Students will apply inquiry techniques to derive concepts regarding light addition.

Engage: Afterimages

Materials:

- Overhead image of apple (magenta and cyan)
- Picture of Texas flag (cyan, black and yellow)

Students will stare at images and then describe the afterimages they observe. An overhead of an apple and a picture of a Texas flag are provided as visuals. Do not share with students what they should expect to see.

Procedure:

1. Describe the procedure to the students before actually engaging them in the activity. Explain to the students that they will stare at the black spot on the apple for 1 minute. (Important: Emphasize that they can blink as often as needed; however, they must focus on the black spot without letting their eyes roam.) Tell students that after they have stared at the image for one minute, you will turn off the overhead and have them continue to stare at the screen.

2. Follow the description above for viewing the apple. Wait before asking students to tell what they observe. They will continue to observe the afterimage for several seconds. After approximately 15 seconds, ask them to describe what they see. (The afterimage for an individual with normal color vision is a red apple with a green stem and leaf.) Introduce the term afterimage. Explain that it is an optical illusion you will observe after staring at another image.

3. Next, have students stare at the flag for a minute. Specifically, have them star at the star. If eyes roam, students will not see the afterimage. Again, have students share what they observe. (The afterimage for an individual with normal vision will be a red, white and blue flag.)

4. Students will ask why they observe these images. They will continue in the next steps of this lesson to explore and explain the answer.
Explore: Light Addition
Students will explore by adding the primary colors of light.

Materials:
- 3 slide projectors
- 2 color slides of each of the following: red, green, blue, magenta, cyan and yellow

Procedure:
1. Set up 3 slide projectors to show the gel filters for red, green and blue, the primary colors of light. (Gel filters are used in stage lighting and are available in numerous colors. The red, green and blue gels provided are accurate matches for the primary color wavelengths.

2. Pre-assess students prior understanding by asking them to name the three primary colors of light. (Some will respond with red, blue and yellow because of prior experiences in art.) After they give responses, ask for a volunteer to man each of the three projectors.

3. One at a time, ask a student to turn on a light to show a color. Then have the student turn off the light before moving to the next student. After each of the three primary colors has been observed, you are ready for light addition.

4. Ask students to predict what they will observe by adding blue and green light.

   Predict: blue + green = ____________

   Next, have the students manning the projectors with slides for blue and green overlap the colors to show the answer:

   Result: cyan

5. Continue with predictions and results in the order listed:
Predict: blue + red = ___________  Result: magenta

$\begin{array}{c}
\text{green} + \text{red} = \\
\text{yellow}
\end{array}$

Predict: green + red + blue = ___________  Result: white

6. Open the class explorations with color slides and allow students to test other possibilities to answer questions.

7. Ask students why the steps above are referred to as “light addition” and what is required for light addition. (Answer: you are adding light back together to get colors and eventually white. For light addition, the light must come from different sources to combine into one.)

8. At this point, group students in teams of 4 to 5 per group to complete the first two sections of the KWL chart.

<table>
<thead>
<tr>
<th>What Do You Know?</th>
<th>What Do You Wonder?</th>
<th>What Have You Learned?</th>
</tr>
</thead>
<tbody>
<tr>
<td>List facts you know from the activities.</td>
<td>List what you want to know after completing the engage and explore activities.</td>
<td>Wait to complete this portion of the chart.</td>
</tr>
</tbody>
</table>

9. As a class discuss the facts and questions generated by the groups of students before moving to the “Explain” component of the lesson.


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<table>
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<tbody>
<tr>
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<td>List what you want to know.</td>
<td>Complete after the “Explain” activity.</td>
</tr>
</tbody>
</table>
Explain: The Eye and Vision

Students will apply information derived through exploration to explain vision.

Materials:

- Overhead of eye anatomy
- Overhead of apple from “Engage” Activity
- Index cards
- Color pencils

Procedure:

1. Provide each student with an index card for eye drawings. Have students work with a partner and take turns making a drawing of one of the partner’s eyes on the card using color pencils.
2. Get students to label as many components on the drawings as they can identify.
3. Using the overhead of the eye, ask students to identify structures they observed in drawing the eyes. Have students discuss their thoughts about the importance of each structure they label. Add additional structures if necessary.
4. Identify the inside components of the eye and emphasize the lens, retina, rods, cones and optic nerve. Briefly tell the roll of each as students review the “Eye Anatomy” sheet.
5. Tell students that humans can only see three colors and ask them to work with their partner to predict the three colors.
6. Have students share their predictions (answer: red, green and blue, the primary colors of light).
7. Once again show the apple transparency and discuss why the afterimage is a red apple with a green stem and green leaves. (As we stare at a color, the cones that see that color become tired. Once we look away, the cones that have not been used will work while the strained cones rest. Staring at a spot will assure that the same cones are stressed.

**Apple explanation:**

Staring at magenta strained the red and blue cones. During rest, the green cones worked.

With cyan, the blue and green cones strained. During rest, the red cones worked.
Staring at yellow strained the red and green cones. During rest, the blue cones worked.

With cyan, the blue and green cones strained. During rest, the red cones worked.

Staring at black allowed all of the cones to rest because black absorbs all light, and no light reflects back to the cones. During rest, all cones worked and the afterimage is white.

8. Have students complete the “What Have You Learned?” section of the KWL chart to demonstrate their understanding of light addition thus far.

(Refer to the Access Excellence document for detailed information on rods and cones.)
Photograph by Kristin Borgeson. Take a look around the room that you are in. Notice how the various images and colors that you see update constantly as you turn your head and redirect your attention. Although the images appear to be seamless, each blending imperceptibly into the next, they are in reality being updated almost continuously by the vision apparatus of your eyes and brain. The seamless quality in the images that you see is possible because human vision updates images, including the details of motion and color, on a time scale so rapid that a "break in the action" is almost never perceived. The range of color, the perception of seamless motion, the contrast and the quality, along with the minute details, that most people can perceive make "real-life" images clearer and more detailed than any seen on a television or movie screen. The efficiency and completeness of your eyes and brain is unparalleled in comparison with any piece of apparatus or instrumentation ever invented. We know this amazing function of the eyes and brain as the sense of vision.

Vision is a complicated process that requires numerous components of the human eye and brain to work together. The initial step of this fascinating and powerful sense is carried out in the retina of the eye. Specifically, the photoreceptor neurons (called photoreceptors) in the retina collect the light and send signals to a network of neurons that then generate electrical impulses that go to the brain. The brain then processes those impulses and gives information about what we are seeing.

Eye Function

A sketch of the anatomical components of the human eye, as we now know it, is shown in Figure 1. The main structures are the iris, lens, pupil, cornea, retina, vitreous humor, optic disk and optic nerve. A discussion of the role of each component will not be presented here. Instead, we will examine the growth of the understanding of the eye's function.
A realistic understanding of the function of the components of the eye began around the 17th century, after the gross anatomy of the eye had been firmly established. It was realized in the 17th century that the retina, not the cornea as was previously thought, was responsible for the detection of light. Johannes Kepler of Germany and Renee Descartes of France, both prominent physicists of their time, made many advances in understanding vision. Much of their work applied the physical concepts of light rays and geometric optics to the vision process. Kepler first proposed that the lens of the eye focuses images onto the retina. A few decades later Descartes demonstrated that Kepler was correct. In a landmark experiment, Descartes surgically removed an eye from an ox and scraped the back of the eye to make it transparent. He then placed the eye on a window ledge as if the ox were looking out of the window. He looked at the back of the eye and saw an inverted image of the scenery outside! Descartes correctly postulated that the image was inverted as a result of being focused onto the retina by the eye's lens.

Around the beginning of the 19th century Thomas Young, a prominent physicist and physician, carried out a number of studies on the eye that resulted in an understanding of how the lens focuses images onto the retina. He also showed that astigmatism results from an improperly curved cornea. We now understand that a number of vision disorders, including both near- and far-sightedness, also result from an improperly curved cornea. The lenses in eyeglasses function by correcting for the improper corneal curve.

We now know the basic function of the components of the human eye and how they participate in the vision process. Light that reflects off of objects around us is imaged onto the retina by the lens. The retina, which consists of three layers of neurons (photoreceptor, bipolar and ganglion) is responsible for detecting the light from these images and then causing impulses to be sent to the brain along the optic nerve. The brain decodes these images into information that we know as vision.

**Microscopic Anatomy: Rod Cells and Cone Cells of the Retina**

It was in the 1830's that several German scientists used the microscope to closely examine the retina. During this time that two different cells were discovered in the retina, the rod cells and cone cells. These cells were named because of their shape as viewed in the microscope.
A microscopic view of the rod cells of a zebrafish shows us how these cells actually look in an animal. Additional research showed that the rod and cone cells were responsive to light and that the retinal **cones** are the color receptors of the eye and the retinal **rods**, while not sensitive to color, are very sensitive to light at low levels. It is the cone cells that allow us to see in color and the rod cells that allow us to see in low light without color. It is because cone cells remain unstimulated in low light environments that we do not see color in dimly lit places. Try this for yourself. Go into a closet and decrease the light level. Soon you will see only shades of gray. Slowly increase the light levels until you can begin to see color. This demonstration usually works well in a closet because of the many different colors of your clothes.

In the human eye, there are many more rod cells in the retina than there are cone cells. The number of rod cells and cone cells in animals is often related to the animal's instincts and habits. For example, birds such as hawks have a significantly higher number of cones than do humans. This let them to see small animals from a long distance away, allowing them to hunt for food. Nocturnal animals, on the other hand, have relatively higher numbers of rod cells to allow them better night vision.
A schematic drawing of rod and cone cells is shown in Figure 2. The cells are divided into two sections. The bottom portion is called the inner segment. It contains the nucleus and the synaptic ending. The synaptic ending attaches to the neurons which produce signals that go to the brain. The top portion is called the outer segment. The outer segment is comprised of a membrane which is folded into several layers of disks. The disks are comprised of cells that contain the molecules that absorb the light.

**Visual Pigments**

During the 1800's the visual pigments were discovered in the retina. Scientists, working by candlelight, dissected the retinas from frog eyes. When the retinas were exposed to day light they changed color. These scientists had discovered that the retina is photosensitive. They realized that the color they were observing was due to presence of a visual pigment, which was given the name rhodopsin. Later studies showed that rhodopsin is a protein that is found in the disks of the rod cell membrane.

Pigments are also found in cone cells. There are three types of cone cells, each of which contains a visual pigment. These pigments are called the red, blue or green visual pigment. The cone cells detect the primary colors, and the brain mixes these colors in seemingly infinitely variable proportions so that we can perceive a wide range of colors. Prolonged exposure to colors, for example when staring at a particular object, can cause fatigue in cone cells. This results in a change in the way that you perceive the color of the object that you are viewing.

The original theory of color vision was introduced by Thomas Young around 1790, prior to the discovery of the cone cells in the retina. Young was the first to propose that the human eye sees only the three primary colors, red, blue and yellow and that all of the other visible colors are combinations of these. It is now known that color vision is more complicated than this, but Young's work formed the foundation of color vision theory for the scientists that followed. The photoreceptor proteins of the cone cells have not yet been isolated. This may possibly be due to the difficulty in obtaining them. There are many fewer cone cells than rod cells in the retina. Also many animals do not have cone cells and hence do not see in color.

**An Important Protein in the Rod Cell: Rhodopsin**

George Wald and his coworkers at Harvard University pioneered our understanding of the molecules responsible for the first steps in the vision process. For this and other work on vision he was the recipient of the 1967 Nobel Prize in Medicine and Physiology. Wald's group was the first to elucidate the molecular components of the rod cell's functional protein rhodopsin. Wald and his co-workers determined that the protein consists of two molecular parts: a colorless amino acid sequence called opsin and a yellow organic chromophore called retinal.
It is now known that the rhodopsin protein has a molecular weight of ~40 kDa. The protein spans the membrane of the rod cell, and is therefore called a trans-membrane protein. The exact structure of rhodopsin has never been determined, however experimental data lead scientist to predict that it contains seven helices or turns. A schematic drawing of rhodopsin in the rod cell membrane is shown in Figure 3. About half of the protein is contained within the membrane with approximately 25% of the protein lying both above and below the membrane.

It is the rhodopsin protein in the retina that absorbs the light that enters the eye. Specifically, it is known that the retinal molecule, which is embedded inside rhodopsin, undergoes photo-excitation by absorbing light. In the photo-excitation process, the rhodopsin absorbs light and is excited to a higher electronic state. Numerous studies have been carried out to try to understand what happens after the rhodopsin absorbs light. Research has shown that upon photo-excitation the retinal part of rhodopsin undergoes a twisting around one of its double bonds. The retinal then dissociates from the opsin. The change in geometry initiates a series of events that eventually cause electrical impulses to be sent to the brain along the optic nerve. Further research is needed to fully understand this complex process.

**Vitamin A and Retinal**

During the early part of the 20th century work continued on the frontier of research aimed at understanding vision. It was also around this time that the relationship between vision and proper nutrition began being studied at universities and agricultural schools. It had been shown during World War I that a vitamin A deficiency caused night blindness. The link between vitamin A and night blindness, however, did not become clear until George Wald and his coworkers isolated vitamin A from the retina in 1933. Prior to this finding the importance of vitamins was poorly understood. Additionally, the complete role of vitamins in physiological processes was unknown.

It is now understood that the human body makes retinal from vitamin A. When retinal dissociates from opsin, some of the retinal is destroyed. To replenish the destroyed retinal, it is important to have a source of vitamin A in your diet. Without this source of vitamin A, night blindness can develop as the rods can not function effectively without sufficient sources of retinal.
Internal and External Structures of the Eye

**EYE ANATOMY**

**Glossary of Eye Anatomy**

**Aqueous**
A water-like fluid which fills the front part of the eye between the lens and cornea. This fluid is produced by the ciliary body and drains back into the blood circulation through channels in the chamber angle. It is turned over every 100 minutes.

**Chamber Angle**
Channels here allow aqueous fluid to drain back into the blood circulation from the eye. May be blocked in glaucoma.

**Choroid**
A very vascular layer between the sclera and retina which serves to nourish the outer portions of the retina. Has one of the highest blood flows in the body.

**Ciliary Body**
A structure located behind the iris (rarely visible) which produces aqueous fluid that fills the front part of the eye and thus maintains the eye pressure. It also allows focusing of the lens.

**Conjunctiva**
A thin lining over the sclera, or white part of the eye. This also lines the inside of the eyelids. Cell in the conjunctiva produce mucous, which helps to lubricate the eye.
Cornea
The clear window through which we see. Actually, this is a very vital part of the eye's focusing, and the curvature of the cornea itself accomplishes about 80% of the focusing of the eye.

Iris
This is the part of the eye which gives it color. It contains muscles which open or close the pupil in response to the brightness of surrounding light. A blue iris actually has a lack of pigment.

Lens
This is located just behind the iris, and helps to focus light. A "capsule" surrounds the lens "nucleus". The nucleus can become cloudy, and this is termed cataract.

Macula
The part of the retina which is most sensitive, and is responsible for the central (or reading) vision. It is located near the optic nerve directly at the back of the eye (on the inside). This area is also responsible for color vision.

Optic Nerve
This contains visual information from the eye, and has about 1.2 million nerve fibers. The optic disc is visible on the inside of the eye, where the nerve is viewed "end on". The sheath around the optic nerve is continuous with that of the brain, and the nerve connects directly into the brain.

Pupil
Essentially, a hole in the iris. This is the black opening in the center of the eye. Its size is controlled by the iris muscles.

Retina
This thin layer lines the inside of the eye and receives light rays, processes them, and sends signals to the brain via the optic nerve. The retina is like the "film of a camera". It is separated from the very vascular choroid by the "retinal pigment epithelium". Sometimes breakdowns in this pigmented layer allow macular degeneration.

Sclera
The white, tough wall of the eye. Few diseases affect this layer. It is covered by the episclera and conjunctiva, and eye muscles are connected to this.

Vitreous
A jelly-like, clear fluid which fills most of the eye (from the lens back). This tends to liquefy with age, and its separation from the retina can lead to retinal tears and detachment.

Information compliments of: Eye Health and Disease

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Elaborate:  Stroop Test
Students will demonstrate the use of color in testing for mental alertness.

Materials:
(per team of two students)

- 1 sheet of color words
- Data Table
- Stop watch or watch with a second hand

Procedure:

1. Have students work in teams to complete the activity as described on the Student Sheet.
2. Once they gather the required data, they should answer the questions.
3. Discuss as a class their observations. Ask students to generate questions they might have about this phenomenon and have them research the topic to find answers.
4. Refer to background information as needed to answer student questions.

Teacher Background Information:

John Stroop first explained the observations of this experiment in his Ph.D. thesis published in 1935. He recognized that reading words took less effort than naming the color of ink used to print the words.

Scientists theorize that choosing a correct response between two conflicting observations is controlled by the anterior cingulate, a part of the brain located between the right and left halves of the frontal part of the brain. This region of the brain serves in connecting thoughts between regions of the brain that are driven by impulse and parts that are driven by reason.

http://www.pbs.org/wgbh/nova/everest/exposure/stroopdesc.html

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Current theories recognize the interference that occurs when given two tasks that conflict because they result from different stimuli.

1. **Speed of Processing Theory**: the interference occurs because words are read faster than colors are named.

2. **Selective Attention Theory**: the interference occurs because naming colors requires more attention than reading words.
STROOP TEST

STUDENT SHEET

Materials:
(Work in teams of 2 per group)
  • Stroop Color Card
  • Data Table
  • Stop watch or watch with a second hand

Procedure:

1. Take turns reading the entire list of color words while the other person records in the Data Table the time required in seconds. First, say the actual words and find the time in seconds. Each student should repeat the activity to read a total of three times and then switch roles with the second student.

2. Next, say the colors of the words and record the time in seconds. Repeat this activity so each student reads the card three times and then switches roles with a second student.

3. Answer the questions below.

Questions:

1. With repeated tries, do you read faster, slower, or the same for the words?

   for the colors?

2. Does what you are reading make a difference? Explain your answer.

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3. Observe the card again. Is your first response to read the words or say their colors?

   If your first response is to read the words rather than read the colors, you have experienced “interference.” Your brain has to make a choice between the actual color and its meaning. Through training and experience, you have learned that meaning is more important than the color of the ink, and if your brain gets different messages from two different stimuli, reading the words or reading the color of ink, interference occurs when you make a choice. The Stroop Test is used by scientists to test the mental alertness of individuals when climbing Mount Everest. It is also used by some to test for Attention Deficit Disorder. Justify why this test would be selected for both of these purposes.

4. Try a computer Stroop Test at the Nova website provided.

   http://www.pbs.org/wgbh/nova/everest/exposure/strooptest.html

5. With your team member, generate your own Stroop Test using something other than color words to create interference. Check your test on another team to see if “interference” occurs. How will you know? (Reading will become more difficult with repeated tries.)

References:
http://www.pbs.org/wgbh/nova/everest/exposure/strooptest.html
http://www.pbs.org/wgbh/nova/everest/exposure/stroopdesc.html
http://faculty.washington.edu/chudler/words.html

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## Data Table: Reading the Words

<table>
<thead>
<tr>
<th></th>
<th>Time 1</th>
<th>Time 2</th>
<th>Time 3</th>
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</thead>
<tbody>
<tr>
<td>Student 1</td>
<td>sec</td>
<td>sec</td>
<td>sec</td>
</tr>
<tr>
<td>Student 2</td>
<td>sec</td>
<td>sec</td>
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</table>

## Reading the Colors

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<td>sec</td>
<td>sec</td>
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</tr>
<tr>
<td>Student 2</td>
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</table>
## Data Table: Reading the Words

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<tbody>
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<tr>
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<td>sec</td>
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<td>sec</td>
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</table>

## Data Table: Reading the Colors

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<tr>
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</tr>
</tbody>
</table>

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Elaborate: HOW PERIPHERAL IS YOUR VISION?

Students will determine at what angle they observe various colors using peripheral vision.

**Materials:**
(per team of two students)

- Colored markers

**Procedure:**

1. Have your partner select a colored marker and stand at your right side, a few steps away. You are not to see the color of the marker.

2. Using the diagram of the protractor, assume your position is at the center of the protractor. Your partner should stand in line with the 0 degree line on the right.

3. Focus your eyes straight ahead on an object across the room. Try to keep from looking at this object all during the activity. While looking straight ahead, tell the color of the marker.

4. Your partner will move the marker around you in an arc. Tell the color of the marker at several intervals until the marker is actually in front of your eyes.

5. Repeat this activity with several colors. For each color, find the angle where you recognize the color.

6. Repeat this activity with several colors. For each color, find the angle where you recognize the color.

7. What general conclusion can you make about seeing color?

8. Cones are the cells on the retina that see color and rods are the cells that see black and white. Based on your observations, what pattern of cell placement would you expect to find on the retina?
ELABORATE: COLOR VISION

Materials:

- Cards for Ishihara Color Blindness Test

Advance Preparation:


Enlarge the images that show numbers within dots and cut them into cards.

Procedure:

1. Allow students to observe cards to identify the numbers that they observe. The Ishihara Test includes an answer key for comparison.

2. Discuss the different types of color blindness. (X-linked for red/green and Chromosome7 for blue). Refer to the Howard Hughes Medical Institute article on color blindness. [http://www.hhmi.org/senses/b130.html](http://www.hhmi.org/senses/b130.html)
Evaluate: Afterimages
Students will apply information on afterimages to construct pictures.

Materials:
- Colored paper for making pictures
  (black, white, magenta, cyan, and yellow)
- Scissors
- Glue sticks

Procedure:
1. Have students complete the “Afterimage Colors Chart” to determine the colors they will observe in afterimages.

2. Assign students the task of making a picture, using the colors of paper provided, with simple designs that will contain at least two of the colors listed below in an afterimage:

   red, green, blue, black, white

3. Their job is to create a picture that will give the correct colors in an afterimage. The pictures should also contain a small black dot towards the center of the image. Students will focus on this dot when they stare at the picture so their eyes will not roam.

4. Have students place the finished images on a white wall or next to a white sheet of paper the same size as their pictures to provide an area for seeing the afterimage.

5. Allow students to test for correct color patterns by staring at one another’s pictures for one minute. They will immediately look at the white background next to the picture until they see the afterimage.

6. Use the rubric provided to assess student understanding.
# AFTERIMAGE RUBRIC

<table>
<thead>
<tr>
<th>Description</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>The &quot;Afterimage Colors Chart&quot; is completed accurately</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>The student picture covers at least 75 percent of the page and clearly shows an image that the majority of students will recognize</td>
<td></td>
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<tr>
<td>The afterimage correctly applies two or more of the following color combinations: red, green, blue, black, white (example: teacher example of a red apple with a green stem)</td>
<td></td>
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<td></td>
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<tr>
<td>The student demonstrates creativity and originality in design</td>
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</tr>
<tr>
<td>The student picture is neat in appearance (glue is not visible and images are cut neatly)</td>
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</tbody>
</table>

**TOTAL POINTS** ____________

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**AFTERIMAGE COLORS CHART**

What color will you see in the afterimage if you stare at the colors given? Write your answers in the chart below. Black and white are included, but remember that they are not actually colors. White is the reflection of all colors and black is the absorption of all colors.

<table>
<thead>
<tr>
<th>\begin{rotate}{90}stare at this color\end{rotate}</th>
<th>afterimage</th>
</tr>
</thead>
<tbody>
<tr>
<td>magenta</td>
<td></td>
</tr>
<tr>
<td>cyan</td>
<td></td>
</tr>
<tr>
<td>yellow</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>white</td>
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</tbody>
</table>
Students will apply inquiry techniques to derive concepts regarding light addition

**ENGAGE: Mixing Paint**

**Materials:**
- Student transparencies (miniatures of the teacher overheads)
- white paper

**Procedure:**
1. Have students explore with the miniature transparencies to see what they discover. (Note: They will better see the image if they place the transparencies on white paper.)
2. Discuss the colors of the transparencies and identify magenta, cyan and yellow as the **primary colors of pigment**. Review with students that these colors were derived from mixing the **primary colors of light**, red, blue and green.
EXPLORE: CHROMATOGRAPHY

Activity Summary:
Students will learn the principles of chromatography by separating the components of black ink. Before performing this lab, students should be familiar with the concepts of polar and non-polar molecules.

Introduction:
Chromatography is a method for analyzing complex mixtures (such as ink) by separating them into the chemicals from which they are made. Because molecules in ink and other mixtures have different characteristics (such as size and solubility), they travel at different speeds when pulled along a piece of paper by a solvent (in this case, water). For example, black ink contains several colors. When the water flows through a word written in black, the molecules of each one of the colors behave differently, resulting in a “rainbow” effect. Many common inks are water-soluble and spread apart into the component dyes using water as a solvent.

Lab Activity

Time required:
- 5 minutes teacher preparation
- 30 minutes lab time

Materials needed for each lab group:
- 1 Large filter paper disc and ½ large filter paper disc
- Scissors
- Pencil for punching a whole through the center of the filter disc
- Small paper cup or Petri dish
- Black water-based marker
- Isopropyl alcohol: water 1:1 ration

Procedure:
1. Use your pencil to poke a small hole into each of the large filter paper discs.
2. Close to the edge of the whole, have each person in the group evenly space a small dot using a water-based marker.
3. Loosely roll the ½ filter paper disc to make a wick. Insert it through the whole of the circle.
4. Add isopropyl alcohol: water to the small cup at a depth of 2 centimeters.

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5. Place the paper disc on the cup with the wick down in the alcohol.

6. Wait about 20 minutes as the wick draws water from the cup and into the filter paper. Record the colors that were produced from each ink spot, beginning with the ones closest to the center and ending with the ones that traveled farthest from the center.

7. Write your group’s name on each filter paper, and set aside to let dry. You will then staple these filter papers to your lab questions.

8. Answer these questions:
   - Identify the mobile phase and the stationary phase. Is the mobile phase polar or nonpolar? Which molecules will be carried by the mobile phase: nonpolar or polar species?
   - Which pigment travels farthest on the paper? Why? Answer in terms of solubility of the ink in the water.
   - Some pens are “permanent” ink; if they were used in this experiment, they would not travel across the paper. Why? What solvent could be used as the mobile phase in order to separate the components of permanent ink?

Students are expected to make the following observations:

   - marks made from the same pen always produce the same separation pattern, i.e., the different colors are in the same order after the separation. The size of the original dot on the paper has no effect on the separation pattern, although the separation is better defined if the dot is smaller.
   - different brands of pen produce different separation patterns.

Reinforcements:

   - Students should be shown that different pens from the same batch (same brand and same model) produce the same separation pattern.

   - The separation patterns produced by different brands of pen are governed by several factors:
     1. The composition of the ink. Different companies use different dyes to make their ink. Some are doing it to produce special physical or visual effects; some are doing it so they cannot be accused of copying other people’s product.
     2. The solubility of each component dye in the carrying liquid. If the dye is not soluble in the carrying liquid, it cannot be carried up the paper, i.e., if the dye is nonpolar, it will not dissolve in the polar water (use the “water and oil don’t mix” analogy). This is the case if a permanent ink pen is used with water as the carrying liquid. Since the permanent ink is not soluble in water (hence the term, "permanent"), the mark stays in the
starting place. Since most permanent inks are soluble somewhat in organic solvents, one can get it to produce a pattern using rubbing alcohol as the carrying liquid. Typically, the most soluble dye will move up the paper the most and the least soluble dye will move up the least. If a dye is very soluble in the carrying liquid, it will follow the top of the water level up the paper closely.

3. **The extent to which the ink clings to the paper.** A dye that is strongly attached to the paper will not move up the paper much.

4. **The length of the paper.** The separation of the different dyes along the paper increases if the carrying liquid is allowed to carry the ink up a longer distance. At the beginning of the experiment, the colors are still bundled together. As the carrying liquid moves across the paper, the separation becomes more and more complete. Note, however, that the order of the colors does not change with the distance traveled.

Reference: North Mississippi GK-12 Project Project #132
EXPLAIN: LIGHT SUBTRACTION

Materials:

• Color filters  (magenta, cyan, yellow)
• Overhead transparencies (separate images of magenta, cyan, yellow and black for picture)
• Student transparencies (miniatures of the teacher overheads)
• white paper

Procedure:

1. Place the magenta filter on the overhead. Have students place their magenta image on a sheet of white paper. Discuss that we see colors because light is reflected back to the eye. Refer back to the light addition activity and ask students to name the primary colors that make magenta (red and blue). Discuss that we see these two colors because they are reflected back to the eye.

3. Have students predict what they will observe when they place the yellow transparency on top of the magenta transparency.

\[ \text{Predict: yellow} + \text{magenta} = \text{________} \]

4. Have students add yellow on top of the magenta. On the overhead, add the yellow filter to the magenta to make red.

\[ \text{Result: red} \]

5. Show the yellow filter individually and ask students what primary colors of light are reflected back to the eye (red and green).

6. Discuss that the transparencies act as filters, and they only allow the colors that are observed to be reflected. When magenta and yellow are combined, they will only allow the color of light they have in common to be reflected back to the eye. The other wavelengths will be absorbed by the pigment.
7. Ask students why yellow and magenta result in red (the only wavelength they have in common is reflected back to the eye). Explain that paint works in the same way. When we combine colors, we subtract the number of colors that can be reflected because pigment will absorb some of the wavelengths. Mixing paint and combining filters results in light subtraction. To demonstrate light subtraction, the light source must be the same (example: overhead). In light addition, the light sources must be different.

8. Have students continue with predictions for mixing the remaining colors of pigment:

\[ \text{Predict: cyan} + \text{magenta} = \quad \quad \text{Result: blue} \]

\[ \text{Predict: cyan} + \text{yellow} = \quad \quad \text{Result: green} \]

\[ \text{Predict: cyan} + \text{yellow} + \text{magenta} = \quad \quad \text{Result: black} \]

9. Tell students, “Black is the absence of color.” Have students justify this statement from the mixing of filters.

10. Look at the combination of transparencies that together make a variety of colors. Discuss why the transparencies together make all of the colors. (They allow areas with magenta, cyan, yellow, red, blue, green, and combinations of varying amounts of these colors combined. The black alters the hues of the colors.)
ELABORATE: FINDING PRIMARY COLORS OF PIGMENT

Students will observe everyday objects to find primary colors.

Materials:

- Color comics
- Magnifying glass
- Various items that show magenta, cyan and yellow
- Food packages that show the color code on the label (cereal and cracker boxes)

Procedure:

1. Have students look at color comics using a magnifying glass to determine the colors of the inks.

2. Show various items that have primary colors and look at the labels on packages to find the codes that establish the colors.
EVALUATION: CONCEPT MAP

Students will demonstrate an understanding of concepts regarding color by producing a concept map.

**Materials:**
(per team of 3-4 students)
- Butcher paper (2’x3’)
- Colored markers
- Paper (3” x 5”) or index cards for words
- Tape

**Procedure:**

1. Have students work in teams to develop a concept map. They should write each word on a small sheet of paper or an index card.
2. Students should then decide on a main word. They can add words if necessary to create their map.
3. Using the guidelines below for concept mapping, have students design a map that includes all of the assigned terms, words they choose to add, propositions and crosslinks. The map should show hierarchy by moving from the most general to the most specific terms.

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Create a concept map, showing four crosslinks, that includes the following terms:

<table>
<thead>
<tr>
<th>light</th>
<th>paint</th>
<th>white</th>
<th>black</th>
<th>cyan</th>
<th>magenta</th>
</tr>
</thead>
<tbody>
<tr>
<td>yellow</td>
<td>addition</td>
<td>red</td>
<td>green</td>
<td>blue</td>
<td>subtraction</td>
</tr>
</tbody>
</table>

**Guidelines for Building a Concept Map**

The steps for building a concept map are as follows:

**Step 1:** Select an item for mapping. This may be a short section of a textbook, directions or results from a laboratory activity, a vocabulary list, or a list of words produced by brainstorming. A single, general concept such as water, sound, force, or magnetism is the starting point.

**Step 2:** Identify the major concepts (objects, events) branch from the general concept. (Each of the concepts can be copied onto a separate small card for easy rearrangement).

**Step 3:** List or rank the concepts from the most inclusive (most general) to the least inclusive (most specific). For example:

```
pizza
sauce
toppings
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Step 4: Arrange the most general concept at the top of the map. Link it to the concepts that are less inclusive. Circle all concepts. (Concepts written on cards can be used in place of circled concepts.) Connect the concepts with arrows showing the direction in which the map is read. Label the arrows with linking words that explain how each pair of concepts is related. These words should bring the concepts together to form a propositional linkage. Overall, the map is read from top to bottom, and it moves from general to specific.

Step 5: Try to branch out as concepts are added by adding additional concepts to the existing terms.

Step 6: Make cross-links between two concepts. Label all cross-links with words that explain how the concepts are related. Represent the cross-links with broken lines or a different color. An arrow can be used to show the direction of the relationship.

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