Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2013 Volume IV: Asking Questions in Biology: Discovery versus Knowledge

How Man's Best Friend Sheds Light on Light – An Inquiry-Based Approach to Understanding Light and Color

Curriculum Unit 13.04.07
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Introduction

Imagine a world without vivid hues of color, a world where you couldn't distinguish the red breast of a robin, or marvel at the design of the monarch butterfly's pattern. Visualize a night sky on Independence Day, where the bursts of light and color of fireworks are greeted with cries of delight from people of all ages. Picture the first time you traveled to the Caribbean Islands or some other visually beautiful ocean locale. The first sense that overwhelmed you was probably not the smell of the salty water or hearing the roar of the waves, but the sight of the clear turquoise sea that made you want to explore its depths.

Humans' sense of sight is often considered the most important sense of all. Our earliest ancestors relied on their eyesight to hunt and kill for survival. When we choose a mate, we frequently base our attraction to the opposite sex on their looks. Today's technology requires the ability to navigate the internet, and there is a recent shift in communication that relies primarily on texting and email. Without the ability to see, we would consider ourselves at a huge disadvantage.

On the other hand, not all creatures are as reliant on sight as humans. Most bat species use echolocation, where they rely heavily on their sense of hearing as they reflect screeches back to their ears to locate their prey. Manatees use the numerous tactile hairs on their bodies to navigate through the murky waters in which they live. Rattlesnakes and pit vipers use infrared vision to detect warm-blooded creatures to prey upon. Dogs and wolves interpret their world through their vivid sense of smell.

Light and color are a part of human life that is often taken for granted. If we need light, we reach for a light switch and turn in on. We don't put much thought into where color comes from. Yet, in order to learn more about color and light, we need to ask questions: Where does light come from? What makes an apple appear red? Do all creatures see the same way as each other? Asking questions is as important as the answers we seek.

The teacher is the role-model for his/her students. If he or she acts like the authority and every answer can be "looked up", the students will never raise their awareness to new heights. Instead, the teacher should encourage students to think about what we do NOT know, as opposed to what we do know, and encourage students to do the same. We are not and never will be omniscient beings, but we should present the quest for answers to the unknown as an exhilarating journey.

Rationale

I designed this unit to appeal to the population within the school where I teach fifth grade. At John S. Martinez School, a majority of students come from Spanish-speaking homes and have learned English as a second language. Consequently, students have limited language skills and learn primarily through hands-on activities and in situations where all of their senses are engaged. Most of the students will enthusiastically state that science is their favorite subject because they are allowed to examine a variety of objects and learn about high-interest topics, however, they often think of science as a time of "play" rather than exercising higher-order thinking skills. Hands-on activities are not enough to prepare students for the future. They must learn to work cooperatively to plan, research, and analyze. They need to ask questions, take risks, attempt to solve problems and accept that sometimes results will not meet their expectations. They should be encouraged to embrace the unexpected results from experiments, for those are often where we gain the most valuable information.

Objectives

The state of Connecticut is presently transitioning from the Connecticut State Science Frameworks to the Common Core Curriculum Standards, on which New Haven Public Schools (NHPS) will base its curriculum. Since 1999, NHPS has been delivering instruction through Science and Technology for Children (STC) kits. These kits are an alternative to traditional textbook-style and rote memorization of scientific concepts. They contain inquiry-based, hands-on activities that focus on various scientific concepts targeted for each grade level.

One of the STC kits presented in the fifth grade is focused on the concepts of light and color. For the past two years that I have taught these units, students greatly enjoyed the activities but there were gaps that prevented them from fully comprehending some of the concepts presented within the kit. The primary objectives of this unit are as follows:

1) To explain the function of the eye
2) To explain how the eye sees light
3) To show how color is perceived
4) To engage students and encourage higher-order thinking

I will be addressing the above-referenced objectives by comparing canine physiology to human physiology. My reason to use the dog's anatomy is based on my observations that many of my students have dogs as pets, or they know somebody who has a dog. They are eager to share stories, both orally and in writing, about dogs. Children are fully aware of the unconditional love that a dog demonstrates. Many students are not introspective or interested in observing themselves, but I hope to increase their engagement by tapping into the emotional bond between children and dogs.

All lessons and activities included in this unit are to take place after a general introduction to light and color. Important terms regarding the qualities of light, such as "transparent", "translucent", and "opaque", can be covered at any time during or after the lessons in this unit.

Implementation

Time is limited in an academic environment. Students are expected to learn core concepts within a given time frame, and teachers are expected to present lessons and differentiate them as needed for students requiring alternative approaches to learning. In fifth grade, the first science kit (on sound) is distributed approximately three to four weeks into the beginning of the school year, followed by light and color within the same quarter. The first few weeks of school are generally dedicated to establishing routines and setting up expectations, although instruction takes place immediately. Time is needed at the beginning of the year for science instruction to set up science notebooks and review the basics of the scientific method, such as how to describe the properties of a given object. I am proposing that this unit, which will provide the necessary background information for the light and color units, be introduced within one week of the start of the academic year. The activities contained in this unit will serve as the model for all aspects of the scientific method, on which all other units will be based. By starting this unit at the beginning of the year, the students will also learn how to formulate testable questions and in turn, develop clear hypotheses.

The importance of noticing and asking questions will be stressed heavily throughout this unit. After all, this is the first crucial step of the scientific process. Students will not be "fed" the knowledge; rather, they will be encouraged to discover new information on their own. In fifth grade, children are easily affected by the opinions of their peers. They are afraid that their questions will be viewed as "stupid". In conversations with my current students, I have discovered that they feel most comfortable asking questions anonymously, where they are not likely to feel judged. They suggested having a mailbox in the classroom where they can submit their questions. I like the idea of doing this for whole group discussions, especially at the beginning of the unit and in the new school year when we are still building an atmosphere of trust, but I still want the students to keep track of their own questions in their own notebooks. We will be working on identifying types of questions early in the school year to give them an idea of what constitutes a "testable question".

Science notebooks will be crucial in helping students maintain records. They will need explicit instruction in how to record important information throughout the curriculum unit, therefore, all activities contained in this unit will include the type of information that students should be recording. The notebook will contain the students' essential questions, hypotheses related to each activity, materials for each observation, and what they observed and concluded during each activity. Also, a word bank will be established since it is important for students to maintain since they will be exposed to new terminology.

Materials do not need to be elaborate to be effective. Students will be given diagrams of the rods and cones in a human eye as well as diagrams of the canine eyes. Photographs and videos of dogs performing various tasks that will illustrate how they see will also provide students with opportunities to notice and ask questions about a dog's visual acuity. Light fixtures with bulbs of red, green, and blue will be necessary to show the combination of colors that can be seen by the human eye, while only two of the colors (green and blue) will be necessary to show the mixture of colors that can be seen through the eyes of a dog. A laser pointer can be used to illustrate the properties of refraction and reflection. Finally, a simple jump rope can serve as a hands-on apparatus to demonstrate the traveling of light in "waves".

How the Eye Functions

Vision begins when light reflects off of an object and enters the eye through the cornea, the outermost layer of the eye. The cornea bends the rays and allows the light to pass through the black center of the eye, called the pupil. The pupil is expanded or contracted by the colored part of the eye, the iris, depending on how much light is available. Light rays pass through the eye into the lens, which then refracts the light and sends it through to the retina at the back of the eye. Within the retina are light-sensing nerve cells called rods and cones. Rods detect movement and allow for peripheral vision, and allow sight in dim light. The cones detect colors and finer details in bright light. The rods and cones send signals to the brain through the optic nerve, which takes in the signals and produces an image in the brain. [11]

The functionality of both humans and canine eyes are relatively similar. However, they have evolved over time to serve the individual needs of each species. The human is diurnal, meaning most active during the night, and relies heavily on sight as its primary sense. The dog evolved from the wolf, whose hunting habits led it to primarily chase prey during the night, using vision secondary to its sense of smell. The domestic dog is crepuscular, meaning it is most active during dawn and dusk. No eye has it all – compromises must be made in visual acuity in order to compensate for seeing in low light.

The first difference between the human eye and the dog's eye is immediately noticeable. Although eye placement varies among breeds of dogs, most dogs' eyes are placed more laterally on their heads than human eyes, which are directly in the front of the face. Humans are designed to look forward, while dogs have a greater field of vision.

Another obvious difference between the eye of the dog and that of a human is the visibility of the sclera, or the "white part" of the eye. Human eyes have much more of the sclera visible, while dogs' sclera does not show as much.

Once inside the canine eye, more differences to human eyes are visible. A dog's eye gathers more light than a human's eye. Both the lens and cornea of a dog's eye are larger than a human's eye. In addition, light entering the dog's eye hits the retina at least twice, resulting in double the light to highlight the image. This redoubling of light accounts for the "creepy dog eyes" that look reflective when we take pictures with a flash on a camera. Once the light is registered in the retina at the back of the eyeball, the photoreceptors within the retina determine the level of visual acuity and ability to detect color. [22]

Photoreceptors of the Eye

The retina is the rear part of the eye that contains the photoreceptor cells that respond to light. There are two types of photoreceptors:rodsandcones.

To compare the photoreceptors between the eyes of humans and dogs, we need to examine the needs and environment of each species. Humans, as diurnal creatures, mainly move about in a brightly lit environment. Many dogs have been bred to utilize their keen sense of movement, in addition to their sharp sense of smell. Humans have more rods in their eyes than cones, but dogs have as much as three times as many rods as we do, resulting in much better sense of motion.

The human cones are not as sensitive to light as the rods. However, our cones are most sensitive to one of three different colors (green, red or blue). Signals from the cones are sent to the brain which then translates these messages into the perception of color. Cones, however, work only in bright light and are used for color vision and for seeing fine details. A person who is "color blind" cannot tell some colors apart from others, and is either missing a certain type of cone in the retina or one type of cone may be weak. [33]

Dogs do not have as many cones as humans, nor do they have the three kinds of cones that humans have that allow us to see red, blue, and green wavelengths. They do not see in black and white as most people believe, rather, they only have two types of cones, those that are sensitive to blue and the other to a mixture of green and yellow. (See figure 1 for the range of colors as seen by a dog, compared to a human's view of color.)

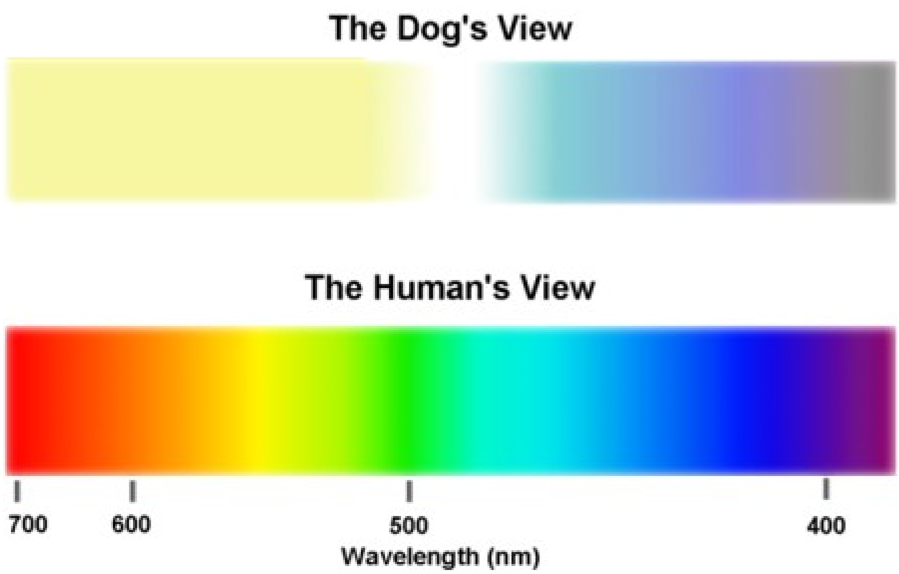


Figure 1: Ranges of color from a dog's view compared to a human's view

(Views provided by Caroline Zeiss, Yale University but it’s all over the internet)

Humans are often baffled when their canine friends cannot see a bright orange or red toy that is right in front of them. While the toy is highly visible to the human, the color of the toy does not register with the dog. The image blends in with the grass. However, if the toy is given a slight nudge, the dog will pick up on the movement because of the distribution and excessive number of rods in its eye.

While the teaching of concepts related to the photoreceptors of the eye, opportunities arise to model the questioning of information we do not know. For example, the questions to the students might include: Is one person's view of color exactly the same as everyone else's? Can there be deviations in the number of cones from one person to the next that would alter the perception of color? Are there gender differences between the perceptions of color? Why do humans even need to see color? It is important to constantly model that questioning continues to be the basis for the search of new information.

The Color of Light

If you ask students what is the color of light, most students respond that it is "white" or "clear". When first asked why an apple is red, the most common answer is that there is red dye in the skin of the apple. Both of these popular misconceptions are difficult to explain to students who are at an age where they are transitioning from the concrete operational stage of development (ages 7 to 11) to the more abstract thoughts in the formal operational stage (beginning at age 12), according to Jean Piaget's stages of development. Hence, it is important to first understand the initial concepts related to light and color before we can create inquiry-based lessons on which students can explore and grasp the concept of why colors appear the way they do.

Our modern understanding of light and color began in the 1660s when Sir Isaac Newton refracted white light into a prism, which separated the light into the colors of the visible light spectrum: Red, orange, yellow, green, blue, indigo, and violet (We often teach children an acronym to help them remember these colors: ROY G. BIV). When Newton first demonstrated that the prism could separate the colors of white light, he had to dispel the theory that the prism "created" the colors. He was able to do this by reflecting the scattered beams into another prism, proving that the separate colors came together to once again create white light. [44]

So if all objects are illuminated by white light, we now ask the question: Why do colors appear the way they do? All colors are absorbed into an object except for the one color that reflects off of it. For example, a blue object exposed to white light will absorb most of the wavelengths except those related to the blue light. The blue wavelengths are reflected off the object. (See the illustration in figure 2)

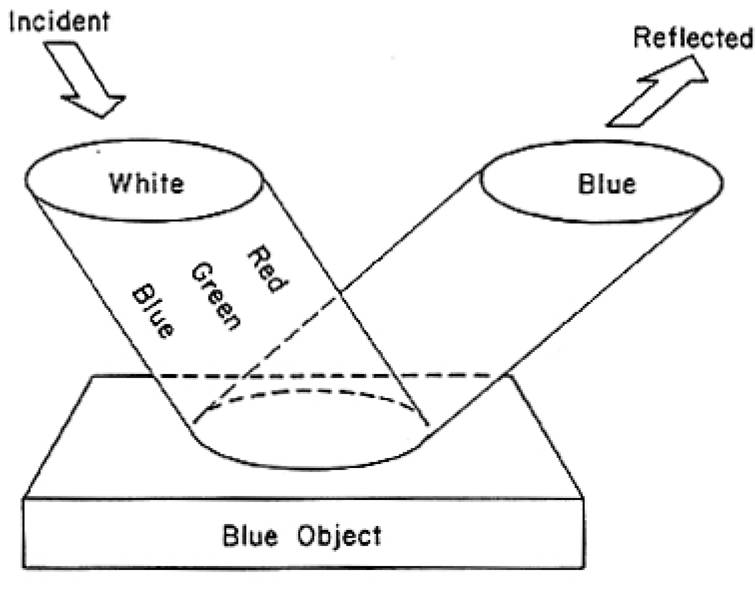


Figure 2: How light is reflected off of an object [55]

(figure 2 from http://www.optics4kids.org/home/teachersparents/articles/color-and-light/)

Students often ask what makes some colors absorb and others reflect. In every object, there are atoms and molecules, which contain electrons. The electrons vibrate at specific frequencies. Similar to a tuning fork or a musical instrument, the electrons of atoms have a natural frequency at which they vibrate. When a light wave with that same natural frequency comes upon an atom, then the electrons of that atom will vibrate. If a light wave of a given frequency strikes a material with electrons having the same vibrational frequencies, then those electrons will absorb the energy of the light wave and will be put into motion. As a result, the light wave with that frequency is absorbed by the object and is not released in the form of light. It is when frequencies of light waves do not match the frequencies of the vibration of the objects that the object will reflect the light wave of the color associated with it. [66]

Although it is interesting that scientists have learned what makes colors appear the way they do, studies continue to focus on how light and color can be harnessed to perform new tasks. The development of fiber optics as telecommunication; the use of lasers for their precision in surgical techniques, as well as in military targeting; the psychological uses of color to stimulate thoughts and feelings lead us to ask new questions: What other uses are there for light and color that we have not yet discovered? We already know that radiation can be used to treat cancer, ultraviolet light can kill bacteria, and blue light can benefit jaundiced newborns, but can light destroy viruses? What are the other possibilities that color can be used for, outside of aesthetic purposes? If we explore these possibilities with our students, we might be able to encourage them to think of new ways to utilize the properties of light and color.

Light Waves

All light, whether it can be seen or not, travels in waves. The human eye can only see light in the "visible light" part of the electromagnetic spectrum. In the visible light section, the light waves are not too long to be seen, such as radio waves, or the waves are not too short, such as gamma rays. See figure 3 below for where visible light falls on the electromagnetic spectrum:

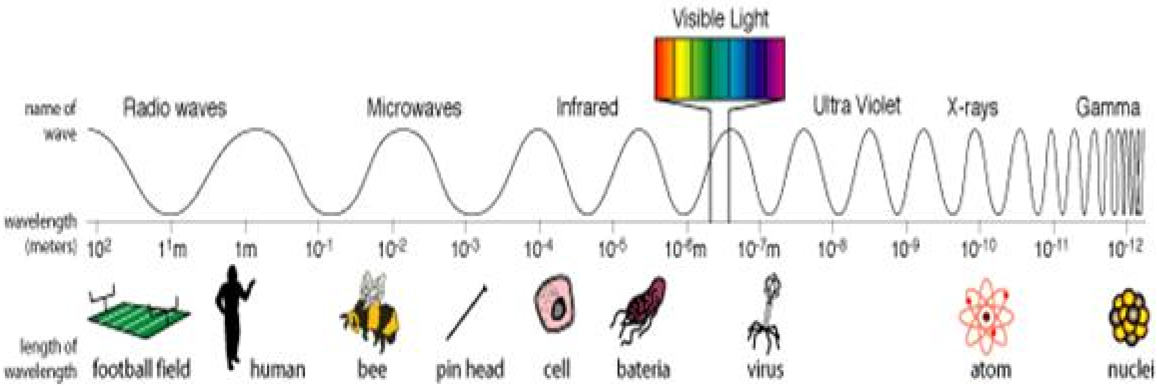
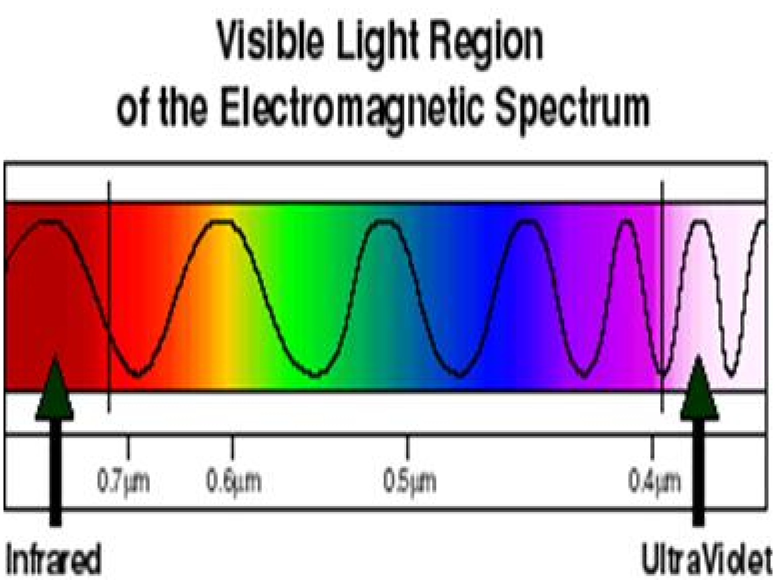


Figure 3 – Light Waves of the Electromagnetic Spectrum

http://science.hq.nasa.gov/kids/imagers/ems/waves3.html

The colors of visible light fall in the "Goldilocks" section of the spectrum; the waves are just the right length to be captured by our eyes. Within the visible light section, each color has its own wavelength (see figures 4 and 5 below). Red has the longest wavelength and violet has the shortest wavelength. When all the waves are seen together, they make white light.



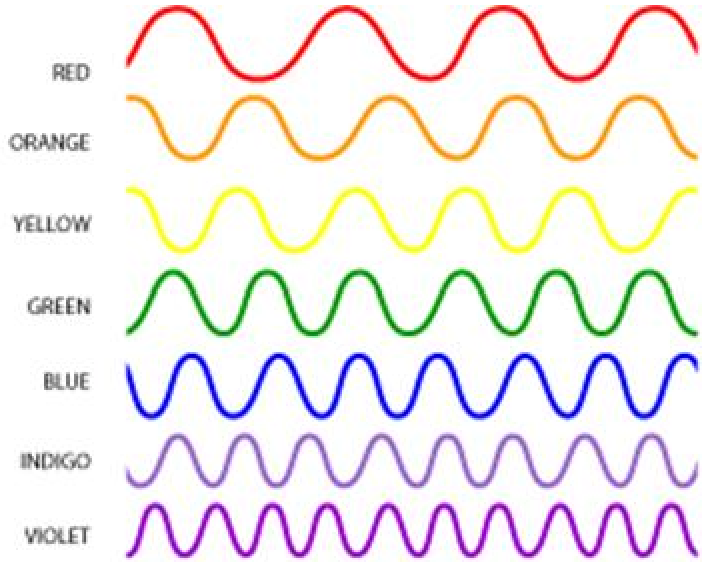


Figure 4: The wavelengths of the individual colors in the visible light part of the electromagnetic spectrum.

http://science.hq.nasa.gov/kids/imagers/ems/visible.html

Basically, light is a type of energy that is ultimately created by movement. Some forms of light cannot be seen by the human eye, and those that can be seen fall in the "visible light spectrum".

As stated previously, a teacher can model the questioning for the traveling of light to explore new possibilities. We can tell students the speed of light is approximately186,000 miles per second, and explain that the nearest star besides the sun is about four light-years away from Earth, but other than saying "Wow!", how can we use that knowledge for the greater good? The teacher can ask students to think about why we might want to travel outside our solar system and how we can make that happen.

Lesson Plans

Lesson 1: Asking Scientific Questions

Objective: Students will understand the difference between the three types of questions: Verification, Significant/Theory, and Experimental questions.

The students will pose different questions that they will categorize into the three different types of questions. Verification questions are basic data collection questions. Significant/Theory questions increase knowledge of a subject, but require prior knowledge to build upon. Experimental questions require in-depth answers that require testing. [77]

Lesson 2: The Visible Light Spectrum

Objective: Students will be able to understand how light travels and what makes light and color visible to the human eye.

The students will use a jump rope to simulate how light travels in waves. By moving the rope very slowly (to the point where it barely looks like it is moving), or so quickly that the movements are almost blurry), they can demonstrate the effect of what is visible to the eye and what is not. Students will follow up with questions about what the effects of movement have on the colors we see.

To illustrate that white light is made up of colors of the visible light spectrum, students will use lamps with colored light bulbs (green, red, and blue). They will combine the colors on a plain white surface to create "white light". This will illustrate that colors can be combined to create white light. Students will be given opportunities to create questions and make predictions before experimenting with combinations of the colors of the light bulb.

Students will also separate white light into the main colors of the visible light spectrum (red, orange, yellow, green, blue, indigo, and violet) by using a prism.

Follow up activity will allow the students to experiment with combining colors of paint to see if the colors combine in the same manner as light.

Lesson 3: Properties of Light

Objective: Students will understand that there are three basic properties of light (refraction, reflection, and absorption) and how those properties affect how we see objects.

To illustrate refraction, shine a laser pointer in a jar that is filled half-way with water. Observe how the beam of light appears bent in the water. Allow students to reflect on how refraction can be utilized to see objects in a new and different way (glasses, telescope, etc.)

To show reflection, shine the laser on a mirror and observe how the angle of the light hitting the mirror correlates to the angle of the reflection.

To discuss absorption, ask students to think about what color shirt they like to wear on a hot summer day. Most students understand that black shirts keep them hotter. Allow students to reflect on absorption of light can be utilized in everyday life (light can be converted to heat as a fuel-efficient energy source).

Finally, the students will use the color light bulbs that were used in lesson two. By placing the light bulbs into lamps and shining them on a white surface, students will notice that the color of the light bulb is reflected back. Students will then write questions before they get to experiment with shining the colored light bulbs onto surfaces with the same color background as the light.

Lesson 4: The Anatomy of the Eye: Human vs. Canine

Objective: Students will be able to identify physical differences between a human eye and a canine eye to discover the impact on vision in both creatures.

The students will examine both exterior pictures of a dog and a human for visible differences in the eyes, including location of the eyes in the skulls. They will also look at diagrams of the eyes for each and note the differences between the main parts of the eyes (basic shape, lens size and shape, cornea shape, location of lens), and then create questions about the impact on vision of the two creatures.

Next, the students will compare diagrams of eyes of various creatures from G.L. Wall's "The Vertebrate Eye and Its Adaptive Radiation", with particular emphasis on noticing differences between diurnal, nocturnal, and crepuscular creatures. Students will consider the advantages of the individual structure of each eye for the vision of the given creatures.

Students will also compare diagrams of the retinas and photoreceptor cells of the human eye to the canine eye. They will consider the behavior and individual needs of both dogs and humans and will create questions of why the eyes are structurally different.

Lesson 5: What Does it All Mean?

Objective: Students will reflect on previous lessons and will apply their knowledge to determine the reasons for given situations.

Students will look at given photographs and explain the reasons for the situations: Photo of a dog that shows light reflecting from the eyes (retinas reflect the light twice to illuminate the image in low light); picture of a dog jumping over blue and yellow hurdles during agility test (these are the colors a dog can clearly distinguish due to the type and number of cones in the dogs' eyes); picture of a dog catching a Frisbee in mid-air (dogs have a great sense of motion based on the number of rods in their eyes); pictures of red apples and green apples (to explain the absorption of all colors except for those being reflected back to the eye); images of a frog's eye and a human eye (external) and explain the reasons for physically different locations on the skull (prey needs to be able to scan for predators approaching from different angles, while predators need binocular vision to run and jump). [8]

Notes

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1. http://www.aoa.org/x6024.xml

2. Alexandra Horowitz

3. http://faculty.washington.edu/chudler/retina.html

4. http://www.howstuffworks.com/innovation/famous-inventors/5-isaac-newton-inventions.htm#page=6

5. http://www.optics4kids.org/home/teachersparents/articles/color-and-light/

6. http://www.physicsclassroom.com/Class/light/u12l2c.cfm

7. http://www.goscienceseven.com/SciMethod/sciquestions.html

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Zeiss, Caroline, PhD, BVSc, DACVP, Yale University. Professor of Comparative Medicine and Associate Professor of Opthamology and Visual Science, interview on Wednesday April 17, 2013.

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Appendix: Implementing District Standards

PS4.B: Electromagnetic Radiation

- An object can be seen when light reflected from its surface enters the eyes. (4-PS4-2)

LS1.A: Structure and Function

- Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction. (4-LS1-1)

LS1.D: Information Processing

- Different sense receptors are specialized for particular kinds of information, which may be then processed by the animal's brain. Animals are able to use their perceptions and memories to guide their actions. (4-LS1-2)

PS3.A: Definitions of Energy

- The faster a given object is moving, the more energy it possesses. (4-PS3-1)

- Energy can be moved from place to place by moving objects or through sound, light, or electric currents. (4-PS3-2),(4-PS3-3)

PS3.B: Conservation of Energy and EnergyTransfer

- Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced. (4-PS3-2), (4-PS3-3)

- Light also transfers energy from place to place. (4-PS3-2)

- Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy. (4-PS3-2),(4-PS3-4)

LS3.B: Variation of Traits

- Different organisms vary in how they look and function because they have different inherited information. (3-LS3- 1)

- The environment also affects the traits that an organism develops. (3-LS3-2)

LS4.B: Natural Selection

- Sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates, and reproducing. (3-LS4-2)