw it as a human psychological experience. Ask: *"If a tree falls in a forest and no one is there to see its green leaves, does the 'colour' actually exist?"*

- *Colour as a Survival Tool:* Discuss Wallace's theory of *aposematism* (page 7) alongside modern branding. If nature uses vibrant colours to warn predators of danger, how do humans use "warning colours" in modern society (e.g. hazard signs, digital UI alerts or even fast-food branding)?

- *The Digitisation of Experience:* Use Claude Shannon's entropy equation (page 5) to discuss the shift from physical art to digital data. Ask students if a high-resolution digital file of Van Gogh's *Starry Night* captures the "information" of the colour as effectively as the physical paint on the canvas?

- *The Genetics of Sight:* Building on Darwin, Mendel and Young (pages 7 & 10), discuss the evolution of trichromatic vision. Why did humans evolve to see RGB? Discuss the "evolutionary trade-off" – is our colour-rich world an objective reality, or just a survival "user interface" designed by our DNA?

- *The Architecture of Emotion:* Contrast the Alhambra (page 14) with Zaha Hadid's Winton Gallery (page 16). The former uses colour for decorative/spiritual geometry; the latter uses it to "visualise the invisible" (maths/airflow). Discuss: *"Can colour make abstract concepts like mathematics or divinity feel more 'tangible'?"*

Practical Demos

- *The "Scattering Simulation":* Use a simple Tyndall effect demo. Shine a laser pointer through a glass of water with a single drop of milk. Students can observe how the suspended particles scatter shorter blue wavelengths, similar to how John Tyndall explained why the sky is blue (page 6).

- *The Modern "Alhambra" Palette:* Inspired by Berzelius's minerals (page 3) and the Nasrid tile chemistry (page 15), have students "map" the chemistry of modern pigments. Provide a list of common household items (e.g., rust/iron oxide, copper coins/malachite) and ask them to research which transition metals create the dyes in their own clothing or digital screens (RGB pixels).

- *Atmospheric Perspective Sketching:* Following Da Vinci's observations of atmospheric perspective (page 6), have students go outside (or use a landscape photo) to create a "depth map." They should use watercolours or pastels to demonstrate how colours become cooler (more blue), softer and less saturated as objects recede toward the horizon. Using the *Atlas of Human Imagination* poster itself, ask students to describe what the colours look like when viewed up close, and at 10 metres distance.

- *The "Newton vs. Goethe" Shadow Experiment:* To demonstrate Goethe's theory of "coloured shadows", set up two different coloured spotlights (e.g. red and green) aimed at a white wall. Place an object in front. Instead of black shadows, students will see cyan and magenta shadows. This proves colour is a *perceptual construction* of the brain, not just light (page 9).

- *Shannon's "Entropy" Photo Analysis:* Ask students to take two photos: one of a minimalist, monochromatic building, and one of a colorful garden or butterfly. Use a basic image editor to look at the "Histogram" or file size of each photo. Demonstrate Claude Shannon's theory (page 5) by showing how more "colour information" (entropy) leads to larger, more complex data patterns. N.B. free online entropy calculators also exist for deeper image analysis of colour.