# INTEGRATED SCIENCE UNIT

## TEACHER GUIDE

## LIGHT! COLOR! PERCEPTION!

SCIENCE

DIGITAL MEDIA ARTS

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EDC
Education Development Center, Inc.

the James Irvine foundation

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The California Center for College and Career

# Education Development Center, Inc.

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SCIENCE

# Unit Overview

*Color perception is a fascinating intersection of physical phenomena and the physiology of the eye and brain. As students explore how human beings and other animals perceive color, they develop a deeper appreciation for the way the nervous system transmits and interprets information from the surrounding environment.*

*Students begin each area of inquiry in this biology unit by experiencing color perception firsthand and developing questions based on their observations. They gain a basic understanding of the relationship of light to color and explore the workings of the nervous system, including the physiology of the eye and the brain and how the two interact to perceive color. Finally, students learn how arts and media take advantage of these physiological interactions to produce a range of visual effects.*

## Unit Length

**5 50-minute sessions**

## Assessment

Unit activities can serve as formative assessment tools. Use student work, including handouts, to gather information about student progress and to identify concepts or skills to reinforce within your instructional practice. The following handouts are particularly useful:

- Questions about color and light on **Handout 4: Light and Color**
- "What Do You Think?" questions about the eye on **Handout 7: The Eye**

The inquiry-based nature of the unit allows students to demonstrate their learning through authentic and relevant applications. For this unit, the summative assessment consists of the following:

- A written summary of students' understanding of color perception
- An analysis and labeled diagram presenting the physiology behind a color effect in an artwork, media piece, or illusion of students' choice

The unit's Assessment Checklist provides criteria for assessment and a suggested weight for each. If you wish to use a rubric, work with same-grade-level or subject-area teachers to develop a tool that is consistent with your school's assessment system.

## Framing Questions

- How do the eye and brain work together in the nervous system to perceive color?
- How do arts and media take advantage of eye and brain interactions to produce visual effects?

## Understandings

- Color is a construction of the eye and brain, not a property of light or matter.
- Vision results when electrochemical impulses are transmitted through the nervous system from the eye to the brain.
- Human color perception varies according to such factors as available light, environment, juxtaposition of colors, and eye and brain physiology.

## Where the Unit Fits In

This one-week unit is designed to be taught when students are studying the physiology of the human nervous system. Through an in-depth exploration of one of the senses—vision—students learn how the nervous system relays information between the environment and parts of the body, specifically, the eye and brain. The study of color perception provides students with hands-on experiences in understanding nervous system functions and the role of electrochemical transmission in sensation, perception, and response. You may wish to teach this unit in conjunction with materials on other parts of the human nervous system, including the other senses.

### Integration with Foundation Courses

This unit integrates biology content and career and technical education (CTE) knowledge and skills. It can be taught before, at the same time as, or after the related unit in *Foundations in Visual Arts*.

***Foundations in Visual Arts, Unit 4: Make Me a World.*** Students study color and the design principles of unity, variation, and repetition to understand how artists create evocative concept art for media productions. For the unit project, students work in teams to create original concept art to convey the setting and emotional tone of a television show, movie, or video game. Discuss with the *Foundations in Visual Arts* course teacher the possibility of using student work from Unit 4 as teaching examples in Part 3 of the biology unit. Some students may wish to use their own artwork for the final assessment activity. Suggest that students use the painting techniques analyzed in the biology unit—complementary contrast, equiluminance, and pointillism—when they create their landscapes and concept art for Unit 4.

### Multi-Disciplinary Teams

Use the following integrated units and integration suggestions for a school- or pathway-wide multi-disciplinary project.

***Settings from Page to Screen* (English Language Arts).** Students research how authors create settings in fiction and explore the relationships between the sense of place in literature, art, and media. For the unit project, students work in teams to develop set designs for several key settings in an imaginary feature film based on a book they read. Work with the English teacher to have students use ideas about color perception and effects from biology classes to choose colors and designs for settings and set descriptions.

## Student Prerequisites

Students should have some familiarity with the concept of visible light as a portion of the electromagnetic spectrum. While the unit briefly reviews the physics of light necessary to understand color perception, a thorough treatment of the physical properties of light is outside the scope of this unit.

## Adapting the Unit

***Supplemental Artwork and Illusions.*** The unit provides links to examples of illusions and color effects in *Media & Resources*. Encourage students to explore perceptual phenomena further by providing supplementary materials from online or other sources or by having students find examples on their own. See *Additional Resources for Teachers* for sources of other artwork and illusions.

***Reading Comprehension.*** This unit requires students to read about and understand many new scientific terms and sophisticated concepts. Students may benefit by employing strategies such as previewing material by looking at graphics and headings, examining derivations for new vocabulary, and, as a class, reading aloud challenging short passages to review key information. Apply additional comprehension strategies as appropriate and adjust activities accordingly.

## Pacing

The unit is designed to take one week. If you are teaching the unit in conjunction with other readings or materials on the human nervous system, you may need to adjust the timing. You may also wish to provide students with additional in-class time for their assessment projects or allow them to complete their assessment work at home.

# Table of Activities

## Part 1: In the Eye of the Beholder (1 session)

Students begin their color studies by comparing their perceptions with those of other students, concluding with an overview of unit activities and assessment criteria.

### Activity 1A: Color Survey

Students explore their perceptions of color by taking a color survey in which they categorize colored crayons and compare their responses with classmates' responses.

### Activity 1B: Introducing the Unit

Students are introduced to the unit content and activities and receive a preview of the assessment criteria.

## Part 2: Light and the Physiology of Vision (3 sessions)

Optical illusions set the stage for investigations to explore the roles of light, the eye, and the brain in color perception.

### Activity 2A: Light and Perception

| | |
|---|---|
| ***2A.1: Illusion 1: Gray or White?*** | Students experience an illusion that introduces how light affects color perception. |
| ***2A.2: The Color Spectrum*** | Students learn about the color spectrum, including wavelength and frequency. |
| ***2A.3: Viewing Colored Objects Under Colored Light*** | Students view some familiar objects under colored light to see how their perception of the objects' color changes. |

### Activity 2B: The Eye and the Image

| | |
|---|---|
| ***2B.1: Illusion 2: After-Images*** | Students begin their exploration of the eye by experiencing an illusion in which they perceive after-images after staring at solid colored squares. |
| ***2B.2: Drawing the Eye*** | Students draw a partner's eye, label the parts they can see, and speculate about how the eye works. |
| ***2B.3: The Structure of the Eye*** | Students learn about the parts of the eye, relate what they learn to their drawings, and learn what happens when light from an image passes into the eye. |
| ***2B.4: Additive and Subtractive Mixing*** | Students use flashlights and filters to conduct experiments in two kinds of color mixing. |

### Activity 2C: The Brain Decides

| | |
|---|---|
| ***2C.1: Illusion 3: The Disappearing Dot*** | Students create and experience an illusion in which part of an image seems to disappear. |
| ***2C.2: What the Brain Sees*** | Students read about the brain's role in perception and learn how the brain interprets visual information and compensates for information gaps. |

## Part 3: Do You See What I See? (1 session)

Students briefly explore three techniques used in arts and media that take advantage of the way our eyes and brain process visual information: complementary contrast, equiluminance, and pointillism.

### Activity 3A: Complementary Contrast

Students view examples of how artists use the juxtaposition of contrasting colors to produce visual effects, and they learn the biological basis for these perceptions.

### Activity 3B: Equiluminance

Students experience how the color phenomenon of *equiluminance* affects the way that the brain interprets shape and color in a work of art. They learn that equiluminant colors appear to vibrate because of the way the brain processes brightness.

### Activity 3C: Pointillism

Students learn about a third type of color mixing called *partitive mixing* and experience the color effects of *pointillism*, a painting style that uses partitive mixing.

### Activity 3D: Assessment

Students summarize their understanding of color perception and analyze the physiological basis for a color effect in an artwork, media piece, or illusion of their choice.

## Advance Preparation

RESOURCES

- Internet resources, provided as links in *Media & Resources*, are recommended throughout the unit for student or in-class use. These Web sites have been checked for availability and for advertising and other inappropriate content. Because Web site policies and content change frequently, however, we suggest that you preview the sites shortly before using them.
- Address any issues, such as firewalls, related to accessing Web sites or other Internet links at your school.
- Look at **Materials Needed** at the end of the unit and order or prepare any needed equipment or supplies. **Appendix A: Equipment Recommendations** provides suggestions for sources of flashlights and filters.
- Make sure that you can darken your classroom to perform experiments in Activities 2A and 2B or find an alternative location for these experiments.
- (Optional): Assemble additional illusions to supplement the illusions on the handouts at the beginning of each activity in Part 2. Numerous illusions, in both color and black and white, are available in books and online. See *Additional Resources for Teachers* for links and references.
- For Activity 3D: Assessment, collect examples of artwork, illusions, or media that demonstrate the color effects explored in the unit: after-images, simultaneous and complementary contrast, equiluminance, and pointillism. Students will choose one of these examples as the basis for the second part of their assessment. Find examples from visual arts classes or print or copy examples from online sources or books. Alternatively, you may wish to provide lists or links to resources for students to search independently. See *Media & Resources* for suggestions.

# Part 1: In the Eye of the Beholder

The activities in Part 1 are designed to guide students in raising questions about the nature of color and visual perception. Students take a color survey to compare their perceptions of color with other students' perceptions, and they go over the unit activities and assessment criteria.

## Length

**1 50-minute session**

## Advance Preparation

- Before Activity 1A, decide whether you will conduct the activity with color crayons or a color slide show. If you are using crayons, determine whether you will do the activity as a class or in groups and then borrow or purchase as many 48-crayon packs as needed. If you are doing the activity as a class, select 15 crayons from the box that you believe students are most likely to perceive differently. (The likeliest choices are those that appear to fall between color categories, such as blue-greens, yellow- or red-oranges, or red- or blue-violets.)

# Activity 1A: Color Survey

Students explore their perceptions of color by taking a color survey, in which they categorize colored crayons and compare their responses with classmates' responses.

## Understandings

- *Perceptions* are subjective, personal, and conscious reactions to stimuli to the sensory system.

## Materials Needed

- **Handout 1: Color Survey**
- 15 crayons selected from a 48-crayon pack (see Advance Preparation)
- Red object, such as an apple or a book with a red cover
- Optional: 48-crayon packs (one pack per group)
- Optional: sets of six paper cups or six sheets of paper (one set per group)
- Optional: Mac- or PC-specific color slide show (see *Media & Resources*)
- Optional: Equipment for displaying color slide show

> **Note:** You may conduct the activity using the Mac- or PC-specific slide presentation provided in *Media & Resources*, using 15 color slides instead of 15 crayons. Be aware that slide color will vary depending on screen monitor and viewing angle. Arrange to have a computer with Internet connection and screen.

**1. Introduce *perception* as a function of the nervous system.**
Establish that the five senses are part of the human nervous system. Tell students that in this unit they take an in-depth look at one sense, vision, to learn how the nervous system facilitates communication between the environment and parts of the body.

Explain that students will explore how and why they perceive colors. Clarify what it means to *perceive*. Discuss how all five senses are active in human perception.

> **Note:** You may wish to have students use an informal definition of visual perception, such as "a way of seeing or understanding what one sees," rather than the broader biological definition, "the body's response to a stimulus from the environment."

**2. Introduce the color sorting activity.**
Ask students:

- What is *color*?

***Possible answers:*** *A property of an object, a property of light, something the eye sees, a construction of the brain.*

Hold up a red object and ask:

- What color is this?
- Do you think your perception of *red* is the same as that of your classmates?

Tell students that they will explore these questions by comparing their perceptions of crayon colors with those of their classmates.

**Distribute Handout 1: Color Survey** and give students time to read it. Explain that you are going to display a series of 15 crayons, each a different color. For each crayon, students will mark on Handout 1 which color they perceive it to be. When they've looked at all 15 crayons, they will compare their perceptions with others in the class.

Explain to students that it is important that they name each color on their own and that they not confer with their classmates. Emphasize that there is no *right* answer.

**Teacher's Notes: Small-Group, Hands-On Alternative to Color Survey (Use in Place of Activity Steps 2–5)**

Give each group of three or four students a 48-crayon pack with the black, white, and gray crayons removed, a set of six paper cups or six sheets of paper, and a pen or pencil. Have each group write the names of the six color categories from **Handout 1: Color Survey** (red, orange, yellow, green, blue, violet) on the six cups or sheets of paper. Tell groups to sort their crayons into these six categories.

Tell groups that each member should sort an equal number of crayons, but that the group should not try to reach agreement on the color of any single crayon. Emphasize that the activity is based on individual perceptions, not group consensus. Tell students not to read the names of the colors on the crayon labels as they sort. (You may choose to remove or cover the labels in advance.)

When groups have finished sorting their crayons, have them create a bar graph to show the number of crayons their group sorted into each color category. Then compare graphs as a class. Ask:

- Did your group sort the same number of crayons into each category as other groups did?
- Which color categories had the greatest variations in perceptions?
- What conclusions might you draw from this activity?

**3. Display crayons.**
Show students the 15 crayons one at a time, providing time for students to record the category of each color on the handout.

**4. Tally and discuss student responses.**
Tally and display the number of responses in each color category for each crayon. For crayons that were classified in two or more color categories, have students create bar graphs to show the number of responses in each category. For example, a crayon that 15 students perceived as blue and 15 perceived as green would have a bar graph that showed two bars of 15 units each, with one bar labeled *blue* and one bar labeled *green*.

**Note:** Review with students how to make a bar graph, as necessary. Draw a graph on the board. Label the color categories along the x-axis. Label the y-axis "Number of Student Responses" and choose an appropriate interval for numbering. As an example, draw two or three bars on the graph.

**5. Discuss responses as a class.**

Have students look at the results for each color:

- For how many crayons did your class perceive different colors?
- Which color categories had the greatest variations in perception?
- What conclusions might you draw from this activity?

**6. Wrap up the activity.**
Ask students:

- Did performing this activity raise any questions for you about color? What are they?

Tell students that they will explore the factors responsible for color perception.

### Teacher's Notes: The Diversity of Perception

Students should discover variation in the way they identified the colors. They will probably agree that color perceptions differ among individuals. They may also talk about color itself being a quality of individual perception rather than a property of an object, but they should have a number of questions about why their perceptions vary.

To extend the discussion, ask students how people might vary in the way they perceive the world through other senses. Examples might include:

- **Taste.** Different sensitivities to sweet or to spicy foods (some people are very uncomfortable eating spicy food, while others enjoy it)
- **Hearing.** Different registers of hearing (some people can hear very high or very low sounds; some people have perfect pitch)
- **Smell.** Differences in ability to recognize scents, such as flowers or foods; differences in comfort levels related to strong odors
- **Touch.** Sensitivities to heat or cold; reactivity to different fabrics, such as wool

## Handout 1:
# Color Survey

Have you ever thought about whether everyone sees colors in the same way?
Here's your chance to find out!

Your teacher will display crayons or slides. Categorize each of the 15 colors under *one* of the six major color headings in the table below. If a crayon or slide doesn't seem to fit well under any of the categories, choose the category that seems best.

| | Color Categories | | | | | |
|---|---|---|---|---|---|---|
| | Red | Orange | Yellow | Green | Blue | Violet |
| Color 1 | | | | | | |
| Color 2 | | | | | | |
| Color 3 | | | | | | |
| Color 4 | | | | | | |
| Color 5 | | | | | | |
| Color 6 | | | | | | |
| Color 7 | | | | | | |
| Color 8 | | | | | | |
| Color 9 | | | | | | |
| Color 10 | | | | | | |
| Color 11 | | | | | | |
| Color 12 | | | | | | |
| Color 13 | | | | | | |
| Color 14 | | | | | | |
| Color 15 | | | | | | |

# Activity 1B: Introducing the Unit

Students are introduced to the unit content and activities and receive a preview of the assessment criteria.

## Understandings

- An *illusion* is an erroneous perception of reality. Something is presented in a way that causes viewers to misinterpret what they see and to perceive it as different from the way it really is.

## Materials Needed

- **Handout 2: Unit Overview**
- **Assessment Checklist: Color Perception**

**1. Go over the unit overview.**
Distribute **Handout 2: Unit Overview** and have students read the introductory paragraphs to themselves. Direct students to the section titled "What You Will Do in This Unit." Explain that they are going to explore how the eye and brain interact with light and enable us to see.

**2. Direct students to the vocabulary list.**
Point out that Handout 2 contains many vocabulary terms they will use in the unit. Tell students to refer to this list as they encounter unfamiliar words in unit activities.

### Teacher's Notes: Vocabulary and Reading Comprehension

This unit contains much scientific terminology that may be new to students. Later in the unit, diagrams of the eye and the photoreceptors on the retina present additional vocabulary. Take advantage of opportunities to use diagrams, word derivations, context clues, and other strategies to familiarize students with key terms.

You may wish to reinforce vocabulary by encouraging students to write sentences or summary paragraphs, use new words in context, or create flashcards for comprehension practice. Incorporating 5-minute games of Vocabulary Bingo or Hangman into daily lessons are another way to strengthen vocabulary.

**3. Review the Assessment Checklist.**

Distribute **Assessment Checklist: Color Perception**. Tell students that by the end of the unit they will be able to summarize the biological processes that allow us to see colors. They will also be able to explain how artists use these processes to produce specific color effects. Go over the assessment criteria with students and answer any questions they may have.

## Handout 2:
# Unit Overview

## Light! Color! Perception!

*How do we perceive color? Is my* red *the same as your* red*? How about my* blue*? Do all human beings perceive color in the same way?*

*Surprisingly, no. A large number of factors affect your perception of a color, including light, other colors next to it, and your own eyes and brain. As you explore how human beings and other animals perceive color, you will develop a deeper understanding of how the nervous system transmits and interprets information from the environment.*

*You'll begin each area of investigation by experiencing a visual illusion (an image that tricks your eyes and brain). Then, using your own observations as a starting point, you will explore, in turn, the relationship of color and light, the* physiology*—biological workings—of the eye, and the way the eye and brain interact with light to create your perception of color. Finally, you will experience how arts and media use color to produce a range of visual effects.*

*As you carry out the unit activities, you will look for answers to the following questions:*

- *How do the eye and brain work together in the nervous system to perceive color?*
- *How do arts and media take advantage of eye and brain interactions to produce visual effects?*

### What You Will Do in This Unit

***Experience mystifying illusions.*** Experience a series of visual illusions and ask questions about what causes them.

***Diagram the human eye.*** Learn what really happens in the eye and brain when you see colors.

***Find out why blue and yellow don't always make green.*** Try two forms of color mixing that produce different results and understand their origins in biology.

***Explore visual effects in art.*** Explore the perceptual tricks used by arts and the media and explain why they work.

## Vocabulary Used in This Unit

***Additive mixing:*** Mixing of colored light, in which wavelengths are added together.

***Complementary contrast:*** Phenomenon in which the juxtaposition of *complementary colors*—colors opposite one another on the color wheel—make each color appear brighter and stronger.

***Cones:*** Photoreceptors in the eye that respond to color, particularly in bright conditions.

***Dichromacy:*** Condition in which a person has only two types of functioning cones and therefore cannot perceive some of the wavelengths of light.

***Electromagnetic spectrum:*** Range of radiation that includes, in addition to visible light, radio waves of all kinds, infrared radiation, ultraviolet radiation, X-ray, and gamma ray radiation.

***Equiluminance:*** Phenomenon in which two colors of equal brightness placed next to each other appear to float or vibrate.

***Frequency:*** Number of waves (measured by successive crests) that pass by a point in space in a certain unit of time (often measured "per second").

***Illusion:*** A false perception of reality; something presented in a way that causes viewers to misinterpret what they see and to perceive it as different from the way it really is.

***Monochromat:*** Person who has only one type of functioning cone.

***Nanometer:*** A unit of measurement equal to a billionth of a meter (abbreviated *nm*).

***Neurons:*** Cells that process and transmit information through electrochemical impulses. Neurons, also known as nerve cells, are the primary component of the nervous system.

***Opponency:*** Theory that states that certain pairs of colors—red and green; yellow and blue—are mutually exclusive. That is, there are no reddish greens or bluish yellows.

***Partitive mixing:*** Type of color mixing in which colors are presented as very small discrete dots, or parts, arranged close to one another, so that the colors are mixed in the viewer's eye. The painting style *pointillism* relies on partitive mixing, as do the printing process and computer monitors.

***Perception:*** A body's response to a stimulus in the environment. Living things perceive the world through their senses.

***Photoreceptor:*** A nerve cell or group of cells located on the retina and specialized to sense or receive light.

***Pointillism:*** Style of painting in which small dots of pure color are placed close to one another.

***Response:*** Function or activity displayed by an organism or part of an organism when activated or excited.

***Rods:*** Photoreceptors in the eye that respond to brightness, but not color. Rods function in low-light conditions.

***Simultaneous contrast:*** Phenomenon in which the juxtaposition of two different colors affects our perception of each color's hue.

***Stimulus:*** Something in the environment that excites an organism or a part of an organism to respond or function.

***Subtractive mixing:*** Mixing of colored pigments, in which certain wavelengths of light are absorbed and others are reflected.

***Trichromacy:*** The theory that any color can be produced using combinations of three primary colors.

***Wavelength:*** The distance between a point on one wave and the same point on the next wave, usually measured between successive *crests* (high points) or *troughs* (low points).

## Assessment Checklist:
# Color Perception

Use the table below to help you complete your final assessment. Make sure to include all the requirements. Your teacher will use this assessment to evaluate your work.

| Requirements | Percentage of Total Grade | Comments | |
|---|---|---|---|
| **Color Perception Assessment** | | **Student Comments** | **Teacher Comments** |
| Summarize what color is and how the nervous system faciliates color perception, including:<br>• The relationship of light to color (20%)<br>• The structure of the eye and the function of its parts, including lens, retina, and photoreceptors (30%)<br>• The role of the brain in receiving and interpreting visual information (20%) | **70%** | | |
| For a chosen example of an artwork, illusion, or media piece that uses a color effect covered in this unit:<br>• Identify or name the effect (5%)<br>• Describe what you perceive (5%)<br>• Explain how the interactions of light, eye, and brain through the nervous system create the perception (10%)<br>• Illustrate your explanation with a diagram comprising the example work, light, the eye, and the brain (10%) | **30%** | | |
| **Total** | **100%** | | |

# Part 2:
# Light and the Physiology of Vision

Students experience three illusions as introductions to three areas of inquiry in color perception. These initial explorations set the stage for investigations into the role of light, the eye, and the brain.

- In Activity 2A: Light and Perception, students explore the relationship between color and light. Learning that perceived color is influenced by a combination of absorbed and reflected light allows them to understand Illusion 1.
- Activity 2B: The Eye and the Image introduces students to the structure of the eye, including the photoreceptors known as *rods* and *cones*. Learning how color-sensitive cones are stimulated by different wavelengths of light allows students to understand how after-images are produced in Illusion 2.
- Activity 2C: The Brain Decides describes how a complex of nerve cells relays messages from the eye to the brain and how the brain interprets visual information. Learning how the brain compensates for missing information by filling in the field of vision reveals the mystery of Illusion 3.

By the end of Part 2, students should understand how the nervous system mediates vision, and the roles that light, their eyes, and their brains play in creating their perceptions of color.

## Length

**3 50-minute sessions**

## Advance Preparation

- Plan for students to work in pairs in Activities 2A.1, 2B.1, and 2B.2. Plan for students to work in groups of four in Activities 2A.3 and 2B.4.
- Before Activities 2A.3 and 2B.4, prepare your classroom so that it can be fully darkened or arrange for an alternate space to perform experiments.
- For Activities 2A.2 and 2A.3, find red, blue, and green objects (sets of three objects per group). Fruits and vegetables, such as apples or tomatoes, blueberries or plums, and green peppers or beans work well.
- Assemble materials for Activities 2A.3 and 2B.4 or have materials displayed where groups can easily assemble their own.
- For Activity 2C.2, choose two images to show as examples of simultaneous contrast and prepare equipment to display them. (See *Media & Resources* for links.)

RESOURCES

# Activity 2A: Light and Perception

Students learn about the role that light plays in their perception of color.

## Sequence

| | |
|---|---|
| ***2A.1:*** ***Illusion 1: Gray or White?*** | Students experience an illusion that introduces how light affects color perception. |
| ***2A.2:*** ***The Color Spectrum*** | Students learn about the color spectrum, including wavelength and frequency. |
| ***2A.3:*** ***Viewing Colored Objects Under Colored Light*** | Students view some familiar objects under colored light to see how their perception of the objects' color changes. |

## Understandings

- Color perception can be influenced by light.
- Color is a construction of the eye and brain, not a property of light or matter.
- White light can be separated into a consistent color spectrum, in which each color is associated with a different wavelength.

## Materials Needed

- Two blank white unlined index cards (1 set per pair)
- Scissors (1 per pair, or 1 available in the classroom)
- **Handout 3: Illusion 1: Gray or White?** (1 per pair)
- **Handout 4: Light and Color**
- Colored objects (1 red, 1 blue, and 1 green object per group) (see Advance Preparation)
- Flashlights (4 per group)
- Colored filters (1 red, 1 blue, and 1 green filter per group)
- Rubber bands or cellophane tape for attaching filters
- **Handout 5: Viewing Objects with Colored Light**

**Note:** If there is a limited supply of flashlights, each group can perform Activity 2A.3 with only one flashlight, as long as students can easily attach and detach the different colored filters.

## 2A.1: Illusion 1: Gray or White?

**1. Introduce illusion activities.**
Explain to students that they will experience three visual illusions as an introduction to three different factors in color perception: light, the eye, and the brain.

For each illusion, they will have two tasks. First, they should simply experience the illusion and describe what they see. Next, they will work with a partner to guess what might be happening in the illusion and come up with a question or two that they would like to have answered.

Have students pair up to experience the first illusion. Distribute index cards, scissors, and **Handout 3: Illusion 1: Gray or White?** to each pair.

**2. Provide class time for students to experience the illusion.**
Guide pairs through the illusion, modeling the steps on Handout 3 as needed.

**3. Discuss students' observations.**
Discuss the procedure students performed in Handout 3. Ask students to share their responses to the questions on the handout:

- In step 2, what colors are the cards?

  ***Answer:*** *Both are white.*

- In step 3, what color was the solid card seen through the hole in the cut card?

  ***Answer:*** *Gray*

- In step 3, what color was the cut card?

  ***Answer:*** *White*

- In step 4, what color was the solid card viewed through the square hole?

  ***Answer:*** *Bright white*

- In step 4, what color was the cut card?

  ***Answer:*** *Gray*

Ask students:

- What questions did you come up with, based on your observations?

  ***Possible answer:*** Students will probably ask some variation of the question, *Why does my perception of the card colors change in each situation?*

Tell students that they will now investigate the role of light in color perception and that this will help them find the answers to their questions.

## Handout 3:
# Illusion 1: Gray or White?

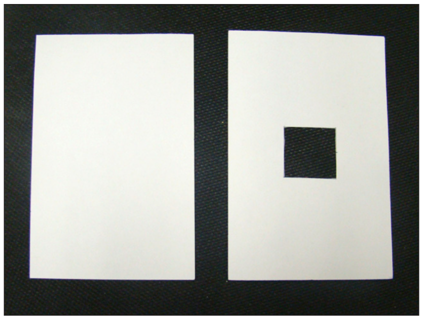
In this illusion, you will watch two cards *change color*!

## Procedure

Perform the following steps with your partner:

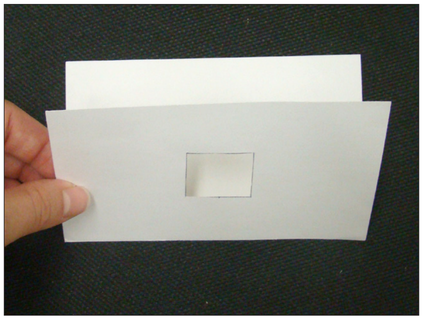
1. Cut a 1-inch square hole in the center of one index card.

2. Place the uncut index card on the windowsill or on a table under a light source. Place the index card with the cut-out square hole beside it.



What colors are the cards?

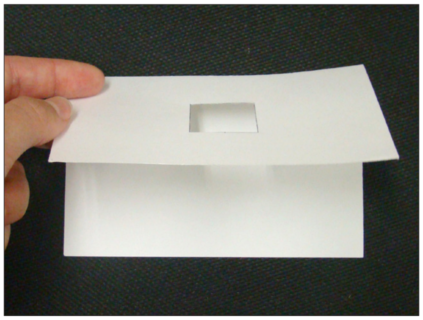
3. Now place the cut card directly above on top of the solid card. Then lift and tilt the cut card toward the light.



What color is the solid card seen through the hole in the cut card?

What color is the cut card?

4. Lay the cut card on top of the solid card again. Then lift and tilt the cut card away from the light. Look at the solid card through the square hole.



What color is the solid card?

What color is the cut card?

Think about how your perceptions of card color changed. Based on your observations, what question(s) would you like to have answered?

## 2A.2: The Color Spectrum

**1. Have students read and answer questions about light.**
Tell students that to understand how the eye perceives color, they will review a few basic properties of light. Distribute **Handout 4: Light and Color**. Have students read the handout and answer the questions posed.

**Note:** The questions on Handout 4 offer a good opportunity for formative assessment.

**Teacher's Notes: Newton's Discoveries and the Color Spectrum**

Interactive demonstrations of Newton's prism experiments, as well as step-by-step experiments for the classroom, are available online. See *Additional Resources for Teachers* for selected links.

If possible, print out Handout 4 in color, so that students can see the gradations of color in the spectrum diagram. Alternatively, project or display a color image of the spectrum. See *Media & Resources* for a link.

**2. Discuss Newton's discoveries and the properties of light.**
Ask students:

- Where might you have observed a color spectrum similar to the one produced by Newton?

  ***Possible answers:*** *A rainbow, a bubble, an oil slick*

- Using what you learned in Handout 4, why do you think you see these colors?

  ***Possible answers:*** *Light bends when it passes through different materials in which light speed varies, such as water, the surface of a soap bubble, or oil.*

Have volunteers share their answers to the rest of the questions on Handout 4:

- What would be the approximate wavelength of a wave with the spectral color red?

  ***Answer:*** *630 to 700 nm*

- What color is a wave with a wavelength of approximately 450 nm?

  ***Answer:*** *blue*

- When you look at a green object, what color is being reflected?

  ***Answer:*** *A green object reflects green light waves.*

- What colors of light does a white object reflect?

  ***Answer:*** *All of the colors that hit it.*

---

**Note:** If necessary, clarify that the last two questions refer to objects that do not emit or transmit light.

---

**3. Have students identify light reflection and absorption for colored objects.**
Have students view a series of objects of various colors. For each object, ask:

- Which colors are being reflected and which colors are being absorbed?

You can use the same objects again in Activity 2A.3.

**Teacher's Notes: The Color Spectrum and Photosynthesis**

To give students a deeper understanding of the importance of light wavelength to biological processes, connect the color spectrum to photosynthesis, either at this time or when your class studies plant biology.

Theodor Wilhelm Engelmann conducted experiments using a microscope with a built-in prism that produced a color spectrum across a microscope slide. Using this "micro-spectroscope," Engelmann exposed a strand of algae to different wavelengths of light. He concluded that the areas exposed to regions of red and blue light generated the most photosynthetic activity.

See *Media & Resources* for links to diagrams and further information about Englemann's findings.

# Handout 4: Light and Color

## Newton's Discoveries

In 1665, Isaac Newton made a groundbreaking discovery about the nature of light. By allowing a sunbeam to pass through a triangular piece of glass (a prism), he demonstrated that the prism divided the white light into various colors. Although Newton saw a progression of gradually changing colors, or gradations, he named seven colors, choosing the number seven to correspond with the seven notes of a musical scale.

Newton described the colors with the names Red, Orange, Yellow, Green, Blue, Indigo, and Violet, which you might remember now by the mnemonic "Roy G. Biv."

In further experimentation, Newton also demonstrated the following:

- The arrangement of the colors in the separated spectrum was always the same.
- Once colors had been separated with the prism, they could not be separated further.
- The separated colors could be "put back together" to yield white light when passed through a second prism.

Newton hypothesized that there was a physical property of light that corresponded to each spectral color, causing each color to bend at a different angle through the prism.

## Light as a Wave

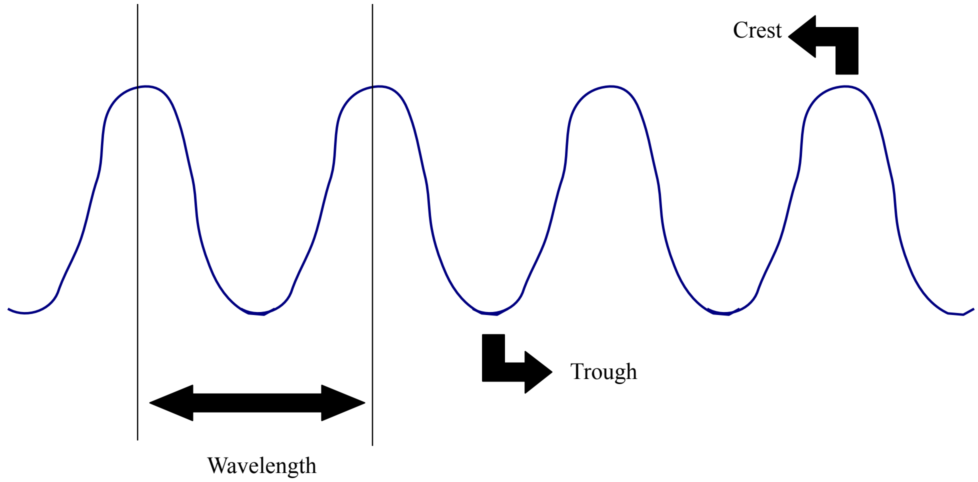
Scientists later determined that light can be separated by shining it through a prism because light behaves as a wave, bending when it passes through materials in which light speed varies.

The color spectrum that Newton observed is the visible part of a larger spectrum, called the *electromagnetic spectrum*. The electromagnetic spectrum also includes radio waves, infrared radiation, ultraviolet radiation, X-ray, and gamma ray radiation.

The two most important properties of waves with respect to the behavior of light are *wavelength* and *frequency*.

*Wavelength* is the distance between a point on one wave and the same point on the next wave, usually measured between successive *crests* (high points) or *troughs* (low points).

The diagram below is a representation of a wave, showing these features.

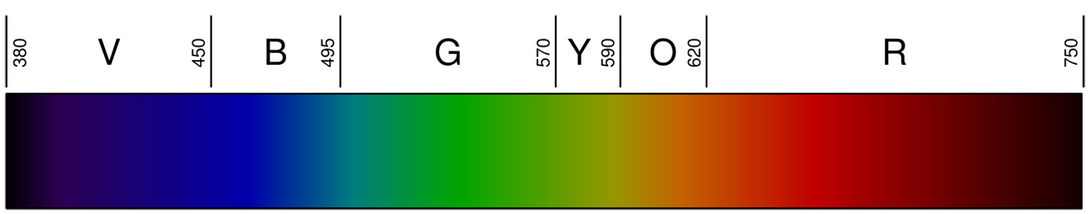



*Frequency* is the number of waves that pass by a point in space in a certain unit of time (often measured "per second").

The distance between two successive crests in the visible spectrum is very small, around 500 billionths of a meter. A billionth of a meter is known as a *nanometer*, abbreviated *nm*.

Our eyes can only detect light in the range of 380 to 760 nanometers. An object that does not emit light appears to be a certain color because the object absorbs certain wavelengths of visible light and reflects other wavelengths. The reflected wavelengths determine the colors we see.

The graphic below shows the ranges, in nanometers, of the spectral colors in the visible spectrum. This spectrum is similar to what Newton observed in his prism experiments. Note that this spectrum does not show a wavelength range for indigo, as most people today do not categorize indigo as a separate color, but rather see it as a shade of blue.



## Questions

- Where might you have observed a color spectrum similar to the one produced by Newton?
- What would be the approximate wavelength of a wave with the spectral color red?
- What color is a wave with a wavelength of approximately 450 *nm*?
- When you look at a green object, what color is being reflected?
- What colors of light does a white object reflect?

## 2A.3: Viewing Colored Objects Under Colored Light

**1. Review what students have learned about light.**
Remind students that they have learned that white light is made up of different-colored light and that each color has a different wavelength. Review with students that when white light strikes an object, what students see as the object's color is determined by the wavelengths of light that are either absorbed or reflected by the object.

Tell students that in the next experiment, they will see what happens to their perception of color when the color of the light that strikes an object changes.

**2. Introduce viewing colored objects under colored light.**
Ask students:

- Have you ever walked into a room with different-colored lighting and suddenly perceived colors differently? Describe your experiences.

  ***Possible answers:*** *Under black light, white clothes glow brilliant white, but all other colors look black. Some students may also have seen minerals glow with different colors under fluorescent light.*

Tell students that in this activity they will view familiar objects under colored light to see how their perception of everyday objects changes. Remind them that each color of light corresponds to a different wavelength range.

**3. Have student groups collect their materials.**
Divide the class into groups of four. Distribute four flashlights, three different-colored filters, cellophane tape or rubber bands to attach filters, **Handout 5: Viewing Objects with Colored Light**, and three different-colored objects to each group.

**4. Provide time for students to perform the activity.**
Darken the room and have students follow the steps on Handout 5. Ask them to record their observations in the table on the handout.

**5. Discuss students' conclusions.**
Ask students:

- Were any of your predictions for the color of the object correct? Explain.
- Why did the color of the objects change under different colors of light? What does this tell you about the relationship between color and light?

  ***Possible answers:*** *Students' conclusions may vary, but they should understand that an object's perceived color changes when the color of light striking the object changes. With each change of light color, the wavelengths available to be reflected and absorbed by the object also change. The experiment demonstrates that color is not an inherent property of an object but instead is influenced by the wavelengths of light striking the object.*

**Note:** Although color is not an inherent property of an object, some students may observe that the tendency of an object to absorb or reflect certain wavelengths of light may be an inherent property of the object.

**6. Revisit Illusion 1.**

Students should now be prepared to understand Illusion 1: Gray or White? Review with students that the amount of light and the wavelengths of light striking an object influence the object's perceived color. Ask:

- Using what you have observed in this activity, how would you explain Illusion 1?

### Teacher's Notes: Explanations of Illusions

All three illusions are explained in **Appendix B: Explanation of Illusions**. When students have finished Part 2, you may wish to give them copies of Appendix B to keep.

***Explanation of Illusion 1***

The color of the index cards seemed to change from white to gray, depending on how you held the cards in relation to the light. You did not actually change the color of the light—you changed the *amount* of light directly striking the cards.

As a result, the surface of the index cards reflected and absorbed different amounts of white light, just as the objects in the previous activity reflected and absorbed different wavelengths of colored light, depending on the wavelengths striking them. In both cases, the change in light altered your perception of the color.

## Handout 5:
# Viewing Objects with Colored Light

In this activity, you will shine different-colored lights on different-colored objects and observe the effects of colored light on your perception of an object's color.

With your group, collect these materials:

- Red, blue, and green objects (1 of each)
- Four flashlights
- Red, blue, and green colored filters
- Rubber bands or cellophane tape

## Procedure

1. Write the names of your three objects in the table below.
2. Predict the color of each object when viewed under each color of light. Fill in the "Predicted Color" column for each object under each color of light.
3. Shine the flashlight with the white beam on each of the three objects. What color do you perceive for each object? Record your observations in the table.
4. Attach the color filters to the flashlights and shine each flashlight on each object. What colors do you perceive? Record your observations in the table.
5. What do you conclude about your changing color perception?

| Object | Color of Light | Predicted Color | Perceived Color |
|---|---|---|---|
| Object 1: ______________ | White | | |
| (Red object) | Red | | |
| | Blue | | |
| | Green | | |
| Object 2: ______________ | White | | |
| (Blue object) | Red | | |
| | Blue | | |
| | Green | | |
| Object 3: ______________ | White | | |
| (Green object) | Red | | |
| | Blue | | |
| | Green | | |

# Activity 2B: The Eye and the Image

Students examine the structure of the eye and how the eye interacts with light to allow us to perceive color.

## Sequence

| | |
|---|---|
| ***2B.1: Illusion 2: After-Images*** | Students begin their exploration of the eye by experiencing an illusion in which they perceive after-images after staring at solid colored squares. |
| ***2B.2: Drawing the Eye*** | Students draw a partner's eye, label the parts they can see, and speculate about how the eye works. |
| ***2B.3: The Structure of the Eye*** | Students learn about the parts of the eye, relate what they learn to their drawings, and learn what happens when light from an image passes into the eye. |
| ***2B.4: Additive and Subtractive Mixing*** | Students use flashlights and filters to conduct experiments in two kinds of color mixing. |

## Understandings

- The eye is a complex organ of the nervous system with many parts that function together to receive visual information. The eye has two types of photoreceptors, known as *rods* and *cones*, which respond to brightness and color.
- Mixing colored light, in which wavelengths are added together, is known as *additive mixing*.
- Mixing colored pigments, in which certain wavelengths of light are blocked or absorbed and others are reflected, is known as *subtractive mixing*.
- Color perception involves both additive and subtractive mixing, as light wavelengths from the light source are "added up" and light wavelengths that strike the object being perceived are either absorbed or reflected.

## Materials Needed

- Red paper square and blue paper square, each approximately 4” x 4” (1 of each per student pair)
- Plain white paper (1 sheet per student pair)
- **Handout 6: Illusion 2: After-Images** (1 per student pair)
- Pencils or colored pencils
- Optional: Additional paper for drawing diagrams
- **Handout 7: The Eye**
- **Handout 8: Mixing Colored Lights and Filters**
- Colored filters (2 red, 2 blue, 2 green, and 2 yellow per group)
- Rubber bands or cellophane tape for attaching filters
- Flashlights (4 per group)
- White wall, screen, or large sheet of white paper taped to the wall
- **Handout 9: Diagrams of Color Mixing**

## 2B.1: Illusion 2: After-Images

**1. Introduce the illusion activity.**

Tell students that they will now experience a second illusion to introduce them to the role the eye plays in perceiving color. The phenomenon demonstrated by the illusion is related to the structure of the eye and to the parts of the eye they will learn about.

Have students form pairs. Distribute a red and a blue paper square, white paper, and **Handout 6: Illusion 2: After-Images** to each pair. Have students read the handout and answer any questions they may have.

**2. Have students experience the illusion.**

Ask students to take turns following the steps to perceive Illusion 2 and to answer the questions on Handout 6 with their partners.

**3. Discuss students' observations.**

Ask students to share their responses to the illusion and to the questions on Handout 6.

> **Note:** After staring at the red paper square, students should see a faint green square on the white paper. After staring at the blue paper square, students should see a faint yellow-orange square on the white paper.

Ask students:

- What do you see when you stare at a bright light or a camera flash and then look away?

  ***Answer:*** *A black after-image*

- Based on your observations of after-images, what questions would you now like to have answered?

  ***Possible answers:*** *Why do I see after-images that are the opposite color? What happens in my eye to make me see something that isn't there?*

Tell students that they will look for answers to their questions as they explore the physiology of the eye in the next activity.

## Handout 6:
# Illusion 2: After-Images

In this illusion, you will perceive colors that are not actually there!

## Procedure

Stare at the bright red paper square continuously for about 30 seconds. Then look at the sheet of plain white paper.

What do you see?

Now try the same procedure with the bright blue paper square. What do you see?

The different colors you see on the sheet of white paper are called *after-images*.

What do you see when you stare at a bright light or a camera flash and then look away?

Think about what you have observed. Come up with a question or two about after-images that you would like to have answered.

## 2B.2: Drawing the Eye

**1. Introduce drawing an eye.**
Have students pair up to draw a diagram of their partner's eye. Give pairs pencils or colored pencils. Provide plain white paper, if necessary, or have students draw their diagrams in a science notebook.

Tell students to write detailed descriptions of all the parts of the eye they can see and draw arrows from each description to its corresponding part. Even if students know the name of a part, have them describe what they see rather than use the name as a label.

Ask students to be as detailed as possible in their drawings but to only draw the parts they can see. Tell them not to try to draw any parts of the eye they can't see, even if they know what those parts are.

> **Note:** As an alternative, you may wish to display or distribute a close-up photograph of an eye for students to draw.

**2. Provide time for students to make their diagrams.**
Circulate around the room, offering guidance as necessary.

**3. Discuss students' diagrams.**
Have students share their diagrams and descriptions. Ask students if, after their close observations, they would like to hypothesize about how the eye works.

> ***Possible answers:*** *Some students may have very little understanding about how the eye works but may speculate that light reflects from an object and enters the eye. A fairly sophisticated understanding might be something like the following: Light enters the eye through the pupil. The lens focuses the image upside down at the back of the eye. The image is sent to the brain, which analyzes the information.*

Tell students that they will now learn more about the parts of the eye and how the eye and brain work together to receive and interpret images.

## 2B.3: The Structure of the Eye

**1. Have students read the handout.**
Tell students they will learn about the parts of the eye and what happens when light from an image passes into the eye.

Distribute **Handout 7: The Eye**. Have students study the diagram of the eye and read the text under the headings "Parts of the Eye" and "What Happens When You See?"

**2. Have students review their eye drawings.**
Ask students to compare the drawing they made of their partner's eye with the diagram on the handout. Using the handout diagram, have them add the names for any parts of the eye they included in their drawing.

**Teacher's Notes: Scientific Terminology**

To reinforce vocabulary related to the eye, reproduce a blank diagram of the eye, without any labels, for a bulletin board or wall display. Have pairs take turns identifying individual eye parts by taping or pinning a card with the part's name and function in the appropriate location on the displayed diagram.

You may also wish to have student pairs create a set of flash cards for eye vocabulary or add these new terms to a set of vocabulary cards developed earlier in the unit.

**3. Relate rod and cone function to students' experience.**
Explain that although both kinds of photoreceptors sense light, rods and cones have different functions. Ask students:

- Have you ever turned off the light at night, or walked into a dark room, and found that you couldn't see anything at first? After a few minutes, what happens?

  ***Possible answers:*** *You see the outlines of some objects; your eyes adjust to the dark; your pupils change size.*

Explain to students that when their eyes adjust to the dark, a biological change is taking place in their eyes. Their pupils immediately get larger. Tell them that this is similar to how a camera lens operates in a dark setting, when it opens more widely to let in more light. Explain that their pupils' getting larger is not the only change in their eyes—the rods and cones in their eyes are also shifting roles.

**4. Have students complete the handout about the eye.**
Ask students to study the diagram of retinal layers, read the rest of the handout, and answer the questions under the heading "What Do You Think?"

**Note:** The "What Do You Think?" questions on Handout 7 offer a good opportunity for formative assessment.

**5. Have students share their responses.**
Ask volunteers to share their answers to the questions on Handout 7.

### Teacher's Notes: Possible Answers for Questions on Handout 7

***Using what you now know about rods and cones, can you explain what might be happening when your eyes "adjust" to the dark?***

The cones, which are not sensitized in dim light, are shutting down, and the rods are becoming activated. Until the rods are fully sensitized, you can't see very well because your cones are not responding.

***If a person had* L *cones and* M *cones but no* S *cones, what color would that person* not *be able to see?***

The person would *not* be able to see blue colors.

***Why do you think the three colors, red, green, and blue, are sometimes called "eye primaries"?***

We think of the primary colors—red, blue, and yellow—as the colors we can combine in different amounts and combinations to make all other colors. Based on the three types of cones, red, green, and blue are the color wavelengths the eye combines to produce all the colors we see.

***Most mammals do not have the range of color vision that humans do. Think about when most mammals are active in the wild. Why might color vision be less important for them? What types of photoreceptors might be most important?***

Most mammals are active at night, when there is little light with which to see color. Rods, which are sensitive to lower levels of light, would be more important than cones for night activities, such as hunting.

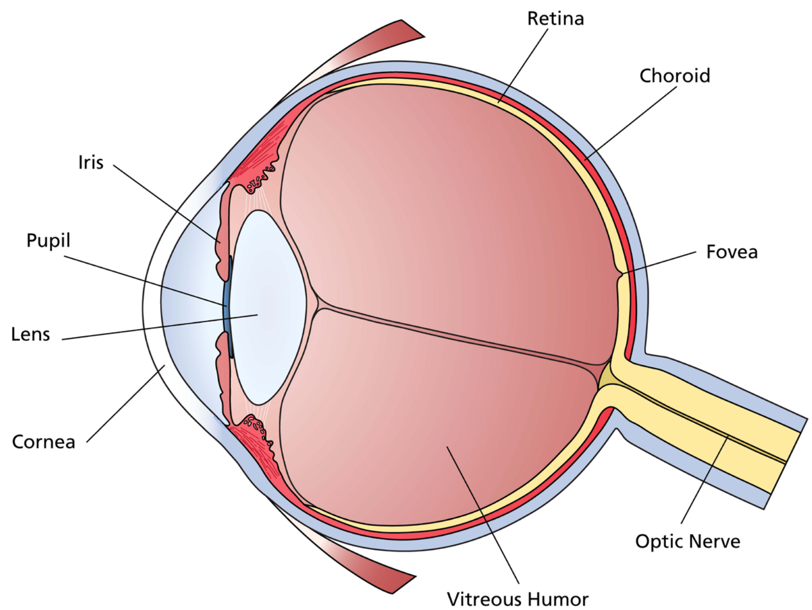
***Why might having red oil droplets in their cones be a helpful adaptation for sea turtles?***

It is probably helpful because the sea turtles can filter out the blue and green background colors of the deep ocean and see more clearly the colors of objects that stand out against the background.

***Why might knowing how our eyes and brains react to the stimuli of different colors be useful for an artist or someone working in the media?***

If an artist is trying to make us see something in a certain way—for example, bright colors or after-images—it would be helpful for the artist to understand how the eye processes light.

# Handout 7:
# The Eye




## Parts of the Eye

***Choroid:*** Layer of blood vessels that nourishes the eye; also acts as a light-absorbing layer.

***Cornea:*** Transparent tissue covering the front of the eye; has nerves but no blood vessels.

***Fovea:*** Small indent in the surface of the retina, where the majority of light that comes into the eye is focused.

***Iris:*** Circular band of muscles that control the size of the pupil. The pigmentation of the iris gives "color" to the eye. Blue eyes have the least pigment; brown eyes, the most.

***Lens:*** Transparent tissue that bends light passing through the eye. To focus light, the lens can change shape by bending.

***Optic nerve:*** The complex web of nerve fibers that transmits information in the form of electrochemical impulses from the retina to the brain.

***Pupil:*** The circular opening in the center of the iris of the eye, through which light passes to the retina. The pupil determines how much light is let into the eye.

***Retina:*** Layer of tissue on the back portion of the eye that contains cells responsive to light (photoreceptors).

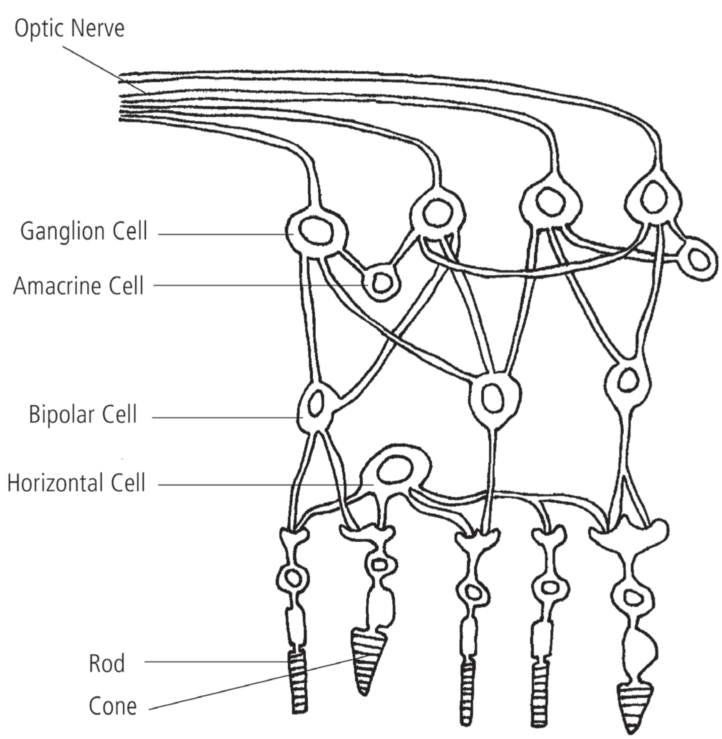
***Vitreous humor:*** Clear, jelly-like fluid found in the back portion of the eye, which maintains the shape of the eye.

# What Happens When You See?

When a person "sees," light enters through the clear *cornea* and *lens* at the front of the eye. The eye itself is filled with the transparent *vitreous humor*. The lens is suspended in the vitreous humor and held in place with a system of muscles. The shape of the lens is unconsciously controlled by these muscles. When rays of light pass through the cornea and lens, the rays bend, focusing an upside-down image on the *retina*, a layer of light-sensitive nerve cells at the back of the eye. The retina is part of the central nervous system.

The most important part of the retina is the *fovea*, a small indent in the surface of the retina. When a person wants to see something in very sharp focus, such as when threading a needle, the lens muscles move to allow the lens to project the image into the middle of the fovea. The majority of the light that comes into the eye is focused on the fovea.

The retina has multiple layers and is covered in about 120 million light-sensitive cells, called *photoreceptors*. There are two types of photoreceptors, called *rods* and *cones*, based on their shapes. About 7 million photoreceptors are cones and the rest are rods. Information about light stimuli received by rods and cones is transmitted to the brain through a complex of nerve cells, or *neurons*—bipolar cells, amacrine cells, and horizontal cells—as shown in the diagram of retinal layers below. These neurons in turn feed into ganglion cells, which come together in the optic nerve to transport light signals to the brain.



## Photoreceptors on the Retina

In bright light, color-sensitive cones are responsible for vision. But in dim light, rods are more sensitive to patterns of brightness—in fact, rods are what allow people and animals to see in the dark. When the environment changes from light to dark, cones shut down and rods take over. Although rods can sense very low levels of light, they are "colorblind." Consequently, you are unable to distinguish color in dim light.

Rods and cones are not distributed evenly across the retina. Cones are most densely concentrated at the main point of the eye's focus, the fovea. Because of this, the fovea is most sensitive to color.

Rods are absent from the fovea, but moving outward from the center of the retina, the number of cones decreases and the number of rods increases. On the edge of the retina, there are no cones, only rods.

## Human Cones and Color

You have learned that different colors of light correspond to different wavelengths on the electromagnetic spectrum. Your cones are able to perceive color because they are sensitive to different wavelengths of light.

You have three types of cones in your retina. Each type is particularly sensitive to a range of wavelengths, which correspond to different colors in the spectrum:

1. ***S*** cones, or short wavelength cones, are most sensitive to blues, colors with the shortest wavelengths.
2. ***M*** cones, or medium wavelength cones, are most sensitive to greens, colors of medium wavelength.
3. ***L*** cones, or long wavelength cones, are most sensitive to reds, colors with the longest wavelength.

Each type of cone is not stimulated exclusively by light wavelengths in its most sensitive range, but each is more sensitive to those wavelengths than to others. When the three types of cones are activated to greater or lesser degrees and in different combinations by light stimuli in the environment, human beings can perceive up to 9 million colors.

People who are colorblind usually possess fewer than three types of cones. *Dichromacy* refers to a condition in which a person has only two types of cones and therefore cannot perceive all wavelengths of light. A *monochromat* has only one type of functioning cone.

The three colors associated with the three types of cones—blue, green, and red—are sometimes called "eye primaries."

# Cones in the Animal World

Early mammals had only one type of cone—***S*** cones—so they could perceive only blues and greens. The next evolutionary step in color vision was the development of a second kind of cone, which increased the range of wavelength to which the eye was sensitized, thereby increasing color vision, an adaptation that helped the survival of certain animal species.

The distribution of color vision in animals might surprise you. Among mammals, only the higher primates, including gorillas and chimpanzees, have three cones, and thus the same range of color vision that humans do. Most non-primate mammals have only two types of cones. Dogs are particularly sensitive to blue and violet colors.

Insects, however, have three cones, and some, like bees, can detect ultraviolet light. And birds have been found to have *four* cones—so they can see colors we can't see!

Sharks have no cones at all and so can't perceive color. Sea turtles, adapted to live in the deep ocean, have red oil droplets in their cones, which filter out short wavelengths. They can see reds, oranges, and yellows, but not greens, blues, and violets.

# What Do You Think?

1. Using what you now know about rods and cones, can you explain what might be happening when your eyes "adjust" to the dark?

2. If a person had ***L*** cones and ***M*** cones but no ***S*** cones, what color would that person *not* be able to see?

3. Why do you think the three colors, red, green, and blue, are sometimes called "eye primaries"?

4. Most mammals do not have the range of color vision that humans have. Think about when most mammals are active in the wild. Why might color vision be less important for them? What types of photoreceptors might be most important?

5. Why might having red oil droplets in their cones be a helpful adaptation for sea turtles?

6. Why might knowing how our eyes and brains react to the stimuli of different colors be useful for an artist or someone working in the media?

## 2B.4: Additive and Subtractive Mixing

**1. Give students an overview of color mixing.**
Point out that students are probably familiar with the process of mixing the primary colors of paint to achieve a seemingly infinite palette of color. Tell them that they will learn that the kind of color mixing that occurs with paint is fundamentally different from the mixing of light that happens in their eyes and brains. In fact, even the three colors considered "primary" are different for mixing paints and mixing light.

Explain that students will explore these two kinds of color mixing using flashlights and colored filters, which will help them understand how the eye perceives color.

**2. Discuss color mixing.**
Initiate a discussion about color mixing by asking students:

- What are *primary colors*?

  ***Possible answer:*** *Colors you mix together to get all other colors.*

- Who has used primary colors to paint?
- What primary colors do you use when painting?

  ***Answer:*** *Red, yellow, and blue*

- Are these the same colors associated with the "eye primaries"—the three types of cones? If not, what are those colors?

  ***Answer:*** *Red, blue, and green*

Explain that people often learn that red, yellow, and blue are the primary colors—the colors we mix to make all the other colors. Ask:

- Can there be more than one set of primary colors? If not, which set is "correct"?

Tell students that they will learn how to answer these questions by comparing two methods of mixing colors.

Remind students that earlier in the unit, they learned how white light can be separated into the color spectrum and that the color spectrum consists of red, orange, yellow, green, blue, indigo, and violet light (Roy G. Biv).

Ask:

- If you recombine all these colors of light, what color do you get?

  ***Answer:*** *White*

- Will you get the same result if you combine red, orange, yellow, green, blue, indigo, and violet paint? Why or why not?

*Answer:* *No, you will get brown or black; mixing light gives you different results than mixing paint.*

**Teacher's Notes: (Optional): Mixing Paints**

Many of your students will have experimented with mixing paint and will know that mixing together red, orange, yellow, green, blue, indigo, and violet paint will not produce white! If you have the time and materials, however, you may wish to have students try mixing different-colored paints in class and observing the results. You may also substitute mixing paints for mixing colored filters in this activity.

Another option is to collaborate with the visual arts teacher for this activity, so that students mix paints in their visual arts class and mix colored lights in biology class.

**3. Introduce the color mixing experiments.**

Tell students that they will work in groups to experiment with two ways of mixing colors and observe the results. First, they will use filters to create different-colored lights, which they will then mix. Second, they will mix colored filters to produce color effects similar to those produced by mixing paints.

**Teacher's Notes: Color Mixing with Filters**

You may need to clarify that even though students are shining light through filters in both explorations, the filters are functioning in very different ways.

When mixing colored light, the filters are being used to create four light sources, each a different color with a different wavelength. These colored lights are then mixed.

When mixing colored filters, students are using a single light source and placing additional filters in front of the light source, with the result that each filter blocks out another set of light wavelengths.

**4. Give groups their materials.**

Each group should receive the following:

- Four flashlights
- Colored filters—two red, two blue, two green, and two yellow
- Rubber bands or cellophane tape for attaching the filters
- **Handout 8: Mixing Colored Lights and Filters**

**5. Have students conduct the color mixing experiments.**

Prepare a section of white wall, a white screen, or tape a large sheet of white paper to a wall. Then darken the room and have students follow the steps on Handout 8.

**6. Discuss the groups' results.**

Have students share results from their Color Mixing Data Tables for each method of color mixing.

- What happened when you mixed the three colored lights corresponding to the "eye primaries"?

  ***Answer:*** *The colors made white light.*

Tell students that when they mixed colored light, they used *additive color* mixing. Remind students of Newton's experiments in which he showed that white light could be separated into different-colored wavelengths and then recombined into white light.

Display the word *additive* and ask:

- Why do you think mixing colored light is called *additive* mixing?

  ***Possible answer:*** *Mixing light of different wavelengths together "adds" to the spectrum of color.*

  **Note:** Additive color mixing is used to create outdoor lighting or lighting effects in theater. Recombining light that has been separated by a prism is also additive mixing.

Display the word *subtractive*. Tell students that when they mixed the colored filters, they were using *subtractive* mixing. Explain that mixing colored filters is similar to mixing any chemically colored substance, or *pigment*. Subtractive mixing is what artists use when they mix oil or acrylic paints or watercolors, make glazes, or create stained glass.

- What happened when you mixed together the three colored filters corresponding to the "paint primaries"?

  ***Answer:*** *Mixing the colors of filters together resulted in no light, or black.*

- Why do you think mixing filters or paints is called *subtractive* mixing?

  ***Possible answer:*** *Each colored filter or paint that you include in the mix blocks out parts of the color underneath it or behind it; mixing different filter colors "subtracts" colors from the spectrum.*

Distribute **Handout 9: Diagrams of Color Mixing** and have students read it to themselves. Answer any questions students may have.

**7. Introduce two color theories.**

Tell students that the theory that every possible color can be produced using combinations of three primaries is known as *trichromacy*. This theory was first developed by artists in the seventeenth century. It is supported by the fact that there are three kinds of cones in the eye—stimulated by red, blue, and green light wavelengths—that are used to process color.

**Note:** Contrary to what students may have learned in the past, *paint primaries* cannot be used to produce every color. Some colors, such as neon colors, cannot be produced by using subtractive mixing of red, yellow, and blue. Other colors cannot be produced without using black and/or white.

**Teacher's Notes: Vocabulary Extension**

You may wish to strengthen students' vocabulary and understanding of scientific terminology by displaying the words *trichromacy*, *dichromacy*, and *monochromat*.

Underline the word part -*chrom* in each word. Tell students that the root word, *chrom*, is from the Greek word *chroma*, meaning "color."

Circle the prefixes *tri*-, *di*-, and *mono*- and ask students what the prefixes mean. Have students put together the meanings of the root and prefixes to come up with their own definitions for each term. Ask students to name other words with these prefixes.

Tell students about the more recent theory, *color opponency*, proposed by Ewald Hering in the late nineteenth century. Hering noted that some pairs of primary colors—red and green; yellow and blue—are mutually exclusive, that is, there are no reddish greens or bluish yellows.

Color opponency theory explains how two light waves of opponent colors cancel each other out when they are combined. Remind students that they observed this cancellation in Exploration 1 when they mixed blue and yellow light and observed the resulting white light.

Color opponency also explains how opposite or opponent colors are produced in after-images.

**8. Revisit Illusion 2.**

Tell students that now that they know how the activation of different types of cones affects color perception and they understand color opponency, they can begin to explain Illusion 2. Have them recall that when they stared hard at a colored square of red paper, they saw a green after-image. When they stared at a blue-colored square, they saw a yellow-orange after-image. Ask students:

- Using what you have learned about cones, color mixing, and color opponency, how do you explain Illusion 2: After-Images?

Solicit students' responses. Use the information below (also provided in Appendix B) to fill in any gaps in their understanding.

**Teacher's Notes: Explanation of Illusion 2**

Cone sensitivity and activation explains why you perceive after-images. As you have learned, green and yellow are "opponent colors" for red and blue, respectively.

When you look at a bright red square, your ***L*** cones are stimulated, so you perceive the long wavelength color, red. But after you stare at the square for a while, your ***L*** cones get tired. When you look at a plain white surface immediately afterward, the cones surrounding your ***L*** cones—which were not stimulated by the long wavelength signal—are still fresh. These surrounding ***M*** cones are now in a higher state of activation than your ***L*** cones, so you perceive the color green.

Because your ***L*** cones become tired and are less activated relative to your ***M*** cones, the effect, as interpreted by your brain, is the same as if you were actually looking at a green square.

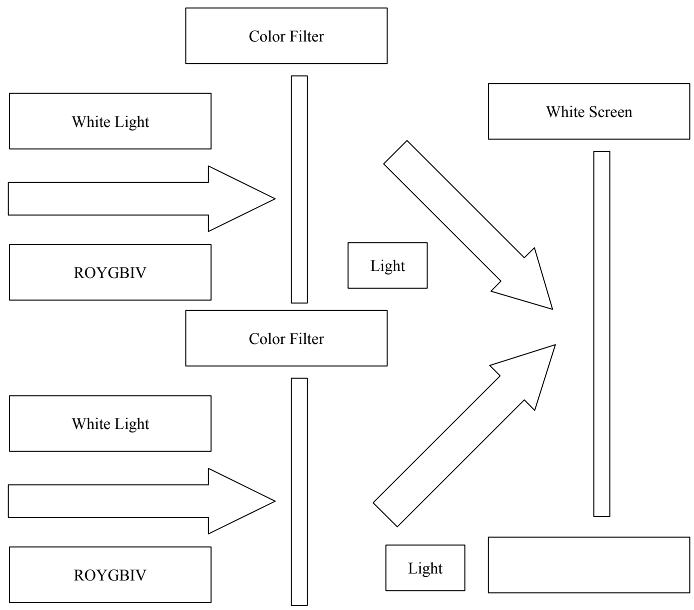
Tell students that although the after-image illusion can be partially explained by a knowledge of cones and color opponency, it is also necessary to understand that the brain interprets the signals that the cones transmit to it.

Explain that, in the next activity, students will learn more about the brain's role as an interpreter of visual information.

# Handout 8:
# Mixing Colored Lights and Filters

Follow the steps below for Explorations 1 and 2. Keep track of your results in the Color Mixing Data Table on the last page of this handout.

## Exploration 1: Mixing Colored Lights

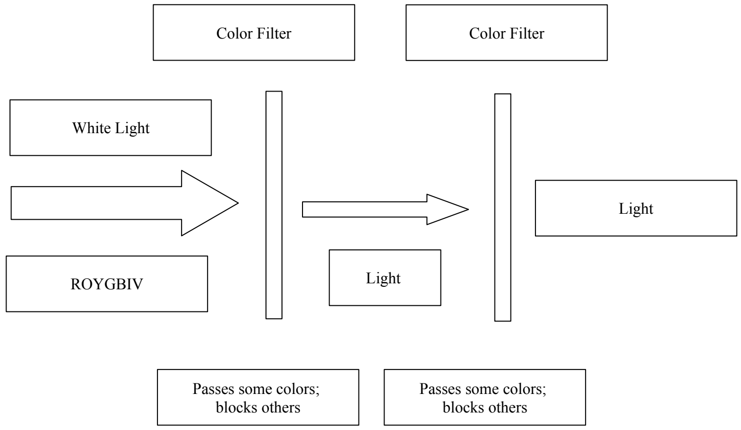



In the first exploration, you will create different-colored light sources and mix the colored light. This is the kind of color mixing that takes place in your eye and brain. As you conduct the experiment, keep in mind the colors of the "eye primaries."

## Procedure

1. Using tape or rubber bands, attach one colored filter over each flashlight, so that you have one red, one green, one blue, and one yellow light.
2. Predict what color will result by mixing each given combination of colored lights in the Color Mixing Data Table. Record your predictions in the column labeled "Exploration 1: Mixing Colored Lights."
3. Project each light separately onto the wall or screen and observe its color.
4. Choose two of the colored lights—for example, red and green—and project them onto the wall so that their spots of light overlap. What color do you see where the spots overlap? Record your observation in the Color Mixing Data Table.
5. Repeat step 4 with each of the following pairs of colored lights: red + blue, blue + green, blue + yellow. Record your observations.
6. Project the three lights corresponding to the "eye primaries," so that their spots of light overlap. What color do you see where the spots overlap? Record your observation.

## Exploration 2: Mixing Colored Filters




In this second exploration, you will use only one light source. You'll mix colored filters by placing one filter over another in front of the light source. Your results will be similar to those you would achieve by mixing paint. As you conduct the experiment, keep in mind the "traditional" primary colors ("paint primaries").

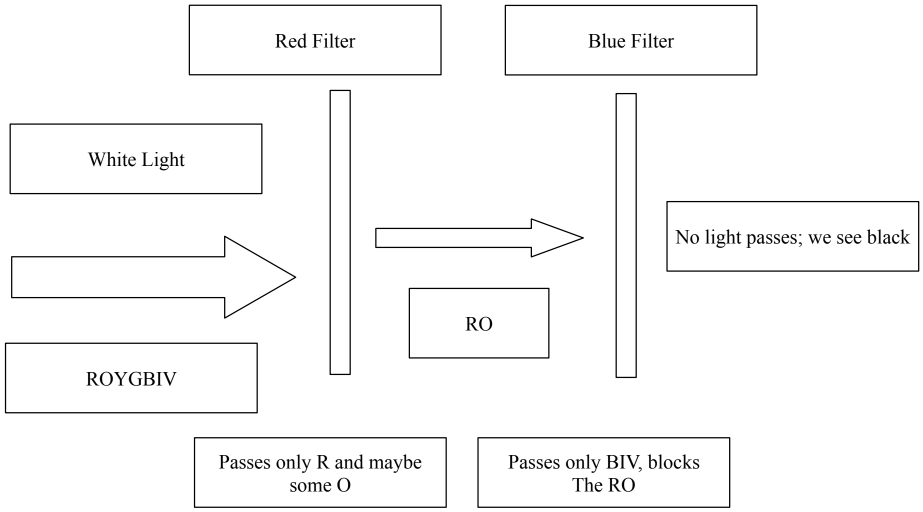
## Procedure

1. Predict what color will result by mixing the combinations of colored filters shown in the Color Mixing Data Table. Record your predictions in the column labeled "Exploration 2: Mixing Colored Filters."
2. Use the flashlights with colored filters on them from Exploration 1. Take the flashlight with the blue filter. Hold a red filter directly in front of it and shine the light through the filter. What color is projected onto the wall or screen? Record your observation in the Color Mixing Data Table.
3. Hold the green and then the yellow filters in front of the flashlight with the blue filter. Record the color that is projected for each.
4. Next, shine the red-filter flashlight through the yellow filter. Then shine the red-filter flashlight through the green filter. What color is projected for each? Record your observations.
5. Finally, shine the red-filter flashlight through both blue and yellow filters at the same time. What color is projected? Record your observation.
6. Look at the Color Mixing Data Table. Compare your results when mixing two or more colored lights (Exploration 1) to your results when shining a single light through two or more filters (Exploration 2). Were the colors you observed similar or different? Describe.

# Color Mixing Data Table

| | Exploration 1: Mixing Colored Lights | Exploration 2: Mixing Colored Filters |
|---|---|---|
| Red & Blue | | |
| Predicted Color | | |
| Observed Color | ***Magenta*** | ***Violet*** |
| Blue & Green | | |
| Predicted Color | | |
| Observed Color | ***Cyan*** | ***Bluish Green*** |
| Green & Red | | |
| Predicted Color | | |
| Observed Color | ***Yellow*** | ***Brown*** |
| Blue & Yellow | | |
| Predicted Color | | |
| Observed Color | ***White*** | ***Green*** |
| Red & Yellow (filters only) | | |
| Predicted Color | | |
| Observed Color | | ***Orange*** |
| Blue, Red, & Green (lights only) | | |
| Predicted Color | | |
| Observed Color | ***White*** | |
| Red, Blue, and Yellow (filters only) | | |
| Predicted Color | | |
| Observed Color | | ***Black (or no light)*** |

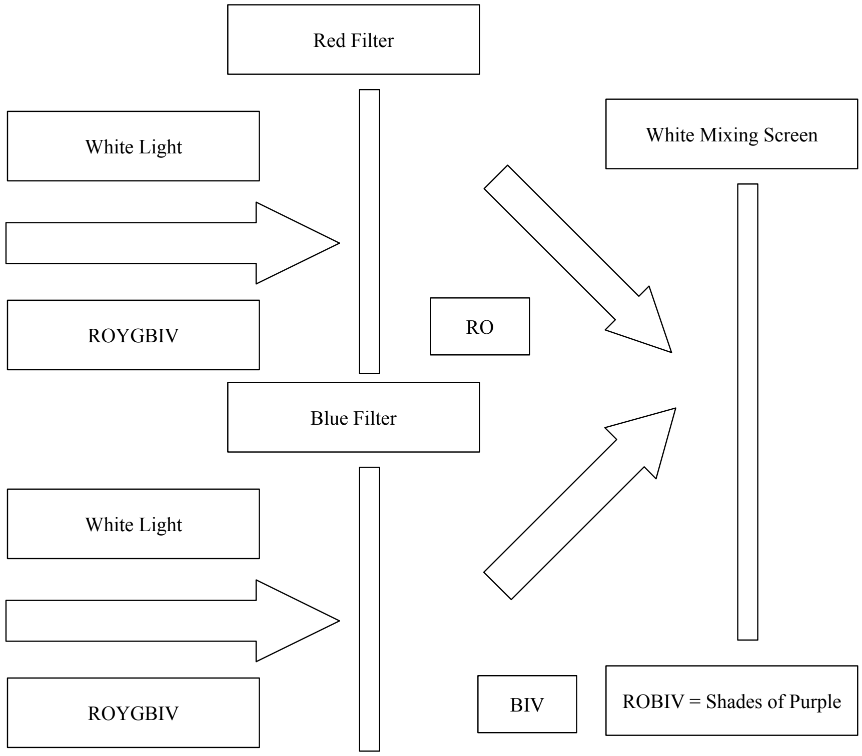
## Handout 9:
# Diagrams of Color Mixing




**Subtractive Color Mixing:** Each subsequent color filter blocks out, or absorbs, more wavelengths of light.

In the above example, the red filter absorbs the Blue, Indigo, and Violet wavelengths of light, passing through only Red and a small amount of Orange wavelengths. The blue filter then absorbs the Red and Orange wavelengths of light, so that the end result is no light, or black.

Each color filter absorbs or "subtracts" more colors from the original light source. In subtractive mixing, the resulting mixed color is always darker than any of the colors that it is composed of.




**Additive Color Mixing:** Each subsequent color adds more wavelengths of light.

In the example above, the red filter passes through the wavelengths of Red and Orange light and the blue filter passes through the wavelengths of Blue, Indigo, and Violet light. The net result is that the wavelengths are combined or "added" to make a purple shade.

In additive mixing, the resulting mixed color is always lighter than any of the colors that it is composed of.

# Activity 2C: The Brain Decides

Students continue to explore the biological mechanisms of vision by looking at how neurons transmit visual information to the brain and how the brain interprets that information.

## Sequence

| | |
|---|---|
| ***2C.1: Illusion 3: The Disappearing Dot*** | Students create and experience an illusion in which part of an image seems to disappear. |
| ***2C.2: What the Brain Sees*** | Students read about the brain's role in perception and learn how the brain interprets visual information and compensates for information gaps. |

## Understandings

- The eye does not always perceive what is actually there.
- The brain interprets visual information sent through neurons from the eye. The upper *thalamus* relays visual information sent through the optic nerve. This information is then processed by the *visual cortex*.
- The brain uses a combination of memory, past experience, and judgment to interpret visual signals.

## Materials Needed

- **Handout 10: Illusion 3: The Disappearing Dot**
- Plain white paper (1 sheet per student pair)
- Optional: Pen (1 per student pair)
- **Handout 11: Brain Connections**
- White handkerchief or white sheet of paper
- Two examples of simultaneous contrast for Activity 2C.2
- Computer with Internet connection to display images for Activity 2C.2

## 2C.1: Illusion 3: The Disappearing Dot

**1. Introduce the illusion activity.**

Tell students that they will explore the role the brain plays in perception by experiencing an illusion they create themselves.

Have students form pairs. Distribute **Handout 10: Illusion 3: The Disappearing Dot**, a sheet of paper, and a pen (if necessary) to each pair.

**2. Have students create and experience the illusion.**

Have students follow the procedure on Handout 10. Give them time to experience the illusion, describe their perceptions, and formulate a question based on their observations.

**3. Discuss students' responses.**

Ask students:

- What did you observe?

  ***Answer:*** *When students closed their right eye and stared at the + while moving the sheet of paper closer, the dot disappeared. When they closed their left eye and stared at the dot while moving the sheet of paper closer, the + disappeared.*

Ask students to share the questions they formulated based on their observations. Tell them that they will look for the answers to these questions in the next activity, when they learn how the brain influences perception.

## Handout 10:
# Illusion 3: The Disappearing Dot

## Procedure

1. Make a small dot on the left side of a plain white sheet of paper.
2. On the right side of the paper, about 6 inches away from the dot, draw a small +.
3. Close your right eye.
4. Hold the image about 20 inches away and look at the + with your left eye.
5. Slowly bring the image (or move your head) closer while looking at the +.
6. At a certain distance, something happens. What is it?
7. Now reverse the process. Close your left eye and look at the dot with your right eye.
8. Slowly move the image closer to you and observe what happens.

Based on your observations, formulate a question that you would like to have answered:

## 2C.2: What the Brain Sees

RESOURCES

**1. Have students relate the brain's role to their own experience with the illusions.**

Display the following quote:

> What we see does not depend entirely on what is out there but also to a considerable extent on what the brain computes to be most probably out there.
>
> John Smythies, *How the Brain Decides What We See*

Ask students:

- What does this quote mean to you?
- Can you think of any times your brain has misinterpreted something you saw?

***Possible answers:*** *Seeing something you want to see and then realizing it really isn't there; mirages; illusions*

**2. Have students read about the brain's role in perception.**

Distribute **Handout 11: Brain Connections**. Have students study the diagram and read the text under the heading "How Does the Brain Allow You to See?" Call on a volunteer to summarize how the eye and brain work together.

Ask:

- Other than allowing you to see images right side up, can you think of another example of the brain compensating for or "correcting" information it receives?

**Note:** If students are unable to come up with examples on their own, you might point out the example of a filmed movie or a flipbook. What they are actually seeing in both cases is a series of separate images, but their brains interpret the signals sent by the eyes as motion.

After discussing students' responses, hold up a white handkerchief or a white sheet of paper and ask:

- What color is this object?

Tell students that if you showed them the handkerchief in full sunlight, in a dim room, or with shadows falling across it, they would probably still perceive the object as white.

The brain's ability to recognize the same color under different lighting conditions is known as *color constancy*. It is the reason that most people see snow as white, the sky as blue, and grass as a bright shade of green, despite the presence of shadows and other changes in illumination.

**3. Discuss how context can change the brain's interpretation of color.**
Explain to students that sometimes the surrounding environment, or context, makes the brain change its interpretation of the color signals it receives from the cones in the eye.

Introduce the idea that surroundings can change our perceptions. Ask:

- Have you ever gone swimming on a cold evening and noticed that the water felt unnaturally warm? Perhaps you returned the next day in the hot afternoon and the same water seemed cool. What do you think was happening?

  ***Possible answer:*** *The contrast between the air and the water was greater when the air was cold, making the water seem warmer by comparison.*

**4. Project images and introduce the concept of simultaneous contrast.**
Tell students you will display two examples in which their perception of a particular color changes. Project the images. For each image, have students describe the colors they see and ask:

- Which color appears to change?
- How does it change?

When students have viewed and commented on both images, ask:

- What do you think might cause this change in perception?

  ***Possible answer:*** *The colors surrounding the color change the viewer's perception. The brain interprets a color as being lighter when it is next to a darker color, and darker when it is next to a lighter color.*

Introduce the term *simultaneous contrast*. Guide students to understand that they experience simultaneous contrast when two colors, placed side by side, interact to change their perception of each color.

**5. Have students revisit Illusion 3.**
Tell students that the brain's tendency to compensate for, adjust, or make sense out of what it sees is responsible for a number of illusions, including Illusion 3.

Have students read "What Is Your Blindspot?" on Handout 11 and see if they can solve the mystery of The Disappearing Dot in Illusion 3.

Have students recall Illusion 3. Remind them that when they closed their right eyes, stared at the + and moved the sheet of paper, the dot disappeared when the paper reached a certain distance. When they closed their left eyes and stared at the dot, the + disappeared. Although students knew that the + and the dot were still there, students didn't perceive them. Ask students:

- Why did the + and the dot disappear?

  ***Answer:*** *As you moved the sheet of paper toward you, the + and the dot were projected directly onto your blind spot.*

- Why do you think you see a continuous white sheet of paper instead of a hole in the paper at your blind spot?

  ***Answer:*** *Because your brain compensates for your blind spot.*

Solicit students' responses. Use the information in the Teacher's Notes that follow (also provided in Appendix B) to fill in any gaps in their understanding.

**Teacher's Notes: Explanation of Illusion 3**

The + and the dot disappear because, at a certain distance, they are projected directly onto your eye's blind spot.

You see a continuous sheet of paper instead of a hole there for the same reason you don't see a hole in the center of your vision when you look straight in front of you. Your brain compensates for your blind spot. The brain fills in the gap with what it *thinks* is there—a continuous white sheet of paper.

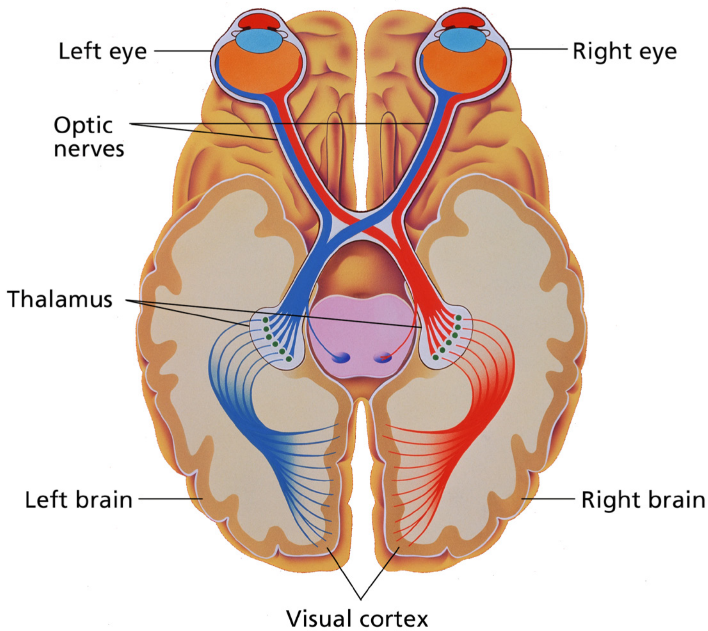
This illusion works because when the + or the dot fall directly on the blind spot, the brain is "tricked" into seeing what it expects to see: something that isn't actually there. The brain makes an assumption based on the surrounding sensory information.

The eye and brain function together to respond to stimuli. The response is influenced by memory, past experience, judgment, and other sensory input.

# Handout 11:
# Brain Connections

## How Does the Brain Allow You to See?

The eye and brain function together in the nervous system to interpret visual stimuli. The optic nerve transmits the visual information via electrochemical impulses from the eye to the *thalamus*, the brain's upper relay center. The signals are then sent to the *visual cortex* in the brain's occipital lobe.




Vision and the brain
J. Bavosi / Photo Researchers, Inc.


The brain's visual cortex interprets the nerve signals. This is what allows you to see. Most of the time, the brain interprets these signals reliably—however, your brain is constantly making decisions about the information it receives based on your experience, memory, and immediate surroundings.

One of the most basic decisions the brain makes is to reorient the image it receives from the optic nerve. The image formed at the back of the retina and sent to the brain is inverted, but the brain corrects the image so that you see it right side up.

## What Is Your Blind Spot?

One way the brain interprets visual signals is to fill in missing information. There is one spot on your retina where all the nerve fibers gather together to form the optic nerve. This spot has no rods or cones—no photoreceptors at all. It is known as your *blind spot*.

Most of the time, you do not notice your blind spot. For example, when you look around you, or at a picture or a page of text, you don't see a blank spot in the middle of your field of vision. Why?

You don't see a blank spot because your eyes aren't the only organ of your nervous system involved in vision. Once sensory information exits the eye through the optic nerve, it travels to the brain, where the brain interprets the visual information.

Your brain compensates for your blind spot by filling in the blank area in the image, using the sensory image data from the surrounding region. So instead of seeing what's actually there, you see what *should* be there according to your brain's calculations. Most of the time this means you experience an accurate uninterrupted view of your surroundings. But sometimes . . . your brain makes a mistake.

Using what you have learned about your blind spot, can you come up with an explanation for Illusion 3?

# Part 3: Do You See What I See?

## Length

**1 50-minute session**

In Parts 1 and 2, students gained a basic understanding of how light, the eye, and the brain interact through the nervous system to create our perception of color. In Part 3, students look at how artists and the media use the knowledge of how people perceive color to create specific color effects.

This section focuses on three techniques used by artists and the media:

- *Complementary contrast*—The phenomenon in which the juxtaposition of opposite colors sharpens our perception of each color.
- *Equiluminance*—The phenomenon in which two contrasting colors of equal brightness placed next to each other appear to float or vibrate.
- *Pointillism*—A style of painting in which small dots of pure color are placed close to one another so that color mixing occurs in the eye and brain.

Students view examples of each technique, reflect on their own perceptions, and learn the physiological explanation for each phenomenon.

> **Teacher's Notes: The Nervous System, Perception, and Other Senses**
>
> You may wish to extend students' understanding of the role of the nervous system in perception by looking at other sense organs with respect to arts and media. Explore the nervous system pathways that transmit sensory information between the skin and the brain in responding to tactile sculpture or between the ear and the brain in responding to music or other sound recording.

## Advance Preparation

RESOURCES

- Collect examples of or links to several paintings of the same object or scene, painted with different colors to create different effects. (See *Media & Resources* for links to snow scenes by Claude Monet.)
- Collect examples of or links to arts and media that demonstrate the color effects of complementary contrast, equiluminance, and pointillism. (See *Media & Resources* for links to the examples used in the Part 3 activities.)
- Optional: Locate examples of complementary contrast in signs or advertising to display in step 4 of Activity 3A.

**Note:** (Optional): If time allows, you may wish to explore other influences on color, such as light, chiaroscuro, or mood effects. Examples from Claude Monet's *Haystack* or *Rouen Cathedral* series make interesting demonstrations.

# Activity 3A: Complementary Contrast

RESOURCES

Students reflect on their own experiences with color in art. They view examples of how artists use the juxtaposition of contrasting colors to produce visual effects, and they learn the biological basis for these perceptions.

## Understandings

- People in the arts, media, and entertainment industry use their knowledge of how people perceive color to create specific visual effects.
- *Simultaneous contrast*—how the juxtaposition of different colors affects our perception of each—is greatest between complementary colors.

## Materials Needed

- Computer with Internet connection to display examples of complementary contrast
- Several paintings of the same object or scene, painted with different colors to create different effects (See *Media & Resources* for links to the examples used in step 2 of Activity 3A.)
- Two examples of artwork with effects created by complementary contrast. The examples modeled are *Café Terrace on the Place du Forum, Arles* and *Night Café in Arles*, both by Vincent Van Gogh. (See *Media & Resources* for links to images of these paintings.)
- Color wheel that shows complementary colors (See *Media & Resources* for link to a color wheel.)
- Optional: Examples of signs or advertising that use complementary contrast.

**1. Connect with students' prior experience of color in art.**
Tell students that they are going to learn how artists use color to alter or enhance the viewers' perceptions of a work of art.

Open a discussion about color in art by asking:

- Have you ever looked at a painting of a landscape or an object and thought, "Those colors don't seem real or accurate"?

Ask students to share some examples. Point out that they have already experienced how their perception of colors can change under different light conditions. Remind them of their experiments in **Handout 5: Viewing Objects with Colored Light**. Ask:

- What color was the red object in white light? In red light? In green light?

Tell students that although their perception of colored objects changes under different-colored lights, under most lighting conditions their brain tells them that a tomato is still red and a green pepper is still green. Sometimes, however, it is not easy to tell what color something is. Ask:

- What color is the sky? The ocean? Snow?
- Do the colors of these things change? Why or why not?

  ***Possible answers:*** *While students will likely give the expected answers that the sky is blue, the ocean is blue or green, and snow is white, reinforce those responses that acknowledge the different colors seen under different lights and shadows.*

Explain that artists often explore how changes in light and surrounding objects affect people's perception of color.

**2. Use artwork to illustrate changing color perceptions.**
Project or display several paintings in which a similar object or scene is painted with different colors to achieve different effects.

As students view each painting, ask questions to draw out the ways in which the artist uses unexpected colors to achieve an effect:

- What are we looking at in this painting?
- What time of day or season is it? What makes you think so?
- What mood or feeling do you think the artist is trying to convey? What visual elements in the painting convey that feeling?

Review with students that although many factors influence our perception of color, our brain sometimes corrects these influences, and we see the color that our past experience has taught us to see. For example, most people see snow as white and the ocean as blue (or maybe green), despite changing light, shadows, and reflections. Artists, however, often resist these “corrections” of the brain and use color effects to try to help the viewer resist them as well.

Tell students that they will now explore some color phenomena used by artists to change, enhance, or even subvert the viewer’s perceptions of color.

**3. Introduce the concept of *complementary contrast*.**
Remind students that in Part 2 of the unit they learned about *simultaneous contrast*—what they experience when two colors, placed side by side, interact to change their perception of each color. Depending on which colors are placed next to each other, colors can seem brighter or duller, lighter or darker.

Explain that artists often employ this principle of *contrast* in working with colors. Some color pairings produce greater simultaneous contrast effects than others.

Ask students:

- What pairings of colors do you think would produce the greatest contrast?

  ***Possible answers:*** *Opposite colors, light and dark colors, opponent colors*

- Are you familiar with complementary colors? What are they? Give some examples.

**Teacher’s Notes: Complementary Colors**

*Complementary colors* are often thought of as opposites. Art students may observe that complementary colors are directly across from each other on a color wheel. Red and green are complementary, as are blue and orange, and violet and yellow. See *Media & Resources* for a link to a color wheel that shows primary (P), secondary (S), and tertiary (T) colors opposite one another.

**4. Display and discuss examples of complementary contrast.**
Tell students they will look at two examples of complementary contrast in artwork. Display the image of the first painting and ask:

- What complementary colors appear adjacent to one another?
- What effect does this create?

Display the image of the second painting and ask:

- What complementary colors appear adjacent to one another?
- What effect does this create?

**Teacher's Notes:**
**Complementary Contrast in Two Works by Vincent Van Gogh**

Tell students that the artist Vincent Van Gogh often painted complementary colors adjacent to one another.

In the painting, *Café Terrace on the Place du Forum, Arles*, blue and yellow are painted next to each other. The juxtaposition of the two colors makes each color look brighter and makes the colors almost glow.

In *Night Café in Arles*, red and green are painted next to each other. This creates an effect of very strong bold shapes that stand out in stark contrast.

Guide students to understand that the pairing of complementary colors makes each color appear brighter and stronger, giving those areas of the paintings added vibrancy, energy, or separation.

Have students recall the effects of simultaneous contrast they observed in a previous activity, in which certain colors appeared to change due to the colors surrounding them. Ask:

- Why do you think that simultaneous contrast effects are greatest with complementary colors?

  ***Possible answer:*** *Our brain perceives sensations most intensely when they are opposites or extremes.*

Suggest to students that complementary contrast effects can be used to draw attention to an image or a specific area of an image. Ask:

- How might complementary contrast effects be used in the media?

  ***Possible answer:*** *To make a message stand out; to get viewers' attention*

**Note:** (Optional): Display and discuss examples of complementary contrast in signs or advertisements.

# Activity 3B: Equiluminance

Students experience how the color phenomenon of *equiluminance* affects the way that the brain interprets shape and color in a work of art. They learn that equiluminant colors appear to vibrate because of the way the brain processes brightness.

RESOURCES

## Understandings

- *Luminance* refers to the brightness or intensity of a color. *Equiluminance* refers to two or more colors having the same level of brightness.
- When equiluminant figures appear next to each other, they seem unstable because our brain has difficulty locating them spatially.

## Materials Needed

- Computer with Internet connection to display examples of equiluminant art
- Two examples of artwork with effects created by equiluminance. The examples modeled are *Plus Reversed* by Richard Anuszkiewicz and *Wild Poppies, Near Argenteuil* by Claude Monet. (See *Media & Resources* for links to images of these paintings.)
- **Handout 12: The Equiluminance Effect**

**1. Introduce *equiluminance*.**
Remind students that in the last activity they experienced how the juxtaposition of complementary colors in a work of art affects their perception of each color. Tell students that now they will learn how the juxtaposition of equally bright colors creates interesting effects because of the brain's processes.

Write the word *luminance* on the board and underline the root, -*lumin*-. Ask:

- Does anyone know what *luminance* means, or know the meaning of another word that contains the root *lumin*-?

  ***Possible answers:*** Luminance *means "brightness." Related words are* luminous*,* luminaria*,* illuminate*, or* illumination*. The root* lumin- *means "light."*

Explain that *luminance* refers to the brightness of a color. Add the prefix *equi*- to the word on the board. Solicit the meaning of the prefix *equi*- (*equal*). Ask:

- What does the word *equiliminance* mean?

  ***Possible answer:*** *Equally bright*

Guide students to understand that two colors that are equiluminant have the same brightness. Explain that when equiluminant colors appear next to one another, they have a curious effect on our perception.

**2. Display and discuss examples of equiluminance.**
Tell students that they will view two paintings that exhibit equiluminance. Display the first example and ask:

- What do you see in the painting? Describe the effect the artist created.

  ***Possible answers:*** *The colors of the painting are equiluminant. The colors seem to vibrate.*

Display the second example, and ask students:

- In this painting, which colors appear to be equiluminant?
- What effect does equiluminance have on your perception of the painting?

**Teacher's Notes: Equiluminance in *Plus Reversed* by Richard Anuszkiewicz and *Wild Poppies, Near Argenteuil* by Claude Monet**

In the painting *Plus Reversed*, red and green are equiluminant, and the colors seem to vibrate. In the painting *Wild Poppies, Near Argenteuil*, the red poppies and the green field are equiluminant, and the poppies seem to float above the field.

Point out to students that in both paintings the colors seemed unstable. Explain that the use of equiluminant colors often produces this sort of unstable effect. Ask:

- Why do you think this happens?

Tell students that this color mystery can be solved by looking at another aspect of the way the brain interprets color signals.

**3. Have students read about the equiluminance effect.**
Distribute **Handout 12: The Equiluminance Effect** and have students read the handout.

**Teacher's Notes: (Optional): Equiluminance in Black and White**

To give students a concrete illustration of how equiluminance disrupts the brain's ability to distinguish subject from background, print black and white copies of the example images of the paintings displaying equiluminance.

Show students both the black-and-white and the color images. Elicit from students that the red and green colors seem to merge in the black-and-white image. Explain that this is because the colors have the same brightness. For black-and-white images to be seen clearly, they need the contrast of differing levels of brightness and shading.

Viewed in black and white, the figures in *Plus Reversed* become very difficult to see, and the poppies in Monet's painting seem to disappear into the grasses. When object and background have the same luminance, it is difficult to perceive edges.

## Handout 12:
# The Equiluminance Effect

## Explanation of the Equiluminance Effect

In the two paintings, you observed how the colors and figures seemed to move on their own. This can be explained by the way the brain processes visual signals.

Two systems in the brain's visual cortex are responsible for visual perception:

- The "Where" system—which controls our perception of motion, space, position, depth, figure/ground separation, and organization
- The "What" system—which helps us recognize objects, including faces, in color and detail

Normally, the brain's "Where" system uses differences in color luminance to distinguish an object from its background. However, when two colors, or the colors of two adjacent figures, are equiluminant—i.e., have the same brightness—the "Where" system cannot distinguish where one color ends and the other begins.

The result is that the "What" system sees the colors and shapes of the figures, but the "Where" system cannot locate them spatially. This creates an effect where colors and shapes seem to vibrate or float and do not remain still.

# Activity 3C: Pointillism

In Part 2B, students learned about two types of color mixing—additive and subtractive. In this activity, students learn about a third type of color mixing, called *partitive mixing*. They view an example of *pointillism*, a painting style that uses partitive mixing, and experience the types of effects that are produced by this painting style.

RESOURCES

## Understandings

- In the style called *pointillism*, artists paint by placing small dots of pure color close to one another on the canvas.
- Pointillist paintings, mosaics, color printing, and computer monitors use partitive color mixing, rather than additive or subtractive mixing. In *partitive mixing*, adjacent dots or patches of color are mixed in the viewer's eye and brain.

## Materials Needed

- **Handout 13: Pointillism**
- Computer with Internet connection to display examples of pointillist art
- A pointillist painting and a detail from the same painting. (See *Media & Resources* for links to an image of the painting *Sunday Afternoon on the Island of Grande Jatte* by Georges Seurat and a detail from the painting.)
- Optional: Examples of a printed out color image and the same image on a computer screen both viewed at high magnification.

**1. Review types of color mixing.**
Remind students that earlier in the unit they learned about two kinds of color mixing, additive and subtractive. Ask volunteers to provide definitions of or summarize the two processes.

Remind students that light is mixed through additive mixing, and that subtractive mixing is what most artists use to mix paints. Tell students that, in this activity, they will learn about a third type of color mixing.

**2. Introduce the concept of *partitive mixing*.**
Display the word *partitive*. Ask:

- What root word do you see?

  ***Answer:*** *Part-*

Explain that in partitive mixing, colors are presented as very small dots, or parts, arranged close to one another but not touching. Ask:

- Do you know what a *mosaic* is?

  ***Answer:*** *A picture or pattern made with small tiles or stones of many different colors placed close together.*

Tell students that a mosaic is one example of partitive mixing. Ask:

- How do you perceive colors in a mosaic, both up close and from farther away?

  ***Possible answer:*** *Up close, you see separate, individual colors. When you view the mosaic from a distance, however, the colors blend with one another and you perceive gradations of a greater variety of colors.*

  **Note:** You might want to provide an example or an image of a mosaic to show the class. You could also note that paint-by-number kits use the same principle.

**3. Introduce pointillism as a painting style.**
Distribute **Handout 13: Pointillism** and have students look at the painting on the handout and read the text below it.  Ask students for their responses to the question:

- Can you guess what the painting style *pointillism* refers to?

Have students look at the artist's brushwork. Ask:

- How do you think the artist applied the paint?

Point out the tiny dots of bright color painted very close to one another. Ask:

- When you view this painting, how do you think color mixing is taking place?

Help students understand that when small dots of separate color are placed close together, the colors mix in the eye and brain of the viewer.

**4. Discuss another example of pointillist art.**
Display another pointillist painting and a detail from that painting.

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**Note:** The link to the painting and detail provided in *Media & Resources* is for *Sunday Afternoon on the Island of Grande Jatte* by Georges Seurat. The detail is from the painting's lower left-hand corner.

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Ask:

- What do you see in this painting?
- What is the effect of partitive mixing on color, shape, and composition? How is the effect achieved?
- How does the effect change when viewing the painting and the detail?
- Why do you think pointillist artists chose to use this painting technique?

  ***Possible answer:*** *Pointillist painters wanted to experiment with mixing paint as though it were colored light.*

Explain that in partitive mixing, artists do not mix most of their colors on a palette, but instead leave colors to be mixed in the viewer's eye. As a result, some of the effects—including bright, luminous colors—are more similar to those created by additive rather than subtractive mixing.

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**Note:** Some pointillist artists also took advantage of after-images. Artists painted dots of color with white canvas surrounding each dot. Viewers would perceive opponent colors as a "halo" around the colored dots, much as students observed green after-images on white paper after viewing red paper squares.

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**5. Introduce partitive mixing in printing and computer monitors.**
Point out that partitive mixing is also the method of color mixing used in computer monitors and printing processes. Ask students:

- Have you ever looked at a highly magnified color picture in a newspaper or magazine or on a computer monitor? If so, what did you see?

  ***Answer:*** *Tiny dots of color. A magnified color image looks much like a pointillist painting.*

**Teacher's Note: (Optional):**
**Partitive Mixing in Print and in CRT or LCD Displays**

Have students view a printed picture or a color image on a computer screen at high magnification to allow them to see the visible dots of color.

In print, the colors that are mixed are inks—cyan, magenta, yellow, and black (similar to the paint primaries). Color mixing on television or computer monitors, however, involves mixing light, and uses red, green, and blue, the eye primaries.

Students may wish to compare the results of these two different partitive mixing processes by observing the color differences between the same color image on a computer screen and on a printout from a color printer. Provide or suggest additional resources to allow students to further explore the use of color in printing and in CRT and LCD displays.

# Activity 3D: Assessment

For their final assessment, students use the Assessment Checklist to guide them as they complete two short projects:

- A written summary of their understanding of what color is and how the nervous system facilitates color perception, including the interactions between light, the eye, and the brain
- An analysis of the physiological basis for a color effect in an artwork, media piece, or illusion of their choice, which includes a labeled diagram showing the role of light, the eye, and the brain in producing the effect

RESOURCES

**Note:** Students may need an additional day or two outside of the week-long unit to complete their assessments as homework or in class.

## Materials Needed

- Examples of or suggested links to artwork, illusions, or media pieces that demonstrate the color effects in the unit: after-images, simultaneous or complementary contrast, equiluminance, and pointillism. (See *Media & Resources* for links to examples to print or display for student use.)
- Students' copies of **Assessment Checklist: Color Perception**

**1. Review with students the criteria on the Assessment Checklist.**
Answer any questions students have on the work that will be assessed or on any topics covered in the unit.

**2. Have students select a work to write about.**
Present students with resources for choosing an artwork, illusion, or media piece that uses one of the color effects they learned about in the unit: after-images, simultaneous or complementary contrast, equiluminance, or pointillism. Provide time for students to select a work.

### Teacher's Notes: Sources of Artwork for Color Effect

You may want to ask students to find an example of a color effect on their own, using the links provided in *Media & Resources* (under Activity 3D: Assessment, Artwork, Illusions, and Media Pieces) or the suggested books and Web sites listed in *Additional Resources for Teachers* (under Part 2: Light and the Physiology of Vision, Sources of Additional Visual Illusions). Alternatively, you may want to print out or copy examples for students to choose from.

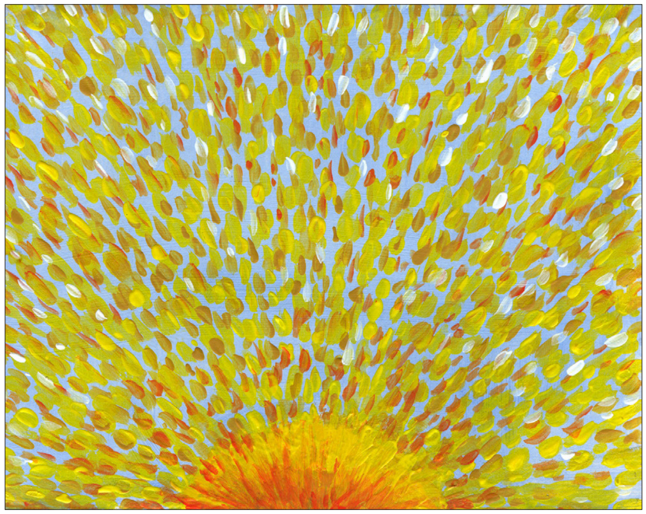
Another option is to have students choose a piece of artwork they created in their *Foundations in Visual Arts* course or an artwork created by another student.

**3. Have students complete the assessment activities.**
Provide time for students to do the following:

- Complete their assessment pieces
- Fill in the Student Comments column on the Assessment Checklist

Have students turn in their final work and Assessment Checklists for review.

# Handout 13:
# Pointillism



Drops of light in pointillistic technique.
Photograph from iStockphoto.

Look closely at the painting above. Describe what you see.

Can you guess what the painting style pointillism refers to?

Pointillism became popular in Europe in the late 1900s. One of the most famous pointillist painters was Georges Seurat. His painting *Sunday Afternoon on the Island of Grande Jatte* was the first publicly displayed and recognized pointillist painting.

Pointillist painters were very interested in the effects of light, and many were aware of scientific theories about color perception. In pointillism, as with most painting techniques, artists begin by using subtractive mixing to develop a basic color palette. But unlike other painting styles, the pointillist artist paints with a limited number of pre-mixed colors. The wider range of colors perceived in the painting are created with a third type of mixing, partitive mixing, which occurs as an active component of viewing the painting.

When you view this painting, how do you think color mixing is taking place?

# Appendix A: Equipment Recommendations

## Flashlights

Any flashlight will work for the activities in this unit, but it is preferable to have students use flashlights that have about the same levels of brightness.

If you are purchasing flashlights for this project, the "Mini Maglites" brand is recommended (http://www.maglite.com/product.asp?psc=2AACELL&pt=R). These are rugged, have high output, and, most importantly, can be focused. They are available in many stores and from multiple online sources.

## Colored Filters

- You can make your own colored filters by using transparencies and red, green, and blue colored markers (the "Sharpie" brand of markers works well).
- You can purchase colored filters online (e.g., a booklet of colored filters) for about $20, including shipping; stock #V39417 from Anchor Optics:
  - Lee Filters: http://www.leefiltersusa.com/
  - Rosco Filters: http://www.rosco.com/
  - Arbor Scientific's Color Filter Kit, a set of six filters—red, blue, green, cyan, yellow, and magenta—that are ideal for this unit: http://www.arborsci.com/
- You may use colored transparency plastic or colored cellophane instead of colored filters. You can order transparency plastic or cellophane online or find it in a local stationery or office supply store.

# Appendix B: Explanations of Illusions

## Illusion 1

Remember Illusion 1? The color of the index cards seemed to change from white to gray, depending on how you held the cards in relation to the light. You did not actually change the *color* of the light—you changed the *amount* of light directly striking the cards.

As a result, the surface of the index cards reflected and absorbed different amounts of white light, just as the objects in the activity reflected and absorbed different wavelengths of colored light, depending on the wavelengths striking them. In both cases, the change in light altered your perception of the color.

## Illusion 2

Now that you know how the activation of different types of cones affects our perception of color, you are ready to understand how Illusion 2 works. Remember that when you stared hard at a colored square of red paper, you saw a green after-image? And when you stared at a blue-colored square, you saw a yellowish after-image?

Cone sensitivity and activation explains why you perceive after-images. As you have learned, green and yellow are "opponent colors" for red and blue, respectively.

When you look at a bright red square, your L cones are stimulated, so you perceive the long wavelength color, red. But after you stare at the square for a while, your L cones get tired. When you look at a plain white surface immediately afterward, the cones surrounding your L cones—which were not stimulated by the long wavelength signal—are still fresh. These surrounding M cones are now in a higher state of activation than your L cones, so you perceive the color green.

Because your L cones become tired and are less activated relative to your M cones, the effect, as interpreted by your brain, is the same as if you were actually looking at a green square.

## Illusion 3

In Illusion 3, when you closed your right eye, stared at the + and moved the sheet of paper, the dot disappeared when the paper reached a certain distance. When you closed your left eye and stared at the dot, the + disappeared. You knew that the + and the dot were still there, but you didn't *perceive* them. As you moved the sheet of paper toward you, the image of the + and then the dot disappeared because, at a certain distance, they were projected directly onto your blind spot.

You see a continuous sheet of paper instead of a hole there for the same reason you don't see a hole in the center of your vision when you look straight in front of you. Your brain compensates for your blind spot. The brain fills in the gap with what it *thinks* is there—a continuous white sheet of paper.

This illusion works because when the + or the dot fall directly on the blind spot, the brain is "tricked" into seeing what it expects to see: something that isn't actually there. The brain makes an assumption based on the surrounding sensory information:

The eye and brain function together to respond to stimuli. The response is influenced by memory, past experience, and judgment, and other sensory input.

# Materials Needed

## Throughout the Unit

- Equipment to display or project vocabulary terms and student responses to activity prompts and questions (blackboard or whiteboard, chart paper, overhead projector or computer, and chalk or markers)

## Part 1: In the Eye of the Beholder

*Writing Supplies and Other Equipment*

- 15 crayons selected from a 48-crayon pack (see Advance Preparation)
- Red object, such as an apple or a book with a red cover
- Optional: 48-crayon packs (one per group)
- Optional: sets of six paper cups or six sheets of paper (one set per group)
- Optional:  Equipment for displaying color slide show

*Handouts*

- **Handout 1: Color Survey**
- **Handout 2: Unit Overview**
- **Assessment Checklist: Color Perception**

*Examples of Media Resources*

- Optional: Mac- or PC-specific color slide show (see Media & Resources)

*Advance Preparation*

- Before Activity 1A, decide whether you will conduct the activity with color crayons or a color slide show. If you are using crayons, determine whether you will do the activity as a class or in groups, and then borrow or purchase as many 48-crayon packs as needed. If you are doing the activity as a class, select 15 crayons from the box that you believe students are most likely to perceive differently. (The likeliest choices are those that appear to fall between color categories, such as blue-greens, yellow- or red-oranges, or red- or blue-violets.)

## Part 2: Light and the Physiology of Vision

*Writing Supplies and Other Equipment*

- Two blank white unlined index cards (1 set per pair)
- Scissors (1 per pair or 1 available in the classroom)
- Colored objects (1 red, 1blue, and 1 green object per group) (see Advance Preparation)
- Flashlights (4 per group)

**Note:** If there is a limited supply of flashlights, each group can perform Activity 2A.3 with only one flashlight, as long as students can easily attach and detach the different colored filters.

- Colored filters (1 red, 1 blue, and 1 green filter per group)

**Note:** Appendix A has information about obtaining flashlights and filters.

- Rubber bands or cellophane tape for attaching filters
- Red paper square and blue paper square, each approximately 4" x 4" (1 of each per student pair)
- Plain white paper (1 sheet per student pair)
- Pencils or colored pencils
- Optional: Additional paper for drawing diagrams
- Colored filters (2 red, 2 blue, 2 green, and 2 yellow per group)
- White wall, screen, or large sheet of white paper taped to the wall
- Optional: Pen
- White handkerchief or white piece of paper
- Computer with Internet connection

*Handouts*

- **Handout 3: Illusion 1: Gray or White?**
- **Handout 4: Light and Color**
- **Handout 5: Viewing Objects with Colored Light**
- **Handout 6: Illusion 2: After-Images**
- **Handout 7: The Eye**
- **Handout 8: Mixing Colored Lights and Filters**
- **Handout 9: Diagrams of Color Mixing**
- **Handout 10: Illusion 3: The Disappearing Dot**
- **Handout 11: Brain Connections**

*Examples of Media Resources*

- Two examples of simultaneous contrast for Activity 2C.2. (See Advance Preparation.)
- Optional: Additional illusions to supplement illusions presented at the beginning of each activity in Part 2. (See Advance Preparation at the beginning of the unit.)

*Advance Preparation*

- Plan for students to work in pairs in Activities 2A.1, 2B.1, and 2B.2. Plan for students to work in groups of four in Activities 2A.3 and 2B.4.
- Before Activity 2A.3 and 2B.4, prepare your classroom so that it can be fully darkened or arrange for an alternate space to perform experiments.
- For Activities 2A.2 and 2A.3, find red, blue, and green objects (sets of three objects per group). Fruits and vegetables, such as apples or tomatoes, blueberries or plums, and green peppers or beans work well.
- Assemble materials for Activities 2A.3 and 2B.4 or have materials displayed where groups can easily assemble their own.
- For Activity 2C.2, choose two images to show as examples of simultaneous contrast and prepare equipment to display them. (See *Media & Resources* for links.)

## Part 3: Do You See What I See?

*Writing Supplies and Other Equipment*

- Computer with Internet connection

*Handouts*

- **Handout 12: The Equiluminance Effect**
- **Handout 13: Pointillism**

*Examples of Media Resources*

- Several paintings of the same object or scene, painted with different colors to create different effects (See *Media & Resources* for links to the examples used in step 2 of Activity 3A.)
- Two examples of artwork with effects created by complementary contrast. The examples modeled are *Café Terrace on the Place du Forum, Arles and Night Café in Arles*, both by Vincent Van Gogh. (See *Media & Resources* for links to images of these paintings.)
- Color wheel that shows complementary colors (See *Media & Resources* for link to a color wheel.)
- Optional: Examples of signs or advertising that use complementary contrast.
- Optional: Examples of artwork to explore other influences on color, such as light, chiaroscuro, or mood effects. Examples from Claude Monet's

*Haystack* or *Rouen Cathedral* series make interesting demonstrations.

- Two examples of artwork with effects created by equiluminance. The examples modeled are *Plus Reversed* by Richard Anuszkiewicz and *Wild Poppies, Near Argenteuil* by Claude Monet. (See *Media & Resources* for links to images of these paintings.)
- A pointillist painting and a detail from the same painting. (See *Media & Resources* for links to an image of the painting *Sunday Afternoon on the Island of Grande Jatte* by Georges Seurat and a detail from the painting.)
- Optional: Examples of a printed out color image and the same image on a computer screen both viewed at high magnification.
- Examples of or suggested links to artwork, illusions, or media pieces that demonstrate the color effects in the unit: after-images, simultaneous or complementary contrast, equiluminance, and pointillism. (See *Media & Resources* for links to examples to print or display for student use.)

*Items Students Need to Bring*

- Students' copies of **Assessment Checklist: Color Perception**

*Advance Preparation*

- Collect examples of or links to several paintings of the same object or scene, painted with different colors to create different effects. (See *Media & Resources* for links to snow scenes by Claude Monet.)
- Collect examples of or links to arts and media that demonstrate the color effects of complementary contrast, equiluminance, and pointillism. (See *Media & Resources* for links to the examples used in the Part 3 activities.)
- Optional: Locate examples of complementary contrast in signs or advertising to display in step 4 of Activity 3A.

# Media & Resources

These recommended Web sites have been checked for availability and for advertising and other inappropriate content. However, because Web site policies and content change frequently, we suggest that you preview the sites shortly before using them.

*Media & Resources* are also available at http://dma.edc.org and at http://dmamediaandresources.pbworks.com, a Wiki that allows users to add and edit content.

## Part 1: In the Eye of the Beholder

### Activity 1A: Color Survey

Macintosh and PC PowerPoint color slide shows, each consisting of 15 color slides, are available as an alternative to using crayons through *Media & Resources*

## Part 2: Light and the Physiology of Vision

#### Activity 2A.2: The Color Spectrum

***Color Spectrum***

*Wikipedia Commons*

> http://upload.wikimedia.org/wikipedia/commons/d/d9/Linear_visible_spectrum.svg

***Englemann's Photosynthesis Experiments***

Action & Absorption Spectra

> http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/A/ActionSpectrum.html

Biocoach Activity, Pearson. Concept 3: The Action Spectrum for Photosynthesis. Animation showing distribution of photosynthetic activity across the spectrum of visible light.

> www.phschool.com/science/biology_place/biocoach/photosynth/action.html#

### Activity 2C.2: What the Brain Sees

***Images of Simultaneous Contrast***

The Eye: Simultaneous Contrast

http://library.thinkquest.org/27066/theeye/nlsimcontrast.html

www.andrewkelsall.com/wp-content/uploads/2009/05/simultaneous-contrast-color.png

www.archimedes-lab.org/images7/color_contrast2.gif

www.psy.ritsumei.ac.jp/~akitaoka/Tcontrastc.gif

www.uncg.edu/~whanthon/illusions/Gradient.illusion.arp.jpg

# Part 3: Do You See What I See?

## Activity 3A: Complementary Contrast

***Same Object or Scene Painted with Different Colors***

Snow scenes painted by Claude Monet

http://store.encore-editions.com/cat221frnimp.html

http://store.encore-editions.com/cat144frnimp.html

www.abcgallery.com/M/monet/monet160.html

http://store.encore-editions.com/cat115frnimp.html

***Color Wheel***

http://northlite.net/ps/images/color_wheel.gif

***Effects Created by Complementary Contrast***

*Café Terrace on the Place du Forum, Arles*, by Vincent Van Gogh

www.paintingmania.com/Arts/Big/2822_big.jpg

*Night Café in Arles* by Vincent Van Gogh

www.abcgallery.com/V/vangogh/vangogh104.jpg

## Activity 3B: Equiluminance

*Plus Reversed* by Richard Anuszkiewicz

www.columbusmuseum.org/media/optic/img/anusz_LG.jpg

*Wild Poppies, Near Argenteuil* by Claude Monet

www.claudemonetgallery.org/Wild-Poppies,-Near-Argenteuil-large.html

## Activity 3C: Pointillism and Partitive Mixing

*Sunday Afternoon on the Island of Grande Jatte* by Georges Seurat

www.georgesseurat.org/Sunday-Afternoon-on-the-Island-of-la-Grande-Jatte--1886-large.html

*Detail of Sunday Afternoon on the Island of Grande Jatte* by Georges Seurat

www.flickr.com/photos/36350735@N05/3806122703/

## Activity 3D: Assessment

### Artwork, Illusions and Media Pieces

***After-Images***

http://boomeryearbook.com/blog/wp-content/uploads/2009/03/byb-optical-illusion-american-flag-clip_image001.jpg

www.gla.ac.uk/t4/cspe/i/manzana1.jpg

www.magiczilla.com/illusions/circles.gif

### Simultaneous Contrast

***The Eye: Simultaneous Contrast***

http://library.thinkquest.org/27066/theeye/nlsimcontrast.html

www.andrewkelsall.com/wp-content/uploads/2009/05/simultaneous-contrast-color.png

www.archimedes-lab.org/images7/color_contrast2.gif

www.psy.ritsumei.ac.jp/~akitaoka/Tcontrastc.gif

www.uncg.edu/~whanthon/illusions/Gradient.illusion.arp.jpg

### Complementary Contrast

Andy Warhol, *Self-Portrait*

http://img2.allposters.com/images/AWI/NR834.jpg

Jasper Johns, *False Start*

www.artnet.com/magazine/features/polsky/polsky2-2-2.asp

### Equiluminance

Peter Baker, *The Cage Triple Illusion*

www.moillusions.com/wp-content/uploads/photos1.blogger.com/blogger/5639/2020/400/thespacage.jpg

Richard Anuszkiewcz, *Diamond Chroma*

www.okcmoa.com/~okcmoa/files/u1/Anuszkiewicz__Diamond_Chroma__1968.091.jpg

Gustavo Acosta

http://2.bp.blogspot.com/_q3S1wI3BuIl/ShRvm4-sbuI/AAAAAAAAABE/Rr8q8yOIPPY/s320/archive_1731_PanAmericanArtProjects-1.jpg

Andy Warhol, *Flowers*

www.inourcloset.com/blog/wp-content/uploads/2009/04/andy-warhol-flowers-1970-fs-ii66.jpg

Andy Warhol, *Marilyn Monroe*

www.alt-web-design.com/photo-tutorials/images/andy-warhol-effect-all.jpg

**Pointillism**

www.psych.ucalgary.ca/PACE/VA-LAB/Brian/pointillism.jpg

www.cc.gatech.edu/cpl/projects/artstyling/images/jl_pointillism.jpg

Georges Seurat, detail of *La Parade*

www.metrospirit.com/Image/19.17/lg%20mw%20pointillism.jpg

# Additional Resources for Teachers

## Unit Overview

### Adapting the Unit

For Supplemental Artwork and Illusions, see the following two sections:

Part 2: Light and the Physiology of Vision, Activities 2A, 2B and 2C (Sources of Additional Visual Illusions)

Part 3: Do You See What I See?

### Advance Preparation

See below under Part 2: Light and the Physiology of Vision, Activities 2A, 2B, and 2C (Sources of Additional Visual Illusions)

## Part 1: In the Eye of the Beholder

### 1A: Color Survey


Adelson, Rachel. (February 2005). Hues and views: A cross-cultural study reveals how language shapes color perception. APA Online. *Monitor on Psychology, 36*(2).

www.apa.org/monitor/feb05/hues.html

Munsell Color Science Laboratory. *Perception FAQ. Ask a Color Scientist*.

www.cis.rit.edu/mcsl/outreach/faq.php?catnum=1#897

Murphy, Pat, Klages, Ellen, Shore, Linda, and the Staff of the Exploratorium. (1996). *The Science Explorer: Family Experiments from the World's Favorite Hands-On Science Museum*. New York: Holt.

*Science Daily*. (October 26, 2005). Color perception is not in the eye of the beholder: It's in the brain.

www.sciencedaily.com/releases/2005/10/051026082313.htm

# Part 2: Light and the Physiology of Vision

## Activities 2A, 2B, and 2C

### Sources of Additional Visual Illusions (also see under Media & Resources, Activity 3D: Assessment)


Echalk. *Echalk Optical Illusions*.
www.echalk.co.uk/amusements/OpticalIllusions/illusions.htm

Gardner, Robert. (1990). *Experimenting with Illusions*. London: Franklin Watts.

Illusion Works, L.L.C. *Color Aftereffect*.
www.psychologie.tu-dresden.de/i1/kaw/diverses%20Material/www.illusionworks.com/html/color_aftereffect.html

Lookmind.com. *Intellectual Development: Optical Illusions, Logical Games, Brain Soft*.
http://lookmind.com/

Seckel, Al. (2006). *Optical Illusions: The Science of Visual Perception*. Ontario, Canada: Firefly Books Ltd.


#### 2A.2: The Color Spectrum


Atmospheric Data Center. What Wavelength Goes with a Color? Retrieved from NASA Web site on October 26, 2009 at
http://eosweb.larc.nasa.gov/EDDOCS/Wavelengths_for_Colors.html

Davidson, Michael W., Kirill I. Tchourioukanov, and The Florida State University. Newton's Prism Experiments. Molecular Expressions: Science, Optics, and You. Interactive Java Tutorials. Retrieved October 26, 2009, at
http://micro.magnet.fsu.edu/primer/java/scienceopticsu/newton/index.html

Gaston, Madeline. Iowa 4-9 Science Project. Teacher Guide for: Colored Light 3-Color of Colorless Light. Retrieved October 26, 2009 at
www.aea10.k12.ia.us/curr/science/sci4-9/Light/LIGHT480.html

Hamann, Michael. Particle Theory vs. Wave Theory. Retrieved October 26, 2009 at
http://74.125.93.132/search?q=cache:5gD_-QIRp6MJ:www1.umn.edu/ships/modules/phys/light.doc+hands-on+newton%27s+prism+experiment&cd=3&hl=en&ct=clnk&gl=us&client=firefox-a

Optics: The Human Eye. Molecular Expressions. Science, Optics, and You—Human Vision Interactive Java Tutorial. (Scroll down to Newton's prisms).
www.teachnet.ie/torourke/Physicswebsite/Optics.htm

The Schiller Lab at MIT. Neural Color of Vision Slide Show. J. The Processing of Color.
http://web.mit.edu/bcs/schillerlab/research/A-Vision/A10-1.html

## Activities 2B: The Eye and the Image, and 2C: The Brain Decides


Baker, Billy. (November 2008). *Artist Vision: Decode Color Perception*. [A neuron turned on in a monkey's brain when shown the color deep purple.]

www.boston.com/news/science/articles/2008/11/10/artists_vision_decode_color_perception/?page=2

Banich, Marie T. (1997). *Neuropsychology: The Neural Bases of Mental Function*. Boston: Houghton Mifflin.

Bianco, Carl, M.D. *How Stuff Works: How Vision Works*.

http://health.howstuffworks.com/eye.htm

Booth, Alexis. *What Animals May See. Some Thoughts on Visual Perception*.

www.pigeon.psy.tufts.edu/psych26/umvelt.htm

Canadian Institutes of Health Research, Canadian Institutes of Neurosciences, Mental Health, and Addiction. *The Brain from Top to Bottom: The Eye, The Various Visual Cortexes*.

http://thebrain.mcgill.ca/flash/i/i_02/i_02_cr/i_02_cr_vis/i_02_cr_vis.html

Catherall, Ed. (1990). *Exploring Light*. Austin, TX: Steck-Vaughn Library.

Hayes, Brian. (May–June 1999). Seeing Between the Pixels. *American Scientist*.

www.americanscientist.org/issues/pub/seeing-between-the-pixels

Kolb, Helga, Fernandez, Eduardo, and Nelson, Ralph. The Perception of Color. *Webvision: The Organization of the Retina and Visual System*. John Moran Eye Center, University of Utah.

http://webvision.med.utah.edu/KallColor.html

Kuehni, Rolf G. (2005). *Color, An Introduction to Practice and Principles*. Wiley InterScience, Malden, MA: John Wiley & Sons.

Livingstone, Margaret. (2002). *Vision and Art, The Biology of Seeing*. New York: Harry N. Abrams, Inc.

McHugh, Sean. *Tutorials: Color Perception. Human Color Perception: Our Eyes and Vision*.

www.cambridgeincolour.com/tutorials/color-perception.htm

National Eye Institute, National Institutes of Health. (October 2008). *Diagram of the Eye*.

www.nei.nih.gov/health/eyediagram/

Neuroscience for Kids. [A newsletter for students and teachers which teaches about the brain and neuroscience.]

http://faculty.washington.edu/chudler/neurok.html

Newton, Isaac. (1990). *Optics*. Published in Great Books, volume 32, Encyclopedia Britannica, Inc.

*Parts of the Eye*.

www.cis.rit.edu/people/faculty/montag/vandplite/pages/chap_8/ch8p3.html

Sobel, Michael I. (1987). *Light*. Chicago: The University of Chicago Press.

Star Gazette. Notes on Nature: Animal Color Vision.
www.stargazette.com/blogs/outdoors/nature/2009/05/animal-color-vision.html

Wagner, Brian Thomas, and Kline, David. The Nature of Colour as Light. *The Bases of Color Vision*. Alberta, Canada: University of Calgary.
www.psych.ucalgary.ca/PACE/VA-LAB/Brian/nature.htm

## Part 3: Do You See What I See?

Bach, Michael. (April 13, 2009). Colour Mixtures. *84 Optical Illusions & Visual Phenomena*.
www.michaelbach.de/ot/col_mix/index.html

Birren, Faber. (1986). *Color Perception in Art*. West Chester, PA: Schiffer Publishing.

Color, Vision & Art. *Webexhibits.org*.
www.webexhibits.org/colorart/jatte.html

Elkins, James. (2000). *How to Use Your Eyes*. New York: Routledge.

Gerritsen, Frans. (1975). *Theory and Practice of Color: A Color Theory Based on Laws of Perception*. New York: Van Nostrand Reinhold Company.

RGB World, Inc. RGB world—understanding color. Retrieved October 26, 2009 at
www.rgbworld.com/color.html

# Standards

This unit was developed to meet the following standards.

## California Academic Content Standards for Laboratory Science, Grades 9–12

### Biology/Life Sciences

**Evolution**

**8.** Evolution is the result of genetic changes that occur in constantly changing environments. As a basis for understanding this concept:

> **a.** Students know how natural selection determines the differential survival of groups of organisms.
> **b.** Students know a great diversity of species increase the chance that at least some organisms survive major changes in the environment.

**Physiology**

**9.** As a result of the coordinated structures and functions of organ systems, the internal environment of the human body remains relatively stable (homeostatic) despite changes in the outside environment. As a basis for understanding this concept:

> **b.** Students know how the nervous system mediates communication between different parts of the body and the body's interactions with the environment.
> **d.** Students know the functions of the nervous system and the role of neurons in transmitting electrochemical impulses.
> **e.** Students know the roles of sensory neurons, interneurons, and motor neurons in sensation, thought, and response.

### Physics

**Waves**

**4.** Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:

> **a.** Students know waves carry energy from one place to another.
> **e.** Students know radio waves, light, and X-rays are different wavelength bands in the spectrum of electromagnetic waves whose speed in a vacuum is approximately $3 \times 10^8$ m/s (186,000 miles/second).

### Investigation and Experimentation

**1.** Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the four other strands, students should develop their own questions and perform investigations. Students will:

**d.** Formulate explanations by using logic and evidence.
**f.** Distinguish between hypothesis and theory as scientific terms.
**g.** Recognize the usefulness and limitations of models and theories as scientific representations of reality.
**l.** Analyze situations and solve problems that involve combining and applying concepts from more than one area of science.

## CTE AME Industry Sector Foundation Standards

**1.2 Science**

*Specific applications of Physics standards (Grades 9–12):*

**(4.d)** Students know radio waves, light, and X-rays are different wavelength bands in the spectrum of electromagnetic waves whose speed in a vacuum is approximately 3 x $10^8$ m/s (186,000 miles/second).

*Specific applications of Investigation and Experimentation standards (Grades 9–12):*

**(1.d)** Formulate explanations by using logic and evidence.
**(1.g)** Recognize the usefulness and limitations of models and theories as scientific representations of reality.
**(1.l)** Analyze situations and solve problems that require combining and applying concepts from more than one area of science.

**11.0 Demonstration and Application**

Students demonstrate and apply the concepts contained in the foundation and pathway standards.

## CTE AME Industry Sector Media and Design Arts Pathway Standards

**A.1.0 Visual and performing arts (VPA) and English-language arts (ELA)**

Students master appropriate visual and performing arts (VPA) and English-language arts (ELA) content standards in relation to visual, aural, written, and electronic media projects and products.

**A1.1 VPA Artistic Perception**

**(1.1, Proficient)** Identify and use the principles of design to discuss, analyze, and write about visual aspects in the environment and in works of art, including their own.
**(1.1, Advanced)** Analyze and discuss complex ideas, such as distortion, color theory, arbitrary color, scale, expressive content, and real versus virtual in works of art.
**(1.4, Proficient)** Analyze and describe how the composition of a work of art is affected by the use of a particular principle of design.

# Bibliography

Color Vision & Art: Vision, Science, and the Emergence of Modern Art. (n.d.). WebExhibits.org. Retrieved June 15, 2009, from www.webexhibits.org/colorart/index.html.

Neuroscience for Kids. (n.d.). *Sight (Vision). The Blind Spot*. [Source of blind spot illusion in Activity 2C.1.] Retrieved September 9, 2009, from http://faculty.washington.edu/chudler/chvision.html

Smythies, John. (January 2005). How the Brain Decides What We See. *Journal of the Royal Society of Medicine, 98*[1]. [Source of quote for Activity 2C.2.] Retrieved June 17, 2009, from http://jrsm.rsmjournals.com:80/cgi/content/full/98/1/18