



## Physical Science in Sight and Sound

Curriculum Unit 16.04.10

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### Introduction

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Anatomy, distilled down to its most basic components, is the study of form and function. It is an intuitive science, easily explored and dissected into neat interconnected systems that function together to maintain homeostasis. Just as these systems are dependent on each other, so too is it important to recognize that anatomy is not a subject in and of itself. In order to truly understand the way the body works, students must have a strong grasp of physics and chemistry.

This is especially true of sensory organs like the eye and the ear. The form and function of these two structures are highly dependent on their ability to capture environmental stimuli and convert them into signals that the body can interpret. As such, a failure to understand the form of these signals leads to a fundamental lack of understanding of how these structures work. A strong understanding of physical science is especially important for understanding what happens when these structures malfunction.

### Rationale

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I am a high school science teacher at a small magnet school. Our health science and sports medicine magnet theme is aimed at providing students with the background materials necessary to pursue careers in the medical and health fields. Many of our students take multiple biomedical science courses each year depending on the track they have decided to follow.

One of the courses that I teach is a health science class that focuses on the advancements of human medicine and bioengineering to help provide interventions to patients with various problems. Two of these units revolve around the ability of the body to interact with the outside world and how medical problems that diminish this ability can be solved using science.

As a teacher of medical science it can sometimes feel like my discipline is rather specialized and disjointed from the other core science courses. Many of my students have difficulty making connections between closely

aligned courses like physical science and chemistry, let alone bringing the knowledge they obtain from those courses into something that seems so far detached as medical biology. As a result, I have discovered that students tend to separate many physical phenomena such as light and sound waves from the organs that we use to sense them. An inability to understand these basic principles diminishes their understanding of how these vital organs work and, even more, prevent a full understanding of how diseases such as color blindness and conductive hearing loss physically impact the body.

This curriculum unit emerged as a way for me to marry these disciplines together in a way that will allow for a deeper understanding of the interventions that have been created to mediate these medical problems.

## Curriculum Content

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### The Eye and Vision

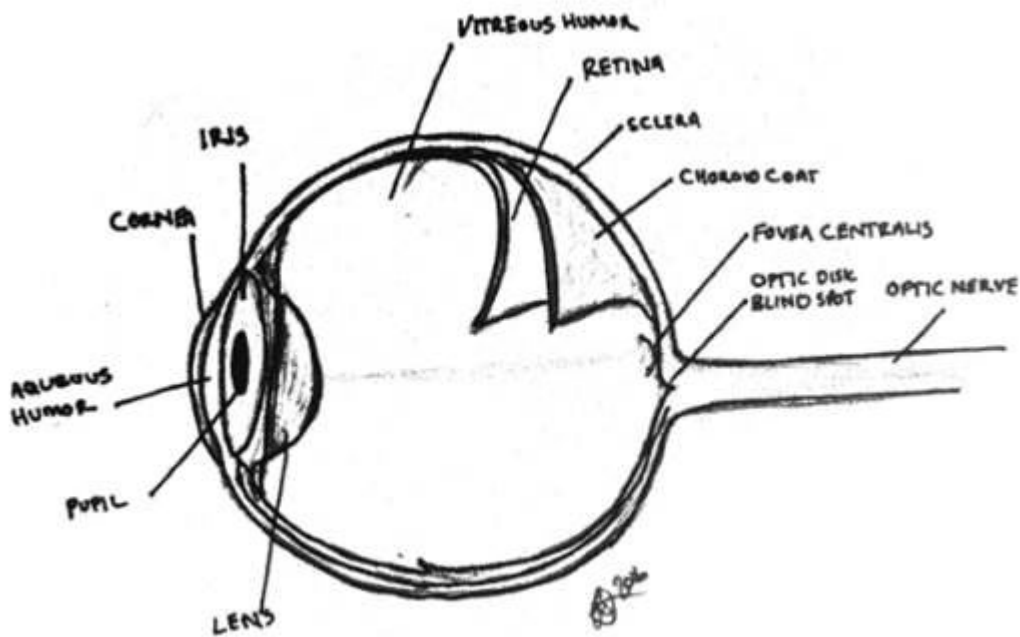
The human eye, a small orb with a diameter of around 1 inch, provides humans with much of the sensory information that we use on a daily basis. From walking to writing, dressing one's self and even reading this paragraph, the eye is responsible for harnessing the visual world and translating it into a "language" that the brain can process to make decisions. Vision not only allows us to enjoy small pleasures like art and our favorite TV show, but it keeps us from harm— from allowing us to avoid walking off the edge of a sidewalk into a busy roadway to letting us evaluate whether the two week old bread in our cabinet is still suitable for consumption.

In order to understand how vision works, one must first understand the basic anatomy of the eye. After that, the logical connection is to understand how the brain interprets this information to form a picture. Once we have examined our light sensing structures, we will look at light itself and the regions of the spectrum that we can, and cannot, see. Finally we will address several visual problems and discuss how modern science and medicine are able to return or, in some cases enhance, vision.

Since a large portion of this unit does deal with anatomy, there are several regional and directional terms that are used to describe the position of different structures relative to one another. If you are unfamiliar with this terminology, it is highly recommended that you look at Appendix C, which contains a list of directional terms.

### Anatomy of the Eye

The eye is made up of several important components that are directly related to the sensing of light. Many other components of the eye are responsible for supporting the organ with this primary function. Each part of the eye is described in detail below, and along with Figure 1, will provide adequate background information for teaching about this organ.



**Figure 1. Anatomy of the Human Eye.** This illustration highlights several key structures of the eye. (Zullo)

The **sclera** , or the white of the eyes, is a tough, fibrous layer that serves many functions that are not directly connected to the sensing of light. This is the portion of the eye that provides shape and protects the other structures inside. The sclera is not the only structure that is responsible for protecting the eye, however.

In the medial anterior portion of the eye is a covering called the **cornea** . The cornea can be likened to a pair of goggles, since it provides further protection to the eye itself. It is relatively thick and strong—made up of five layers of cells—which are clear to allow light to pass through. This portion of the eye also serves a secondary protective function—it contains both pain and pressure (touch) sensory neurons that allow the eye to respond if it comes into contact with any foreign particles.

Behind the cornea, is the front, or the anterior chamber of the eye. The eye itself is not a single chamber. It is, in fact, two separate chambers divided by the lens. The anterior chamber is the front part of the eye. It is filled with a watery substance called **aqueous humor** . This slightly watery fluid helps provide the correct shape to the cornea and also to assist in light refraction. This fluid is constantly being replenished by special tissues called the ciliary processes—structures that are also responsible for suspending the lens. This fluid serves other functions as well, including providing amino acids and glucose to other parts of the eye for nutrition. <sup>1</sup> It is believe that the aqueous humor may also serve an immune function, as it contains immunoglobulins. <sup>2</sup>

While the aqueous humor is responsible for bringing nutrition to a large portion of the eye structures, the eye itself is supplied with fresh oxygen and nutrients through the highly vascularized layer called the **choroid coat** . This tissue layer serves a second purpose of darkening the inner chamber of the eye to prevent light reflection. This layer is darkly colored because of the presence of melanin—which helps to absorb stray light from bouncing around the eye and prevents the development of macular degeneration by light toxicity. <sup>3</sup> In humans, the phenomenon known as photographic red-eye occurs when there is uncontrolled reflection in the back of the eye, highlighting the highly vascularized choroid coat and retina. Animals do not have this same “effect” and instead have eyes that may appear to glow due to a layer of melanin-poor tissue called the

**tapetum lucidum** . This structure, absent in humans, allows for animals to have strong night vision.

The colored part of the eye is made up of a muscle called the **iris** . Color of the eye is related to the amount of melanocytes that are found in the tissue. The more melanin, the darker the eye color appears. Melanin expression begins after birth when the *OCA2* gene is activated, which is why many babies when born have blue or lighter color eyes that may darken. <sup>4</sup>

The iris functions much like the iris of a camera would. Its main function is to control the amount of light that is able to enter through the back of the eye through the **pupil** , or the hole in the center of the iris. Too much light to the back of the eye can cause damage and can obscure the surroundings.

Imagine walking out of a dark theater into a bright summer day. The bright lights can be painful and leave spots in front of your eyes. To compensate for too much light, your iris will constrict, narrowing the opening to prevent too much light from entering the rear or posterior chamber. In comparison, if you are sitting in a bright room and suddenly all of the lights go out, plunging you into darkness, your iris will contract, causing your pupil to dilate and allow additional light to enter. The same phenomena can be observed walking into a building on a bright day. Iris movements, and thus the size of the pupil, are controlled through antagonistic smooth muscles called the sphincter and dilator pupillae. A contraction of the sphincter pupillae closes the iris, making the pupil smaller while the dilator muscles open up the pupil.

The **lens** is located posterior to the pupil. It is a disk shaped structure that is made up of concentric layers of cells that are laid down yearly. The lens itself is elastic and can flex to allow the eye to focus on objects at different distances. The lens curves both assisting with this ability to focus. However, as the lens ages, these curves change and the lens becomes less flexible, causing age related vision problems such as far-sightedness. This is why, as adults move past middle age, they often require reading glasses when previously they did not.

As previously mentioned, the lens is supported by ligaments that are attached to the **ciliary body** , a sublayer of the choroid body. These ligaments are responsible for helping to bend and flex the lens into the correct shape to allow for clear views at near and far distances. This process of bending the lens to shift between objects near and far is called accommodation, a phenomenon that will be discussed later.

Behind the lens is the posterior chamber of the eye. Like the anterior chamber, it is not hollow. The **vitreous humor** , a jelly-like substance, fills this portion of the eye. It provides interior support to the sclera, aids in light refraction, and also keeps the layer called the retina in place against the posterior wall.

The **retina** is the sensory portion of the eye. Covering the back half of the eye, lying on top of the choroid coat. It is the most important structure for sensing light. As light passes through the lens, it is focused on the retina in the posterior chamber of the eye. This triggers specialized cells named rods and cones, which will be discussed in the next section concerning light sensing structures and the brain.

The retina is anchored to a single point to the back of the eye called the **optic disk** , where it leads into the **optic nerve** . This small spot in the eye lacks any rods and cones and thus, and results in the “blind spot”—a non-light sensing region of the retina. Finding the blind spot is a simple classroom activity that can be done with minimal supplies. Instructions for demonstrating the blind spot are located below in the section titled “suggested activities”. While the retina is anchored at one spot, it is possible for it to become detached at any point around the eye due to aging or physical trauma. During aging, vitreous fluid begins to shrink, allowing the retina to pull away from the choroid coat and tear, causing a loss of peripheral vision and further

blinds spots <sup>5</sup>. Head trauma such as a blow to the head or whiplash from a car accident may similarly cause the vitreous humor to shift or leak. If this occurs, retinal tearing may also occur.

## Light Sensing Structures and the Brain

As previously mentioned, the retina is the light sensing portion of the eye. Light flows into the eye past the cornea, through the pupil, and is focused by the lens on the retina which contains two light sensing structures called rods and cones. Rods and cones are both photoreceptors and are activated by different wavelengths of light. Rods are responsible primarily for scotopic vision, meaning they are active in low or dim light. For example, when walking around at dusk or stumbling around a darkened room one relies more heavily on the rods of the eye than the cones. These light sensing structures are more numerous than the cones and are found in greater angular separation from the fovea centralis. These structures have low spatial acuity, meaning that they are not able to strongly detect shapes of objects. Rods are missing entirely from the fovea centralis.

It is believed that the function of rods is a survival feature—they provide vision in low light environments including night vision, are sensitive to motion detection, and provide us with our peripheral vision <sup>6</sup>. These traits are important in allowing the eye to quickly sense danger approaching from the side, allowing for us to react. For this reason, the rod does not need to have high visual acuity—we do not need to know what *exactly* is coming but merely that something *is* coming — to serve its purpose.

Cones are activated during times of photopic vision or high intensity light, and are also responsible for the detection of color along the visible light spectrum. Cones are highly concentrated (up to  $1.5 \times 10^5$  cones/mm<sup>2</sup>) <sup>7</sup> in a region of the eye called the **fovea centralis**, a subcomponent of the macula lutea in the retina. This area is found just lateral to the optic disk and is the area where light is directed. There are three types of cones in the human eye, able to sense short, middle and long wavelengths of light (S-cones, M-cones, and L-cones, respectively). Each type of cone is photosensitive to different areas of the spectrum due the differences in the photopigments that they have. For example, S-cones are more highly active in the blue ranges of light, M-cones in the green ranges, and L-cones in the red ranges. <sup>8</sup>This does not mean that these cones are sensitive to only that particular range. The spectrum of these cones are overlapping, allowing them to perceive a wide spectrum of colors in response to the particular ratio of each that are active.

Unlike rods, cones are in areas for high visual acuity. The fovea centralis and the macula lutea are both highly focused areas, allowing for sharp details. This portion of vision allows for humans to focus on specific objects.

When light is focused on the retina, a photoreceptor chemical called rhodopsin is activated. This activation excites sensory neurons that are attached to the rods and cones, generating an electrical impulse. This impulse is channeled into the optic nerve which leads out of the optic disk and into the optic chiasma, a portion of the brain where the two optic nerves physically cross, located on the ventral or bottom side of the brain. Once in the optic track these signals are sent to the occipital lobe of the brain to be interpreted.

## Vision and the Light Spectrum

Visible light comprises one part of the electromagnetic spectrum. Electromagnetic wave frequencies depend on the number of cycles that travel through a specific point per unit time. The number of these cycles that pass through the point per second is measured in hertz (Hz). The visible light spectrum ranges from  $75 \times 10^{14}$  Hz (400 nm) to  $4.3 \times 10^{14}$  Hz (700 nm). <sup>9</sup> More commonly, visible light is described in terms of wavelength, which

varies inversely with frequency. For example,  $75 \times 10^{14}$  Hz corresponds to a wavelength of 400 nm, and  $4.3 \times 10^{14}$  Hz is 700 nm.

There are several important functions of light that contribute to vision. Reflection, refraction, and dispersion will be discussed in this section.

Reflection assumes that light will travel as a straight line or ray until it hits a surface. Once it hits that surface it is absorbed and emitted from that material. This type of behavior is described with the ray theory of light, and ignores many of the wave principles that will be discussed later. On a smooth surface without any inclusions, such as a mirror, light will be emitted in a ray with the same angle as it hit the surface, and is known as specular reflection. Inclusions which result in a rough or irregular surface will cause diffuse reflection where the angle at which the light is emitted is different from the angle it hit the surface. <sup>10</sup>

Reflection allows our eyes to see. When light hits an object, specific wavelengths of light are absorbed. Some of these wavelengths are emitted back by the object depending on the photopigments that are in it. <sup>11</sup> For example, the grass appears green because the wavelength that corresponds to green light is *not* absorbed. This light is released and it is absorbed by the cones in the eye, triggering “color” vision.

Refraction occurs when light impinges upon a transparent surface. When this occurs, light is “bent.” That is, when light travels from one medium (air) into a second medium (liquid) that have different refractive indices, a straight object such as a pencil that is placed in the liquid appears bent or disjointed. <sup>12</sup> Because of the differences in speed through the two media, the light appears to bend, and this can be used to determine the refractive index of a material or substance. For example, the refractive index through air is 1.000 and the refractive index through the aqueous humor is 1.336. <sup>13</sup>

Several eye conditions exist because of refractive errors. If the eye itself is too long or too short, light is unable to focus on the retina. If the eye is elongated, light will be focused before the retina, causing nearsightedness. If the eye is shortened, the image will focus behind the eye causing far sightedness after accommodation. Both of these cases can be treated by using lenses to refocus the light on the correct place of the retina.

Astigmatism occurs if the cornea itself is distorted. Astigmatisms or uneven lens surfaces may cause the light to scatter slightly, leading to blurry vision. <sup>14</sup> In astigmatism, the eye is unable to evenly focus light because the cornea has an uneven surface. As the cornea is irregularly shaped, the light passes through the cornea at different angles, causing the image focused on the retina to look blurry or distorted. <sup>15</sup>

### **Medical Interventions: Near and Far Sightedness**

As with any organ there are instances where the body is not able to operate optimally. This section discusses some of the interventions that are currently used for various eye impairments that have occurred as a result of physiological defects.

The first set of interventions will apply to near and far sightedness and how we can use concave and convex lenses to redirect the light to the correct location of the eye. In cases of myopia, the subject is able to see objects that are near, but objects at a distance are blurry. This occurs because the image is focused in front of the retina before the fovea centralis. In order to correct this, glasses with diverging lenses are used which move the light back against the retina. The opposite is true in hyperopia or people who are far-sighted. They

are able to see clearly at a distance but have difficulty looking at objects close up. This is because the image would be focused “behind” the eye, past the retina. Converging lenses cause the light to focus sooner than it would normally, allowing for clearer vision <sup>16</sup>.

Two of the most innovative medical interventions include colorblindness correcting glasses and the bionic eye.

Colorblindness is a condition where the eye’s color sensing cones do not correctly detect their normal corresponding wavelengths of light. There are several forms of colorblindness and it is often passed down through sex-linked inheritance. As such, colorblindness is more often found in men than women. One of the most common types of colorblindness is deuteranopia, more commonly known as red-green colorblindness.

In deuteranopia, the eye has difficulty sensing light in the green wavelengths because the M-opsins are misshapen due to a genetic abnormality on the X chromosome. Instead of picking up “green” they respond more strongly to the longer wavelengths that correspond with orange or red. This often causes a muddying of colors and the inability to distinguish red and green wavelengths. This will not only affect the ability to perceive these two colors, but most colors in the perceivable light spectrum. Since both red and green cone are triggered, the colors might appear to be a muddy yellow color. For examples of what different types of colorblindness might look like to someone who is experiencing them, visit the resources section below.

Recently, a new type of corrective glasses on the market, released by the company EnChroma, helps to restore some of the color spectrum to people who are red-green colorblind. These glasses work by filtering out light that falls between 550 nm and 570 nm—a range of the spectrum that is usually just outside of the range of a normal green cone. <sup>17</sup> By filtering out these wavelengths of light, the green cone is, essentially, shifted back into a normal range so it is not excited inappropriately. This filtration of stray light fixes the signal coming into the eye, allowing green cones and red cones to be excited at the correct times and the eye to interpret these stimuli as the correct colors. A link to their website is listed below in resources.

The last intervention that will be discussed in this section is the bionic eye. While this may seem like something out of a science fiction movie, bionic eyes have become a reality for people suffering severe retinal damage. In patients who have lost the ability to sense light, retinal implants are used as a substitute.

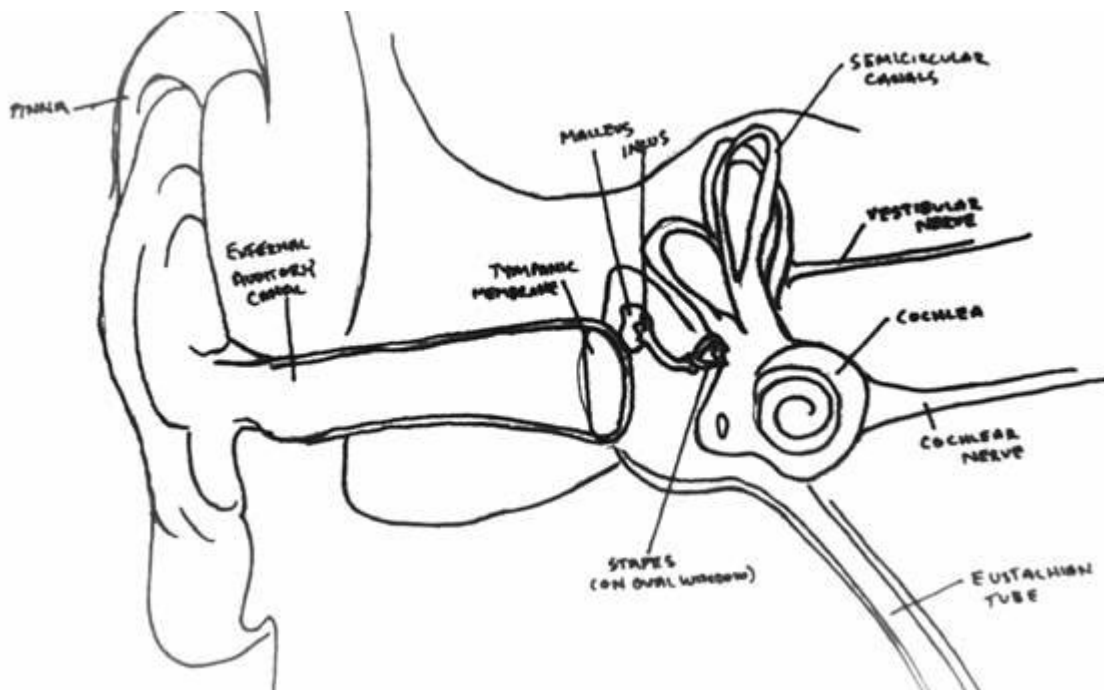
Patients are fitted with a pair of special glasses that have a video camera embedded in the side. The camera captures the image and sends wireless impulses to the back of the retina where a sensor has been implanted. <sup>18</sup> These signals stimulate the optic nerve similarly to how the rods and cones would be directly stimulated by light. The eye is then able to send this signal to the brain for decoding.

## **The Ear and Sound**

Our eyes are not our only way to sense the world around us. Hearing and the ability of people to perceive sound is also a critical way for humans to understand and evaluate the world around them. Sound provides us with valuable information and a richness to our sensory interpretation of our environments. For most humans and animals, sound is a critical source of communication. Not only does hearing allow us to interpret a string of vocalizations together to create words, but it also allows us to hear the tone and timber behind the things people are saying—providing us with information about the inflection behind those words. Our ability to perceive sound provides us with information that we may not even notice initially. For example, the human ear is able to discern the difference between hot and cold water when being poured. <sup>19</sup>

## Anatomy of the Ear

The ear comprises three main areas: the outer, middle, and inner ear, all of which assist in hearing to some degree. In this section, the structures of the ear are described in the same order that sound travels through them (Figure 3).



**Figure 3. Anatomy of the Human Ear.** This illustration highlights several key structures of the ear. (Zullo)

The outer ear is what many people think of when we talk about ears, but the ear actually extends into the skull far deeper than we might imagine. The fleshy part of the outer ear is the **pinna** and it is responsible for directing sound waves towards the auditory canal. Think of the pinna as a funnel for sound, helping to focus sound waves inward.

Just past the pinna is the **auditory canal**. Like all orifices open to the outside world, this structure has a few forms of protection to prevent the collection of foreign particles and to help keep pathogens at bay. The auditory canal uses sebaceous glands to secrete a substance called ear wax, or cerumen. Ear wax not only assists in keeping foreign particles away from the middle and inner ear, but it also helps to keep the ear dry by providing a water barrier.<sup>20</sup>

Just past the auditory canal is a membrane called the **tympenic membrane** or the eardrum. This structure serves as the divider between the outer ear and the inner ear. In the presence of sound, the tympanic membrane will vibrate. These vibrations are what is collected and transmitted through the rest of the ear and into the brain for decoding.

The middle ear, just posterior to the tympanic membrane, holds several important structures. This small portion of the ear is located adjacent to the temporal bone of the skull and connects with the **pharynx** or throat. This is often why some people may experience tickling sensations in their throat when they have tickling in their inner ear. This chamber of the ear is pressurized, with the **eustacian tube** serving as a way of helping to maintain the same atmospheric pressure as the environment.



There are three small bones, or **ossicles**, in the middle ear which are responsible for collecting and transmitting the sounds from the tympanic membrane. The **malleus**, **incus**, and **stapes** (or hammer, anvil, and stirrup). The malleus is positioned so that the proximal end is at the tympanic membrane and the distal end is free to swing much like a hinge. When vibrations hit the tympanic membrane, the malleus strikes the incus which is fused to the stapes. The vibrations travel through these two bones and enter into the inner ear, where the stapes abuts the cochlea. <sup>21</sup>

The ossicles of the middle ear serve a very important function by helping to channel the vibrations in sound past the air-fluid interface of the outer and inner ear. The hammering of the malleus causes vibrations that are able to travel through the cochlea. It is estimated that, without these ossicles serving as an intermediary, about 99.9% of the energy from sound waves would be prevented from reaching the inner ear. <sup>22</sup>

The inner ear itself is deep within the temporal bone of the skull. As previously indicated, the main structure of the inner ear is a fluid filled chamber called the **cochlea**. This organ is shaped like a snail. The large, “shell-like” portion of the cochlea is actually a tube filled with fluids called the **cochlear duct**. When the malleus strikes the incus and sends vibrations through the stapes, these vibrations impinge on the **oval window**, a thin membrane. The force is transferred from the bone, through the oval window into the fluid filled environment of the cochlear duct. Delicate cells called the **organ of Corti** are stimulated by these vibrations. Much like the rods and cones of the eyes, these cells are attached to sensory neurons. The sensory neurons transmit their signal along the **cochlear nerve** into the temporal lobe of the brain, where sound is interpreted.

The inner ear serves a secondary function in addition to being able to transmit sound. Opposite the cochlear duct is a series of loops called the semicircular canal. These structures also contain a gel-like liquid called endolymph and hair like cells. However, instead of being activated by sound, as the head tilts side to side, the endolymph acts as a liquid level. <sup>23</sup> These impulses are sent to the cerebellum in order to help with balance and body positioning.

## Sound and Sound Waves

Sound is generated in waves when a disturbance disrupts the medium. For example, consider a tuning fork. Tuning forks are composed of two short tines and a long stem. When this tuning fork is struck, the two tines push together and pull apart causing compressions and rarefactions in the air. These compressions act as “ripples” that are passed on through the air from the source of the disturbance. The sound that we hear is based on its vibration frequency. <sup>24</sup> Frequency is classified as the number of oscillations within a given second—the number of times that this wave is being generated. The unit of hertz (Hz) is the number of those waves that occur per second. <sup>25</sup> For example, a tuning fork at 512 Hz goes through that many cycles per second.

Sound is a longitudinal wave, which means that both the particle motion that is generated and the velocity are traveling in parallels from the source. Sound is able to travel through gas (air conduction), liquids, and even thin solids depending on how elastic the medium. <sup>26</sup> Sound cannot travel through vacuum. A medium is required which could be a gas, solid, or liquid.

There exists a sound spectrum, similar to the light spectrum previously discussed. Sounds below 20Hz are considered infrasonic. Sounds in the infrasonic region might include the noises that occur during earthquakes, tsunamis, and other weather disturbances. There is some indication that, while humans are unable to hear at

these frequencies, animals like elephants and cattle are able to detect these sounds and respond to them.

Sounds above 20 kHz are considered to be ultrasonic. Ultrasound is considered to be above the range of hearing for humans, but it is an important diagnostic tool in medicine. <sup>27</sup> Ultrasound frequencies can be used as an alternative to X-rays. It operates in a similar process to echolocation—sound is bounced off of the object and collected by computer devices to form pictures. Dog whistles used for training operate at ultrasonic frequencies.

When discussing sound, there are several important relative terms. Often, we use the term volume for sound. Loudness, however, is relative. For example, if you spend time with someone who has moderate to severe hearing loss, the volume on their TV, radio, or other auditory devices may be turned up to levels that are painful for a person who has normal hearing. For this reason, the physical quantification of sound is done is known as intensity. Intensity is measured in joules per second (J/s) through a square meter. <sup>28</sup> As the sound propagates further from the source, the intensity decrease since it is spread over a larger area. Decibels are a much more commonly used term for classifying intensity of sound.

The human range for hearing is between 20 Hz and 20 kHz. In the human auditory range, sound intensity is discussed in decibels, or db. To provide some perspective, a whisper is around 30 db, average conversational speech is at 60 db, and a concert with amplifiers is near 110 db. Exposure to noises more intense than 90 db for prolonged periods of time can cause hearing loss. Decibels are on a logarithmic scale. Every 10 db is a factor of 10 larger intensity, so something that is 60 db is 1000 times louder than 30 db (and a concert at 110 db is 100,000,000 times louder than a 30 db whisper). <sup>29</sup>

## Hearing Tests

There are several tests that can be used to identify hearing loss, both conductive and sensorineural. Conductive hearing loss is defined as difficulty in conducting sound from the outer through the middle ear. Often times, there may be a problem with either the tympanic membrane or the ossicles as these structures are responsible for conducting sound from the environment. Sensorineural hearing loss is characterized by problems in the cochlea, where sound is unable to be captured or conducted along the nerves. These tests are often performed by an audiologist, or a medical professional who is trained in ear, nose, and throat (ENT) diseases. The tests described below are all tests that can be performed by students in a classroom, but it is important to recognize that, unless performed by a professional in a controlled sound environment, these tests are not considered diagnostic.

The Rinne test is performed in order to look for differences for problems in conductive hearing. This test is use to look for differences in a single ear (unilateral) and requires the use of a tuning fork. This test works by comparing the ability to perceive sound that is transmitted by air conduction as opposed to sensorineural hearing. For this reason it is important that this test is completed in conjunction with additional testing.

To complete the Rinne test, a 512 Hz tuning fork is struck and held against the mastoid bone proximal to the ear of interest. The patient is instructed to indicate when they are no longer able to hear the sound to signal. At that point the tuning fork is moved next to the auditory canal. Again, the patient is instructed to indicate when they can no longer hear it.

In normal hearing, air conduction lasts longer than bone conduction, meaning that a person should hear the tuning fork for roughly as long or equal to the length of time they were able to hear it at the mastoid. If this is not the case, the following scenarios could be possibilities: If the conduction is longer at the bone than it is by

the auditory canal, this could be indicative of conductive hearing loss of the outer and middle ear. A second possibility is indicative of sensorineural hearing loss, where both bone conduction and air conduction are decreased. In this case, the bone conduction may still be longer than the air conduction, but both durations are less than would be expected in normal hearing.

A second test that is often used to identify hearing loss is a pure tone test. This test generates a graph called an audiogram. In a pure tone test, an audiometer is used to play beeps at different frequencies and decibels. A graph is generated based on the threshold needed to hear the sound. This test can also be used to test for differences in air conduction vs bone conduction.

The audiogram is usually run at frequencies between 250 and 8000 Hz and two lines are generated, graphing the thresholds. Normal hearing can usually sense tones in the range of 0-20 db while moderate hearing loss thresholds are increased to 41-55 db. Anything between 71-90 db is considered to be severe hearing loss. <sup>30</sup>

### **Aging and Hearing**

As adults age, presbycusis or age related hearing loss, may occur. According to the National Institutes of Health, one of every three people between ages 65 to 74 experiences some form of hearing loss. This number increases by age 75 to nearly 1 in 2 adults. This hearing loss is usually bilateral and is gradual. <sup>31</sup> As a result, many adults may have difficulties hearing tones in the higher or lower frequencies. This might manifest as the inability to clearly hear the voices of children or women who tend to speak in higher octaves, or not being able to hear the phone ring. Many adults lose the ability to hear frequencies above 16 kHz, including the sound of a mosquito. <sup>32</sup>

Presbycusis can be caused by several environmental factors. Adults who work in an occupation that requires them to be exposed to long periods of noises may experience hearing loss at specific frequencies. In addition to prolonged periods of noise, noises at high decibel levels can also cause hearing loss. In these cases, a single exposure may be enough to cause damage. <sup>33</sup>

### **Medical Interventions: Hearing Aids and Cochlear Implants**

There are two medical interventions that often arise in conversations about hearing loss—the hearing aid and the cochlear implant. Both of these devices allow someone who is hard of hearing or deaf to have some sound returned, however the way they operate are very different.

Hearing aids are small external devices that fit just inside of the auditory canal, much like an ear bud on a set of head phones would, or sometimes behind the ear. Hearing aids amplify sound, by increasing the vibrations that are entering the patient’s ear. The first part of the hearing aid is a microphone, which picks up sounds. These sounds are then converted into an electrical signal that passes through the amplifier. The amplifier boost the “volume” of the sound by increasing the impulse’s power. <sup>34</sup> This signal is then released into the auditory canal through a speaker <sup>35</sup> where the ear interprets the newly augmented soundwaves.

Since the hearing aid relies on the ear’s ability to pick up the signal that is sent into the cochlea, it is important that at least some of the delicate hair cells that make up the organ of Corti are still functioning. If there is too much sensorineural damage, then other medical interventions must take place.

Hearing aids take advantage of the ears natural processes by just providing a stronger set of vibrational waves for the inner ear to interpret. Cochlear implants, however, do not rely on amplification of sound at all.

These implants are used to bypass the middle and inner ear exchange all together in order to deliver sound waves directly to the auditory nerve. <sup>36</sup>

Cochlear implants are more invasive than a hearing aids since they require an implant to be incorporated directly into the head. This device, however allows patients who are deaf, or nearly so, to hear when a hearing aid would not be sufficient. In these cases, the inner ear is usually malformed or too severely damaged to transmit a signal along the auditory nerve.

This device works using a similar system to the hearing aid. A microphone that is in the external portion of the cochlear implant is responsible for picking up surrounding noises. Those noises are then sent to a speech processor which is found outside of the ear. This small computer converts the found to signals that the transmitter on the outside of the skull passes to the magnetic receiver implant that is found inside of the head, just superior to the ear. <sup>37</sup> This receiver takes the signal and converts it into an electrical impulse that travel through electrodes into the electrode array that is directly linked to the auditory nerve.

This system allows the sound to bypass the ear altogether and can be one of the only treatment options for children and adults who are profoundly deaf. However, because there is no way to completely replace the number of nerve hairs that are found in the cochlea, this implant is not a perfect solution. The small array of electrodes is trying to do the job of thousands of hair cells. For this reason, patients often rely on sign language and lip reading to supplement the information that they are able to obtain from the cochlear implant.

Furthermore, there is a large amount of cultural bias for and against the implantation of hearing aids. Members of the deaf community are strongly against infant or toddler implantation because it removes that child from deaf culture. Many feel that being deaf is not something that needs to be fixed, but rather an aspect of one's self that should be embraced.

Often, children who receive cochlear implants adapt well enough that they are able to interact with the world much as a hearing child would be able to. They grow up learning how to use the information from the cochlear implant and lip reading to give them a good picture of the auditory world around them. Parents in the hearing community who have a profoundly deaf child may never allow their child to develop the skills of ASL that would allow them to communicate with members of the deaf community. <sup>38</sup>

Deaf parents who choose to have their deaf child implanted often face criticism from the deaf community since it can be seen as robbing their child of their culture. Since a strong emphasis is put on oral communication rather than just ASL, children could grow up experiencing a different language from their parents and relatives. The movie *Sound and Fury (2000)* explores this difficult decision as deaf parents of a deaf child must decide whether or not to have their children receive the cochlear implant. More about this movie is found under the sample learning activities and the resources tab.

## Sample Learning Activities

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The following section outlines some sample activities that can be used in the classroom during the eye and ear units. This section provides a brief overview of the activity and resources that are useful for supporting student learning. Additional teacher and student resources can be found under Appendix A.

### **Modeling of the Eye and of the Ear**

Students who are learning about anatomy benefit from multiple exposures to the structure and positioning of these organs. For this reason, it is highly recommended that students are not given pre-labeled diagrams to memorize the labels, but are asked to come up with models and drawings of their own. Students should all create their own drawings of the eye and ear to put into their notes, being mindful of the relative position of all components.

Student generated models for the eye and ear are also relatively strong tools that can be used to facilitate student learning. Students can receive a half sphere of a hollowed Styrofoam ball that can serve as the base for an eye. From there, they can add the anterior chambers and the interior components to complete their model. The same process can be used to make an ear. Modeling clay is a useful and inexpensive tool that can allow students to build structures for both the eyes and the ear. Once students have generated their models, they should explain the structures and functions that are within their model and how they play a role in the detection of light and sound.

### **Eye Dissection**

The second activity that is highly recommended for studying the eye is an eye dissection. Students can follow along with teacher instructions or use a guided video from the Exploratorium (referenced under Appendix A) as they dissect. Students should make qualitative and quantitative observations about the eye including the differences between the aqueous and vitreous humor, the dimensions of the lens, and the relative thickness between the different layers of the eye.

As students dissect, especially if cow eyes are being used, it is important to point out the relative differences between human and non-human eyes. The cow eye will have a tapetum where human eyes will not. Other anatomical differences may also include the size and the oval pupil shape. If enough musculature is left on the cow eye, it is also useful to denote that the cow eye only has four muscles, allowing it to move up, down, left, and right while humans are in possession of six muscles. This allows the eye to roll clockwise or counter clockwise, providing a greater range of motion past what the cow eye experiences. Students can experience this range of motion for themselves. Have students hold their heads still while their partner draws an imaginary clock around their face. Students should be able to roll their eyes a full rotation.

### **Eye Disorder Lab Activities**

There are several mini labs that can be completed for this unit that allow students to explore the differences between “normal” and “abnormal” vision, as well as tricks that help to point out key features of human anatomy. Many of these items can be done with easy to obtain materials, but Carolina offers a visual perception kit that contains these items and many more. More information about this kit is listed below in Appendix A. As with all labs that look specifically at the ability of the body to perform functions as a test of

“normality”, it is crucial to emphasize to students that these classroom lab exercises are not diagnostic but exploratory in this setting. If students are highly concerned about the results of a test they may want to consult their parents or physician.

The first activity requires a Snellen chart—one of the standard visual acuity charts that you see when you go to the doctor’s office. The Snellen chart is used to help doctors determine patient’s visual acuity. A patient is placed 20 feet away from the chart and is asked to read down the lines, starting from the large E, until they can no longer clearly distinguish the letters. Many students may already be familiar with this process from visits to the optometrist. Next to each row is a series of numbers (20/10, 20/20, 20/30, and so on). These numbers are a ratio between the number of feet needed to see clearly for the patient and the number of feet needed to see clearly for an average person. For example, someone who has 20/20 vision is able to see clearly from 20 feet what the average person is able to see clearly from 20 feet. A person with 20/30 vision is able to see the same thing at 20 feet that an average person can see from 10 feet further away, i.e., 30 feet. Someone who is near sighted, however, has a ratio where the second number is significantly higher than the average 20, for example, 20/80.

To perform this test, have students stand at a line 20 feet from the Snellen chart. Students should remove their glasses for this activity as prescriptive lenses will increase visual acuity. Students will cover first the left eye and read out-loud as far down as possible on the chart. A partner is useful for helping to identify letters that the student misses. After, students should switch to their right eye and repeat. The same process can be repeated again with both eyes and with corrective lenses if the student has them.

To look for the blind spot in the eye, the place where the retina attaches to the optic disk that feeds back into the optic nerve, students can use a simple tool. Using a piece of paper that has the blind spot markers on it (usually a dot and a cross), students start by holding their piece of paper at about arm’s length, with their nose between the dot and the cross. Closing the left eye, students should stare at the image of the circle with their right eye. Slowly, students can move the piece of paper towards their face continuing to focus on the circle. At around a foot from the students face, they should notice that the cross that was on the lateral edge of the page has disappeared. This same process can be repeated with the other eye by following these same steps.

Students can experience color vision and color vision fatigue many ways. There are numerous websites that provide examples of what opsin abnormalities might look like and tests that students can take to see if they have color blindness.

A second activity that would require some preparation on part of the teacher is to obtain many different colored flosses or wool yarns and string them on a black cardboard. This activity works best if there are a number of red and greens and blues that are similar in shade but not exact. Students will then need to match strings of floss to the identical bunch on the board without physically holding up the sample. This type of test is a Holmgren-type color vision test. While not the most accurate test for colorblindness, it can be a useful tool for demonstrating the ability of the eye to detect slight differences in color.<sup>39</sup> Many students will find that shades of blue that are closely matching are very difficult to distinguish without physically placing the strings on the board, partially because of the location of blue cones in the periphery of the fovea centralis.

The last activity that is easily performed in a lab setting revolves around fatiguing cones. Students should receive a square piece of transparent green or red plastic cut in 3x3 inch squares. Students should look through the plastic with a single eye at a ceiling light (remind students to use good judgement and not to

stare into lights that are too bright). For this demonstration to work well, students should make sure that their entire field of vision is covered by the piece of plastic and that they try not to blink. Students should continue looking for 1 to 1.5 minutes through this piece of plastic. When they are done, students should look down at a white surface. What should appear is the opposite color—if the student was looking through red, they should see green and vice versa. This process can be duplicated also by looking at a red and green image on a screen and then turning their gaze to a blank wall.

### **Simulated Hearing Loss Lab**

Students can visit several websites that allow them to experience what it might feel like to have different types of hearing loss. A link for this website is found under Appendix A. Students also have the ability to test their own hearing using a Rinne test (as described above) and to create their own audiograms using a pure tone test. It is important to note that students should be careful never to listen to the same pure tone too loudly or for too long because, as previously mentioned, this can cause damage to the inner ear.

### **Cochlear Implant Conundrum**

An excellent tie-in of culture and community revolves around cochlear implants. Students should be given several articles about the way the cochlear implant works, how effective they are in young children, and also the reasons why or why not to have this procedure performed. Students can also use the visual text *Sound and Fury* in which both sides of the argument are presented.

There are several ways students can share this information. Students may be asked to debate one another about whether all deaf children should be given this surgery.

Or, the scenario can be posed as a role play where a pair of students are the parents of a child who has been diagnosed as being deaf. In this scenario, it is important to establish whether the parents are both hearing or deaf or a combination of the two. Other students should be asked to play the roles of doctors, school teachers, ASL specialists, speech therapists, family and friends (both deaf and not), and other community leaders. The role of the surrounding ensemble is to persuade the family to either give the child the implant or to not have their child implanted. It is also important for students to come to the realization on their own that the family might elect to have their child receive the implant later in life and that this can bring on complications of its own.

## **Appendix A—Resources for Teachers and Students**

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### **Resources for the Eye and Light**

**Cow Eye Dissection:** This website contains a video walk through of a cow eye anatomy. The step by step instructions make it an excellent tool to play during the cow eye dissection.

[http://www.exploratorium.edu/learning\\_studio/cow\\_eye/](http://www.exploratorium.edu/learning_studio/cow_eye/)

**Color Vision Testing:** There are many different websites that contain color vision testing tools. The website that is posted below includes visual representations of what it would look like if a patient lacked certain photoreceptive structures in the eye, which makes it especially powerful when talking about color blindness.

<http://colorvisiontesting.com/what%20colorblind%20people%20see.htm>

Color Vision Correcting Glasses: The following is the link for the color vision correcting glasses listed in this paper. This website includes additional information about the glasses and the color vision deficiency that they correct. <http://enchroma.com/test/instructions/>

Blind Spot Lab Tester: This website includes instructions for students to test the location of their blind spot. <https://visionaryeyecare.wordpress.com/2008/08/04/eye-test-find-your-blind-spot-in-each-eye/>

Visual Perception Kit: The visual perception kit mentioned in this paper can be found on the Carolina website, item number 684527.

### **Resources for the Ear and Sound**

Rinne Test: This video demonstrates how to perform a Rinne test with a 512c Hz tuning fork. <https://youtu.be/GeC0A-cDx9w>

Pure Tone Test and Audiograms: This website is an excellent tool for creating student audiograms. It is very important to note that single tones played over a long period of time or at a high decibel can cause hearing damage. Students should not start at the highest decibel, but should work from the lowest dB and work until they are able to hear the tone. [http://www.audiocheck.net/testtones\\_hearingtestaudiogram.php](http://www.audiocheck.net/testtones_hearingtestaudiogram.php)

Hearing Loss Simulator: This website allows students to experience simulated hearing loss at varying levels of severity. <http://www.hearinglikeme.com/hearing-loss-simulator/>

*Sound and Fury* (2000): This movie follows members of a deaf family as they decide whether or not to have their deaf infants implanted with a cochlear hearing aid. <http://www.imdb.com/title/tt0240912/>

Official Statement by the National Association of the Deaf on Cochlear Implants: This bulletin, posted by the NAD outlines the impact that cochlear implants can have on the deaf community. This is an excellent read for students and teachers alike as outlines the unintended consequences medical advancements may have on a community. <https://nad.org/issues/technology/assistive-listening/cochlear-implants>

## **Appendix B—Standards**

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Material in this unit can be used to cover aspects of the Next Generation Science Standard for high school regarding waves and electromagnetic radiation and to develop student's proficiencies in the Common Core State Standards for English Language Arts in multiple areas depending on the focus of the class. In addition, the anatomy focus of this unit fits with the New Haven standards for anatomy and physiology.

A few of these standards are listed below.

### **Next Generation Science Standards**

HS-PS4-1: The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.



HS-PS4-5: Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.

### **Common Core State Standards**

ELA-Literacy.RST.11-12.1: Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

ELA-Literacy.RST.11-12.2: Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

ELA-Literacy.RST.11-12.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

ELA-Literacy.RST.11-12.7: Integrate and evaluate multiple sources of information presented in different formats as well as in words in order to address or solve a problem.

## **Appendix C—Glossary of Directional Terms**

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Anterior: More forward or near the head. Ex. The knee cap is on the anterior of the body

Distal: Away from a given point. Ex. The hand is distal from the shoulder joint.

Inferior: Below a specified point. Ex. The nose is inferior to the eyes.

Lateral: Towards the side. Ex. The ribs are lateral to the sternum.

Medial: In the middle. Ex. The sternum is medial to the clavicles.

Posterior: Further back or towards the rear. Ex. The occipital lobe is posterior to the temporal lobe.

Proximal: Close to a given point. Ex. The femoral head is proximal to the pelvic girdle.

Superior: Above a given point. Ex. The nose is superior to the lips.

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