

# LIGHT & COLOR

Use this handbook to learn more about the app. Each section includes interaction tips, background information, vocabulary words, and discussion questions.

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# *Light & Color* by Tinybop

Imagine a world without light. In the darkness there would be no color — we would experience reality through only touch, taste, and sound. Lucky for us, light and color are everywhere, bringing beauty and wonder to our everyday lives. But do you know how light and color are made? Or why we see things the way we do? Have you ever wondered what makes red, red and green, green?

In *Light & Color*, we'll take a close look at light and color. We'll explore how light moves, how it's measured, manipulated, and perceived in the world. We'll also explore color mixing and naming. Finally, we'll explore what color makes us feel. This handbook will offer facts, ideas for experiments, and prompts for conversation as you dive into the world of light and color.



# How light and color are made

Most of the light in our universe comes from the stars in the sky. Stars produce **electromagnetic radiation** that moves through space as waves. All the radiation produced by a star is called the **electromagnetic spectrum**. We see a small slice of those radiation waves as colors as they interact with the world: shorter wavelengths show up as blue or purple, while longer wavelengths appear as orange and red. We call the small sliver of this spectrum that our eyes can pick up the **visible light spectrum**.

The Sun — the star at the center of our solar system — is the main source of light on Earth. It's a giant ball of gas that burns at a very high temperature, giving off energy that includes visible light. Without the Sun, our world would be dark and cold. At night, you might notice that the moon appears to give off some light — but the moon does not actually produce light at all. Instead, its surface is made of gray rock that reflects light from the sun back to Earth. In other words, the moonlight we see is actually reflected sunlight.

Light that is not sunlight is ultimately made by reactions between elements that were created in stars that emit energy. This is true for everything from light bulbs (**incandescent light**) to fireflies (**bioluminescent light**).

Interestingly, other creatures see different parts of the spectrum and perceive the world very differently than we do. Bees, for example, see visible light and ultraviolet light while snakes mainly see infrared.



## DISCUSSION QUESTIONS

- What are the most important sources of light in your life?
- How many sources of light can you identify?
- How do sources of light differ?





# How light moves

## REFLECTIONS

Have you ever shouted and heard an echo? Echoes are produced when sound moves like a wave through the air and then bounces back to your ears.

Light moves through the air in the same way that sound does — but much faster. It takes only eight minutes for light to travel from the Sun to Earth! Light bounces off of everything it touches — this is called **reflection**. Smooth surfaces reflect light in one direction, while rough surfaces reflect light in many directions. Have you ever noticed that smooth surfaces tend to be shiny while rough surfaces tend to appear flat?

Reflections allow you to see the objects in your world. For example, if you look into a mirror, you're seeing light reflected off the shiny surface of the mirror and back to you. But everything around you — the fruit bowl on your table, the truck outside, the water in your tub — reflects light, too.

All objects reflect different wavelengths of light. Consider an apple: the skin of a green apple absorbs most colors, but it reflects green. Our eyes pick up the green wavelength, and our brains tell us "This is a green apple".

# REFRACTION

Light travels in straight lines but can be bent when it passes through things like water glass or clear plastic. When light is bent, it is called **refraction**. Have you ever noticed that if you put a pencil in a water glass it appears to bend?

Different colors of light have different wavelengths and bend at slightly different angles when passing through water or glass. If white light (which is a combination of all the colors of light) enters a glass of water at certain angles, you'll see a spectrum of light emerging on the other side. Prisms work the same way.

## MAKING RAINBOWS

Have you ever seen a rainbow after a rainstorm? We like to think of rainbows as a sign of luck but, really, they form under very specific atmospheric conditions. After it rains, water droplets remain suspended in the air. If there's a break in the clouds, sunlight passes through these droplets, bouncing off the backside of them and going back the way it came. Since sunlight is made up of many different wavelengths of light, these colors are separated when the refracted light exits the water droplet — and sometimes if we are standing in the right place we are lucky enough to see a beautiful rainbow as a result!

## **RAINBOW SHAPES**

All rainbows are actually giant circles (the shape of raindrops). If you are high in a mountain or on a plane, sometimes you can see a circular rainbow (from the ground the bottom part of a rainbow is obscured by the earth).

Rainbows always appear when the Sun is fairly low and on the opposite horizon. You'll never see a sun and a rainbow together. This is even true if you spray a mist of water into the air to make a small rainbow.



## TRANSPARENT, TRANSLUCENT, AND OPAQUE

**Transparent**, or see-through, objects — such as glass or water — let light pass through, creating a shadow that is barely noticeable.

A **translucent** object will let some light pass and will create a softer shadow.

An **opaque** object, such as a tree or a brick wall, does not let any light through and creates a harsher shadow.

Are *you* transparent, translucent, or opaque? Is any part of your body translucent?

## **MAKING SHADOWS**

The shape of the object always determines the shape of the shadow. However, the size and shape of the shadow changes depending on the light source and where the light source is coming from.

The size of the light source can sharpen or blur a shadow. For example, a small spotlight often creates a clearer shadow than an overhead room light. The sharpness of this shadow can also change depending on how close it is to the object or what angle it hits the object at.

Have you ever noticed that shadows outside change throughout the day? If you see a shadow cast by a tree early in the morning, you might notice it starts to look different by midday. This is because as the Sun changes place in the sky, the angle it hits the tree changes.

When the light source is higher up, like the sun mid-day, the shadows will be shorter. If the light source is lower to the ground, the shadows will be longer.

## IN THE APP

Move the Sun around. What do you notice?

How do shadows move?

Tap the sky to create clouds and rain. See if you can create a rainbow. With the sun in the sky, what do you have to do to see the rainbow?



Tap the rainbow to take a peek inside.

What does a rainbow look like to a dog?



Inside the house, experiment with prisms and mirrors, opaque objects, and translucent objects. How do they react to sunlight, incandescent light, candlelight, and lasers?

Do the mirrors in the app work like real mirrors?

What happens when you point lasers at the mirrors?



How are opaque, translucent, and transparent objects different? Can you find examples of translucent, transparent, and opaque objects around you?



## DISCUSSION QUESTIONS

- Why do you think you can never see the Sun and a rainbow at the same time?
- When do you see rainbows most clearly? What angles are best for rainbow viewing?
- How can you change the size of your shadow?
- Does your shadow look the same in the summer versus the winter? How about the morning versus the afternoon? Why?





# Mixing colors

What happens when you mix yellow and blue paint? What about red and white? How might you create your favorite color? There are millions and millions of colors in the world. When mixing colors, it is important to remember that there are different ways to mix colors depending on the material or medium we're working with. For example, the colors that come from mixing paints are not the same as those that are made by mixing lights.

## MIXING PAINT - SUBTRACTIVE MIXING

**Primary colors** are the most basic colors that can be mixed to make other colors. Traditional color theory explains mixing pigment-based inks and paints. According to this theory, the three primary colors are **red**, **blue**, and **yellow**. Some people consider white and black to be primaries as well. These colors can be mixed together to create just about any color you can imagine. Can you guess which of these colors will create orange when mixed together? What about green or purple? Interestingly, you can't mix these colors to get white.

**Orange**, **green**, and **purple** are made from a mixing of two primary colors. They are called **secondary colors**. **Tertiary colors** are formed by mixing equal parts of a primary color and a secondary color.

Mixing paints is an example of **subtractive color mixing**: light bounces off paint and colors are absorbed into that color paint. Red paint absorbs all colors except red. Blue paint absorbs all colors except blue. When red and blue are mixed together, we perceive the newly created color as purple.

If you mix all three primary colors together in subtractive mixing, the paint absorbs most of the colors on the spectrum — and we perceive the mixed blob of paint as dark gray or black.

But what about colors not found in the rainbow, like pink or brown? These colors often require the addition of black, white, or gray — our neutral colors. Mixing a color with black creates a **shade**, mixing with white creates a tint, and mixing with gray creates a **tone**.

Mixing paints is never exact. Different kinds of paint will mix differently. We try to simulate paint mixing in our app, but because we use computers rather than paints, our simulations will never be perfect!

## MIXING LIGHT - ADDITIVE MIXING

If you are reading this on a screen, the colors you see are made by mixing light, rather than pigments. When mixing light, the three primary colors are **red**, **green**, and **blue** (often abbreviated RGB).

Mixing light is more exact than mixing pigments and is how most scientists think about mixing colors.

Mixing lights is an example of **additive color mixing**: White light is the combination of all the various colors of light and can be made by adding red, blue, and green light.



## IN THE APP

Drag in different colors of paint to mix them together.

What colors can you create?

Can you create secondary colors? What about tertiary colors?

Pull your mixed colors apart. In our app, you can unmix orange to back to red and yellow. How is this different from real world color mixing?

As you create colors, take a look at the color wheel.

What do you notice?

Try comparing mixing paints to what you see on the screen.

What do we get right? Where does our simulation fail?

Turn on different lights to create new colors.

What do you notice?

Are there colors that you can mix with light that are hard to make with paint? What colors are difficult to make with light?



## DISCUSSION QUESTIONS

- Take a look at the colors inside your favorite book. Are they primary, secondary, or tertiary? What colors would you mix to recreate them?
- Next time you're watching TV, consider the colors on the screen. How do you think they were created?



# Sorting colors

There are countless ways to sort colors. Light to dark, bright to dull, or by their hue. How do you organize your crayons? We sometimes organize colors into color systems, but there's no right or wrong way to sort color.

Some colors vary in their darkness and lightness, or **value**. Other colors might vary in their brightness and intensity, or **saturation**. Saturation is sometimes also referred to as **chroma**.

People sometimes group colors into families such as **warm colors** (red, orange, or yellow families), or **cool colors** (blue, green, or purple). Think of fire and ice!

## SPECTRUM



## SATURATION



## WARM COLORS



## IN THE APP

There are lots of different ways to sort colors. Which one is your favorite?

When sorting color blocks, which ways of sorting are easy?

Which ways are hard?



## DISCUSSION QUESTIONS

- What's the warmest color you can think of? The coldest?
- What places in your neighborhood are defined by color?  
Are there any places in your life that are sorted by color?
- Have you ever tried to sort your book spines by their color?  
Does this make books easier to find or harder?  
What about your crayons?
- Do you find it pleasing when things are sorted by color?



# Naming colors

We know the names of common colors like red, yellow, blue, green, orange, and purple.

We might even be able to easily identify and name more complex colors like magenta, scarlet, or turquoise. But what about beyond that? There are infinite colors in our world and,

therefore, infinite naming possibilities! And the crazy thing is that for many colors, there is no exact color name for it. Different cultures have different names for colors. In some cultures, the names given to specific colors didn't exist until they were named by a company selling paint or crayons.

There are hundreds of systems for naming colors, and one single color can have several different names. What you might name Brick Red, others might call Rusty Red. Colors are also defined differently depending on the language you are speaking. Many ancient languages, for example, don't have a word for blue.



## IN THE APP

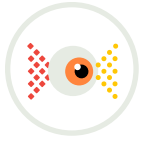
Look around your room. Is there a color that you see but you don't know the name of? With our AR tool, you can collect different colors from your world and discover the closest name using a variety of different color naming systems. What do you think of the name? Are you surprised by it? Maybe you've found a brand new color that you can name yourself!

The color list called Werner's was developed by a German geologist who looked for colors in nature. The web list was defined by a committee of people who standardized the color names used on websites. The popular list was made by asking thousands of people what various colors should be named.



## DISCUSSION QUESTIONS

- Consider a box of crayons. What do you think of the names of the colors? Would you name them differently?
- There are lots of themes in color naming. For example, colors are often named based on foods (mustard yellow) or things in nature (forest green). What other themes or categories can you think of?



# How we see

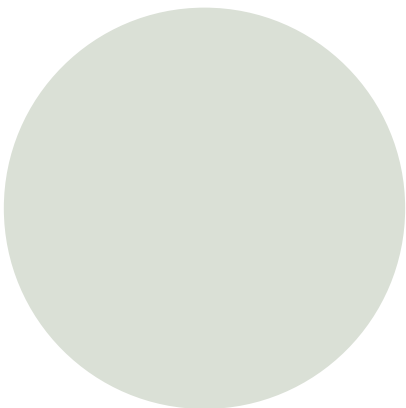
We use our eyes to see — obviously — but how? How do our eyes work and process the world around us? Light enters our eyes through a lens in our pupil and is then refracted to focus an image on the back of our **retina**, which is like a tiny movie screen on the back of your eyeball.

Then our **optic nerve** turns visible light into signals which our brain is able to interpret everything we see. Fun fact: your eye projects the images on your retina upside down. Your brain has to flip it!

Some people have a condition called color blindness in which they have trouble telling the difference between certain colors, or more rarely, they might not see color at all. So, for example, some color blind people might see red and green as the same color. Others might have problems telling the difference between blue and green. Finally, a very small number of color blind people might only see the world in shades of gray.

There are certain types of light that our optic nerve cannot detect, such as **Infrared (IR) light** and **Ultraviolet (UV) light**. Different living creatures have different types of eyes — as a result, they perceive the world very differently than one another. Biologists have categorized 10 different types of eyes! Some are wildly different from our own. Bees, for example, have five eyes, and two of those eyes are made of thousands of lenses. Although they can't focus their eyes like we can, they can detect ultraviolet colors which we can't see.

This helps them find flowers!



## IN THE APP

Take a look inside the house through the eyes of different creatures. What are some of the differences between the vision of a human and a dog? A human and a bee? How about a dog and a bee?



## DISCUSSION QUESTIONS

- How do you imagine your life would be different if you saw the world the way bees do?
- What are the differences between what color blind people see compared to others?





# Color and emotion

Have you ever noticed that a color makes you feel a particular way?

We sometimes connect certain colors to certain emotions. For example, warm colors might make us think of happiness, while cooler colors are often linked to sadness. Of course, not all colors are associated with the same emotion for every person! Hot pink might make you feel excited, while it might make someone else feel sad. **Color psychology** is the study of how different colors influence people's moods or emotions.

## IN THE APP

Play around with different colors and see what feelings come to mind. Does lime green make you feel excited or curious? What about a rich red? As you play, think about some of your favorite colors and see if there are any links between those colors and how they make you feel.



## DISCUSSION QUESTIONS

- Next time you're in the grocery store, take a look at the colors on the different packages. Which colors do you see most? Why do you think certain colors are used and others are not?
- Do certain colors make you hungry? Have you ever noticed that fast food restaurants use certain colors in their designs?
- If you were designing the cover of a children's book, what colors would you use? Any you would avoid?

# Glossary

## **Additive color**

A color that starts off as black, but becomes white as more colors are added. Mixing lights is an example of additive color mixing.

## **Analogous colors**

Three colors next to each other on the color wheel. For example, blue, green, and blue-green.

## **Bioluminescent light**

Light produced by a living being.

## **Chroma**

The purity of a color or how much the color has been mixed with white, black, or gray. Chroma is also sometimes referred to as saturation.

## **Color wheel**

The organization of color around a circle. The color wheel helps us understand relationships between colors.

## **Complementary color**

A color that, when mixed, cancel each other out and create a grayscale color. These colors are opposite each other on the color wheel.

## **Cool color**

A color family consisting of blues, greens, and purples.

## **Color psychology**

The study of how different colors can influence a person's mood, emotion, or reaction.

## **Electromagnetic radiation**

Energy, or light, that travels in waves.

## **Electromagnetic spectrum**

All the radiation produced by a star.

## **Hue**

A particular color or shade.

**Incandescent light**

Light that is produced by heating a wire filament.

**Infrared (IR) light**

Electromagnetic radiation with wavelengths longer than visible light.

**Neutral color**

A color that does not appear to have any color. Gray, white, and black are all neutral colors.

**Opaque object**

An object that does not allow any light to pass through.

**Optic nerve**

The nerve that carries information from the retina to the brain.

**Primary color**

Basic colors that can be mixed together to create other colors.

When dealing with pigments, these colors are red, yellow, and blue.

When looking at lights, our primary colors are green, red, and blue.

**Pupil**

The opening in our eyes that allows light to pass through.

**Quaternary color**

Quaternary colors are created when equal amounts of two tertiary colors are mixed.

**Reflection**

The return of light waves from a surface.

**Refraction**

The bending of light as it passes through one transparent object to another.

**Retinas**

Thin layer of tissue on the back of our eyes that receives light and sends these signals to the brain for visual processing.

**Saturation**

How strong or weak a color is.

**Secondary color**

Secondary colors are those that are formed from mixing equal parts two primary colors.

**Shade**

New shades are created when black is added to any pure hue.

**Subtractive color**

A color that starts off as white becomes darker and moves towards black as more colors are added. Mixing paints and pigments is an example of subtractive color mixing.

**Tertiary color**

Tertiary colors are created when one primary color is mixed with a secondary color.

**Tint**

New tints are created when black is added to any pure hue.

**Tone**

New tones are created when neutral gray is added to any pure hue.

**Transparent object**

Clear objects that allow light to pass through.

**Translucent object**

Allows some light to pass through.

**Ultraviolet (UV) light**

Electromagnetic radiation with wavelengths shorter than visible light, but longer than x-rays.

**Value**

The lightness or darkness of a color.

**Visible light spectrum**

The portion of the electromagnetic spectrum that the human eye can see.

**Warm colors**

A color family consisting of reds, yellows, and oranges.



## **RESOURCES**

Buthelezi, T., Dingrando, L., Hainen, N., Wistrom, C., & Zike, D. (2017).

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