Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2013 Volume III: Sustainability: Means or Ends?

Light, Vision, Art

Curriculum Unit 13.03.01
by Carol Boynton

Introduction

Science and art are ideal subjects for young students. Their innate curiosity encourages them to ask questions, look for answers, try new methods and look at things in a new way. The strategy of inquiry comes very naturally to them as they begin to navigate the physical world and learn what it has to tell them. As a teacher of primary-level students, I find it this happening in their daily life, while they are sitting right at their desks – How many ways can I balance a pencil? What happens if I tip this milk carton almost over, will anything spill? What happens when I mix colors together with crayons or watercolors or paint? Why do my glasses make that circle of light on the ceiling?

Simple, but interesting, daily experiments, designs, and curiosities are continuous in a classroom. And why not – they are fun and informative! In this six-week curriculum unit, science students in second grade will experiment with light and how we, as humans, see objects and color. Through a variety of hands-on activities and experiments, the students will learn the fundamentals of the physics of light, the biology of vision, and art as an intersection of the two.

Rationale

Edgewood School is an arts-integrated magnet school with a focus on visual literacy as a school-wide initiative. This approach to visual learning inherently allows, supports and encourages cross-curricular teaching and embraces all types of learners. Our students are provided opportunities throughout the year to visit the many Yale University art museums, which offer rich experiences that build fundamental skills. Our neighborhood/magnet school setting is a rewarding environment, with students coming to school each day from a variety of home circumstances and with differences in academic levels. As a result of these variables, the children have differing levels of background knowledge and life experiences. Teaching through the arts opens the doors and minds to learning opportunities.

There are three main concepts that I want my second grade students to explore throughout this unit: I want them to understand that seeing (or vision) is a process that requires light; I want them to understand how the basic vision process works; and I want them to understand how artists (like themselves) use light and vision in conjunction with each other to create their work. There will be three main areas of focus. The students will experiment with reflection, refraction, and diffusion; they will create a basic model of the exterior and interior of the human eye; and they will work with the interaction of light and vision to create and analyze art.

Concepts/Content

This curriculum unit integrates science and art, specifically connecting the physics of light and visual understanding. In her book *Vision and Art: The Biology of Seeing,* Harvard neurobiologist Margaret Livingstone explores and explains the inner workings of vision. Her research and work demonstrates how we see art ultimately depends on the cells in our eyes and our brains. Using Livingstone's book as a foundation and springboard, this unit covers the fundamentals of light, the biology of vision, and the connection between the two. How do our eyes and brains coordinate to perceive line and color? How do elements like perspective, luminance, color mixing and shading produce certain effects in art work?

Science and art naturally overlap. Both are a means of investigation. They both involve testing ideas, theories, and hypotheses as mind and hand come together, whether in the laboratory or the studio. Artists, like scientists, study materials, people, culture, history, and religion and learn to transform information into something else. In ancient Greece, the word for art was techne, from which technique and technology are derived—terms that are applied to both scientific and artistic practices.

The Fundamentals of Light

Light is both obvious and mysterious. We are covered in yellow warmth every day and dismiss the darkness with incandescent and fluorescentbulbs. But what exactly is light? We catch glimpses of its nature when a sunbeam angles through a dust-filled room, when a rainbow appears after astormor when a drinking straw in a glass of water looks disjointed. These glimpses, however, only lead to more questions. Does light travel as a wave, a ray or a stream of particles? Is it a single color or many colors mixed together? And what are some of the common properties of light, such as absorption, reflection, refraction and diffraction?

Over the centuries, our understanding of light has changed. Some of the earliest scientists and philosophers considered the true nature of this mysterious substance that stimulates sight and makes things visible. The first real theories about light came from the ancient Greeks. Many of these theories described light as aray-- a straight line moving from one point to another. Pythagoras, best known for the theorem of the right-angled triangle, proposed that vision resulted from light rays emerging from a person's eye and striking an object. Epicurus argued the opposite: Objects produce light rays, which then travel to the eye. Other Greek philosophers, most notably Euclid and Ptolemy, used ray diagrams quite successfully to show how light bounces off a smooth surface or bends as it passes from one transparent medium to another.

Around AD 1000, Arab physicist Alhazen concluded from his experimental observations that light actually travels into the eye. He observed that "the eye, when looking at a very strong light, feels pain and may be damaged." He also observed that the eye registers an afterimage after looking at a bright light. In 1604, Johannes Kepler introduced the idea that light is emitted by sources like the sun and is the reflected from object into the eye.

By the 17th century, some prominent European scientists began to think differently about light. One key figure was the Dutch mathematician-astronomer Christiaan Huygens. In 1690, Huygens published his "Treatise on Light," in which he described theundulatory theory. In this theory, he speculated on the existence of some invisible medium -- an ether -- filling all empty space between objects. He further speculated that light forms when a luminous body causes a series of waves or vibrations in this ether. Those waves then advance forward until they encounter an object. If that object is an eye, the waves stimulate vision.

Although this stood as one of the earliest wave theories of light, not everyone embraced it, including Isaac Newton. In 1704, Newton proposed a different idea in his great work *Opticks* , describing light as corpuscles, or particles and proposed that the different colors of light have different masses. Because of Newton's stature in the world of science, his findings stood for a hundred years until, in 1801, Thomas Young, an English physician and physicist, designed and ran one of the most famous experiments in the history of science. It's known today as thedouble-slit experimentand requires simple equipment -- a light source, a thin card with two holes cut side by side and a screen.

To run the experiment, Young allowed a beam of light to pass through a pinhole and strike the card. If light contained particles or simple straight-line rays, he reasoned, light not blocked by the opaque card would pass through the slits and travel in a straight line to the screen, where it would form two bright spots. This isn't what Young observed. Instead, he saw a bar code pattern of alternating light and dark bands on the screen. To explain this unexpected pattern, he imagined light traveling through space like a water wave, with crests and troughs. Thinking this way, he concluded that light waves traveled through each of the slits, creating two separate wave fronts. As these wave fronts arrived at the screen, they interfered with each other. Bright bands formed where two wave crests overlapped and added together. Dark bands formed where crests and troughs lined up and canceled each other out completely. Young's work sparked a new way of thinking about light.

In the 1860s, Scottish physicist James Clerk Maxwell formulated the theory ofelectromagnetism. Maxwell described light as a very special kind of wave -- one composed of electric andmagneticfields. The fields vibrate at right angles to the direction of movement of the wave, and at right angles to each other. Because light has both electric and magnetic fields, it's also referred to aselectromagnetic radiation. Electromagnetic radiation doesn't need a medium to travel through, and, when it's traveling in a vacuum, moves at 186,000 miles per second (300,000 kilometers per second).

In 1905, Albert Einstein suggested that the wave theory of light might be incomplete, and that light has some characteristics of particles. He studied thephotoelectric effect. First, he began by shiningultraviolet lighton the surface of a metal. When he did this, he was able to detect electrons being emitted from the surface. This was Einstein's explanation: If the energy in light comes in bundles, then one can think of light as containing tiny lumps, orphotons. When these photons strike a metal surface, they act like billiard balls, transferring their energy to electrons, which become dislodged from their "parent" atoms. Once freed, the electrons move along the metal or get ejected from the surface. The particle theory of light had returned. The quantum theory of light -- the idea that light exists as tiny packets, or particles, called photons -- slowly began to emerge.

Today, physicists accept the dual nature of light. In this modern view, they define light as a collection of one or more photons propagating through space as electromagnetic waves. Photons make it possible for us to see the world around us. In total darkness, our eyes are actually able to sense single photons, but generally what we see in our daily lives comes to us in the form of billions of photons produced by light sources and reflected off objects. If you look around you right now, there is probably a light source in the room producing photons, and objects in the room that reflect those photons. Your eyes absorb some of the photons flowing through the room, and that's how you see.

Light and Color

Imagining light as a ray makes it easy to describe three well-known phenomena: reflection, refraction and scattering. Inreflection, a light ray strikes a smooth surface, such as amirror, and bounces off. A reflected ray always comes off the surface of a material at an angle equal to the angle at which the incoming ray hit the surface. In physics, this is called thelaw of reflection in which "the angle of incidence equals the angle of reflection."

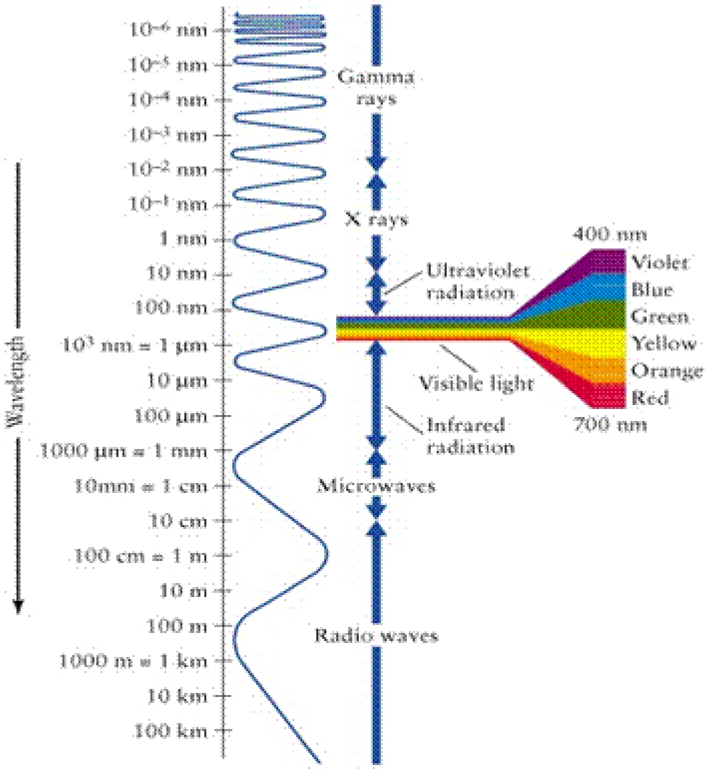
Refraction is the bending of light as it encounters a medium different than the medium through which it has been traveling. This meeting place of two different media is called the interface between the media. All refraction of light (and reflection) occurs at the interface. This is the phenomenon that occurs when it looks like the straw in the glass in bending.

Of course, we live in an imperfect world and not all surfaces are smooth. When light strikes a rough surface, incoming light rays reflect at all sorts of angles because the surface is uneven. The surface of paper is a good example. The actual roughness of the paper becomes visible when viewed under a microscope. When light hits paper, the waves are reflected in all directions. This is what makes paper so incredibly useful -- you can read the words on a printed page regardless of the angle at which your eyes view the surface.

When light falls on an object, some is absorbed. The light that is not absorbed is reflected off the object's surface; this is the light we see. For an object to appear colored, it must absorb some part of the visible spectrum and reflect the rest. It was Isaac Newton who discovered that objects appear colored because of the character of the light they reflect.

To understand color, it is first necessary to be more specific about light. Light is usually defined as that portion of the electromagnetic spectrum visible to the average human eye. It is commonly called "visible light" and subdivided into seven major colors—red, orange, yellow, green, blue, indigo, and violet. Visible light lies on the electromagnetic spectrum in between infrared and ultraviolet light. This "visible light" corresponds to a wavelength range of 400 - 700 nanometers (nm) and covers a color range of violet through red. The human eye is not capable of "seeing" radiation with wavelengths outside the visible spectrum. Ultraviolet radiation has a shorter wavelength than the visible violet light; infrared radiation has a longer wavelength than visible red light. The white light is a mixture of the colors of the visible spectrum and conversely, black is a total absence of light.

Color can be defined both in objective terms, as the specific electromagnetic frequencies in the visible-light range, and in subjective terms, as something perceived and experienced by an individual. The objective components of color are: a source of radiant energy, like the sun or a light bulb; a medium through which that energy travels, such as air; and an object, such as an apple, that absorbs and reflects different portions of the light spectrum. The subjective components of color are: the apparatus that responds to the



reflected light (the cones and rods in the retina of the eye) and the brain that interprets the information received as color and generates sensations in response to that information. The optic nerve carries visual information from the cones and rods to the visual cortex of the brain, where the experience of color is made conscious and human emotions, associations, and memory are generated, a connection to the artistic response. The next section will deal more directly with the biology of visual processing.

When considering light and color together, it is important to discuss additive and subtractive mixing . This phenomena crosses the scientific and artistic fields in somewhat similar ways. Young students learn to identify primary colors in art class and experiment with mixing paints and creating new colors. Primary colors are defined as a set of three colors that, when mixed in various combinations, can produce every color in the spectrum. Scientists work with two sets of primary colors - red, green and blue when dealing with light (also known as additive primaries), and magenta cyan, and yellow when dealing with pigments (also known as subtractive primaries). Artists use only one set of primary colors - red, blue, and yellow. In all cases, all the possible colors of the visible spectrum can be obtained by mixing these primaries in different combinations and proportions.

When working with light, the scientist may use a process of combination called additive mixing, which can be demonstrated by projecting colored light in the three additive primaries onto a white screen. When green light is projected over red light on a white screen, the viewer will actually see yellow since the combination of red and green light is perceived as yellow. The combination of red and blue light is magenta, and the combination of green and blue light is cyan.

The Biology of Vision

Vision allows us to make sense of our world and to acquire knowledge about what is around us. It is commonly thought that the eye is like a camera, sending a high-resolution image of the visual world to the brain. In fact, what actually happens is that light enters the opening in the front of the eye, the pupil, and the lens focuses the image on the retina which is a sheet of layers of neural tissue on the back of the eyeball. These layers are comprised of ganglion, bipolar, and horizontal cells. The photoreceptor cells are, which follow in this layering, are the cells that respond directly to light. They contain light-absorbing chemicals, pigments that generate a neural signal when they absorb light. The light activates the rod and cone photoreceptors, which then convert the light into an electrical signal that is sent to the brain via retinal neurons.

When light passes into the photoreceptor layer, some of it is absorbed by the photoreceptor and any leftover light is absorbed by a layer of pigment cells at the back of the eye. This pigment connects directly to the fact that we are diurnal animals, active when there is plenty of light. Our eyes are designed for acuity rather than for light sensitivity.

We have two kinds of photoreceptors, rods and cones, which generate signals in response to light. Rods and cones are not distributed evenly across the retina – the cone density is higher at the center of the gaze than in the periphery, where the rods do the work.

We have three different types of cones, each kind containing a different kind of pigment and each responding best over a different range of visible wavelengths, long-, middle-, and short-wavelength cones. They are sometimes called red, green, and blue cones. These three cone types allow us the benefit of color discrimination – being better able to distinguish differences between light reflected off various surfaces.

It is helpful to think of visual processing in terms of two systems, the what system and the where system. Each are different in the ways in which they process light signals. The where system is the more primitive of the two visual systems. It deals with information about depth, spatial organization, position, figure/ground and motion. In other words, it deals with all of the aspects that a human would need to navigate his or her environment. Most animals have only the where system although there are a few animals that have both, such as certain squirrels and primates. Humans, as well as most mammals, navigate their environment using this system. The what system uses both color and luminance to define the shape of objects and the color of surfaces.

There are four fundamental ways in which these systems process light signals: color selectivity, contrast sensitivity, speed and acuity (resolution). The "where" system is colorblind, has a high sensitivity to differences in brightness (contrast), is fast and transient, and has a slightly lower acuity than the "what" system. The "what" system uses and carries information about color, requires larger differences in brightness, is slower and higher in sharpness (acuity) than the where system.

Throughout this unit, students will be engaged in a variety of experiments with light. We are fortunate to be in a school with many windows, which I see as an avenue of research that will include shadows, darker or brighter days, color through prisms and acetate panel. How does light appear on different materials and does the nature of the material matter? What are the physical behaviors of the light throughout our school day in our classroom? Documentation and measurement will help students track their findings. Students will learn about the eye itself and create models that show their learning. With some background knowledge now of light and vision, students will, in the classroom and on our travels to the museum, begin to apply their knowledge as they analyze what they see.

Teaching Strategies

The approaches for this curriculum unit will vary to reflect the learning styles of all students. Included will be:

Experiential Learning: The major strategy for this unit is to engage the students in hands-on learning. I want them to be actively participating as scientists, not observing a demonstration by the teacher or looking at examples in books. The activities will be designed to be exploratory for the students so they are engaged in the enjoyment of the process as well as the product. A wide range and variety of "light producers" and art materials will be included in the exploration and design.

Differentiated Instruction: Lessons and activities will be targeted to maximize learning. The students will use a variety of approaches, working sometimes individually and sometimes in small groups, determined by the complexity of the activity. With the varying levels and background, guidance and pacing will need to be closely monitored.

Cooperative Learning: The students will be given opportunities to work as cooperative groups to complete assignments and activities. This strategy will allow students to work collaboratively taking on various roles necessary to complete the work, with a focus on success for all. In groups of six, the students will demonstrate comprehension as they present to the class their culminating project of light sources examples.

Classroom Activities

Physics of Light Activities

Before conducting any of the following experiments with the students, be sure to run some practices to ensure that the lighting in the room works to achieve the desired outcome.

Students will consider and discuss the following questions: What is light? What happens The students will any responses on chart paper or the board to refer back to as the unit progresses.

Share with the students that scientists who study light admit that they don't know everything there is to know about light. But whatever light is, we're very lucky that it exists: **light is what enables the human eye to see.**

Scientists do know how light reacts under certain conditions. Three reactions of light are demonstrated in the following science experiments. These experiments can be done in one session or over a couple of lesson times. Space and distribution of materials can be challenging. These experiments should be conducted with groups of 3-4, with each student having the opportunity to perform the activity. Preparing 4-6 sets of materials is helpful making setup, cleanup and transition easier.

Experiment #1: Light Reflection – Make a Disappearing Penny Reappear

Items needed: pennies, bowls, water

> Place a penny in the center of a small opaque (you can't see through it) shallow bowl.
> Set the bowl on a table in the classroom
> Group members take turns keeping an eye on the penny as they slowly backs away from the bowl.
> Tell your friend to stop as soon as the edge of the bowl just blocks his view of the penny.
> Now tell him you will magically make the penny reappear.
> Slowly fill the bowl with water without disturbing the penny.
> Does your friend see the penny come back into view?

Observation: After a sufficient amount of water is added to the bowl, your friend says he can see the penny.

Explanation: As water fills the bowl, the reflection of the penny bends around the bowl to the surface of the water, making your friend think that he can see the penny again.

Experiment #2: Light Refraction – Make a Simple Magnifying Glass

Items needed: jars or drinking glasses, cereal boxes

> Place a clear round jar or drinking glass close to the ingredients list on a cereal box. (This choice of reading material might inspire the students to practice this at home.)
> Look through the jar at the printing.
> Are the words easy to read?
> Now fill the jar with water and place it close to the ingredients list again.
> Are the words easier to read?

Observation: When the jar contains water, the printing on the cereal box appears much larger.

Explanation: As light enters the curved jar, its course is altered or bent by the water. This bending, or refraction of the light, results in your homemade magnifying glass.

Light Diffusion – Make a Simple Light Projector

Items needed: construction paper in five colors, five round items to use as patterns, pencil, scissors, glue stick, shoeboxes with lids, ruler, one flashlight per group

Teacher preparation:

Measure, draw and cut a one-inch square in the center of each small end of each shoebox. This would be a good project for a volunteering parent to help with.

Student Preparation:

Students in their groups will cut five circles from different colors of construction paper in the following diameters: 3 inch, 5 inch, 7 inch, 9 inch, 11 inch. Provide round items or templates for patterns. The students will glue the circles in a target format with the 3-inch circle onto 5-inch circle, the 5-inch onto the 7-inch, the 7-inch onto the 9-inch, and the 9-inch to the 11-inch.

Place the lid on the shoebox.

Experiment:

Dim the lights in the classroom where the experiments will take place.

One group member holds the construction-paper target up

Another group member holds the shoebox about one foot away from the target.

A third group member shines the flashlight through the holes in the shoebox so the light falls directly on the center of the target.

Gradually move the target away from the shoebox.

What happens to the light as the target is moved?

Observation: As the light source becomes farther away from the target, the light spreads over more of the target's surface and its brightness becomes dimmer.

Explanation: The beam of light is strongest and brightest inside the shoebox. Once it passes out of the box, the light begins to spread out in straight lines to fill the larger area. Some of the light rays reflect or bounce off the paper target and scatter around the room. This scattering of light is called diffusion.

Follow Up:

Read *The Magic School Bus Gets a Bright Idea: A Book About Light* to the class. In this story, Ms. Frizzle's class thinks the PTA light show is pretty wild, but really surprising things happen when the show is over. Ms. Frizzle and the Magic School Bus arrive just in time to help solve the mystery and teach about the properties of light. She starts the story explaining to the students that "there is no sight without light." This is a helpful transition text for students to begin learning about the biology of the eye.

Biology of the Eye Activities

Activity #1: *The Eyes Have It: The Secrets of Eyes and Seeing*

Students will listen to the read-aloud and generate a word bank in their science journals as well as on chart paper or bulletin board area. The introductory text blends photos and cartoon-style art to explain the fun facts and serious science about the human eyes as well as the visual systems of other creatures.

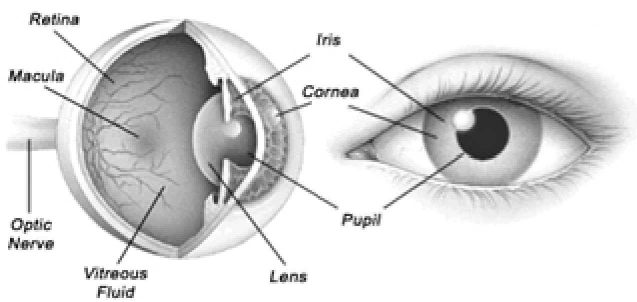
Activity #2: Students will use the glasses cardboard template (similar in size to 3-D glasses) to identify parts of the human eye.

Items Needed: cardboard templates of glasses, colored pencils, science journals

Procedures:

Using colored pencils, students will draw and label the parts of the eye on the front (lens) part of the glasses, including iris, pupil, sclera, upper lid, lower lid.

Students will then label the sides of the cardboard glasses with the internal parts of the eye, including retina, macula, vitreous fluid and optic nerve. An enrichment component could include identifying the rods and cones in a cross-section of the retina.



Art Connection Activity

Activity: Color vs. Black and White

Luminance is measured light reflecting off a surface. Brightness is perceived luminance, therefore luminance is objective and brightness is subjective. This activity will help to demonstrate the difference between the two.

Items needed: images on pages 112-137 in *Vision and Art: The Biology of Seeing* or several prints of paintings, black and white copies of the same paintings, crayons, markers, chart paper for vocabulary

Vocabulary to introduce: three dimensional, shading, luminance, depth

As a exploratory activity, students will create colorful illustrations using crayons or markers. Once the pictures are done, photocopy them in black and white. Students will make comparisons about the two versions of their work.

After creating their own images, students will be introduced to a variety of colorful paintings and/or prints. Class-wide discussion of colors and objects in each print will help the students "read" the painting and discover information about it - what do you notice, where do your eyes go, what might be happening are all prompts for conversation and vocabulary. After viewing the images, students will see the same image in black and white and discuss the questions and prompts. What used to stand out and now is less obvious? What other changes do you see?

Individual Culminating Activity

Kaleidoscope from a Potato Chip Can

Almost everyone has looked through a kaleidoscope (from a Greek phrase meaning "to view a beautiful form"), a popular toy invented by Sir David Brewster in 1816. This activity will bring the work of the eye and physics of light together in a fun, useful activity.

Making a Simple Kaleidoscope

Items needed for each student:
regular size can of Pringles Potato Chips
cardboard from a cereal box
aluminum foil
scratch paper/newspaper
tape
nail or knitting needle
clear acetate
translucent, plastic gemstones, buttons, glitter

Procedures:

1. Turn the can upside down. Use the scissors (or a large knitting needle or nail) to puncture an eyehole about 6 mm in diameter inward in the center of the metal end.

2. Decorate the outside of the can.

3. Cover 3 strips of 22 cm x 6.25 cm cardboard strips cut from the cereal boxes with aluminum foil.

4. Tape the foil-covered strips into a equilateral triangle prism. Use several pieces of tape to hold the configuration in place.

5. Fit the triangular prism into the can.

6. Cut a circle from the stiff clear acetate precisely the size of the can opening.

7. Lay the circular shape on top of the triangular prism.

8. Line the inside of the can between the acetate circle and the top rim of the can with a cardboard spacer strip, joining the ends with a small piece of tape.

9. Fill the upper compartment about half full with the acrylic gemstones or other translucent items, then put on the plastic lid.

10. Hold the kaleidoscope up to the light, look into the eyehole, and

Slowly rotate the can. The three mirrors will reflect the objects under the lid and produce the kaleidoscope effect.

Reading List

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

Marmor, Michael F. and James G. Ravin. *The Artist's Eyes: Vision and the History of Art.* New York, N.Y.: Harry N. Abrams, 2009.

Waldman, Gary. *Introduction to Light: the Physics of Light, Vision, and Color.* Mineola, N.Y.: Dover Publications, 2002.

Solso, Robert L.. *Cognition and the Visual Arts* . Cambridge, Mass.: MIT Press, 1994.

Zeki, Semir. *Inner Vision: An Exploration of Art and the Brain* . Oxford: Oxford University Press, 1999.

Websites

http://www.brainartproject.com/

Brain inspired art projects

http://neuroimages.tumblr.com/

Artistic depictions of the brain or neuroscience data

http://www.huffingtonpost.com/2012/05/23/greg-dunn_n_1534366.html

Article about neuroscientist and artist Greg Dunn

http://www.dailytelegraph.com.au/entertainment/whats-on/two-tonne-nerve-centre-ofbiennale/story-e6frexmi-1225859067810

Example of a sculpture inspired by neuroscience

http://neurobureau.projects.nitrc.org/BrainArt/Competition.html

A brain and neuroscience inspired art contest

http://thebeautifulbrain.com/

Information about the brain and the relationship between science and art

Appendix - Implementing District Standards

In accordance with the New Haven Public School District Science Standards, after completing this unit, the students will be able to:

A INQ 1: Make observations and ask questions about objects, organisms, and the environment.

Students will be involved in discussions and experiments in small groups as well as in whole class settings. They will keep a science journal that tracks their questions, hypotheses, and illustrations of their learning.

A INQ 3: Make predictions based on observed patterns.

A INQ 4: Read, write, listen, and speak about observations about the natural world.

Students will demonstrate understanding of the phenomena of light and color through classroom demonstrations and by documenting their learning in their science journals.

A INQ 5: Seek information in books, magazines, and pictures.

Students will be using images of paintings and mentor texts on light and vision to support their learning.