Seeing Art through the Eye of a Physicist

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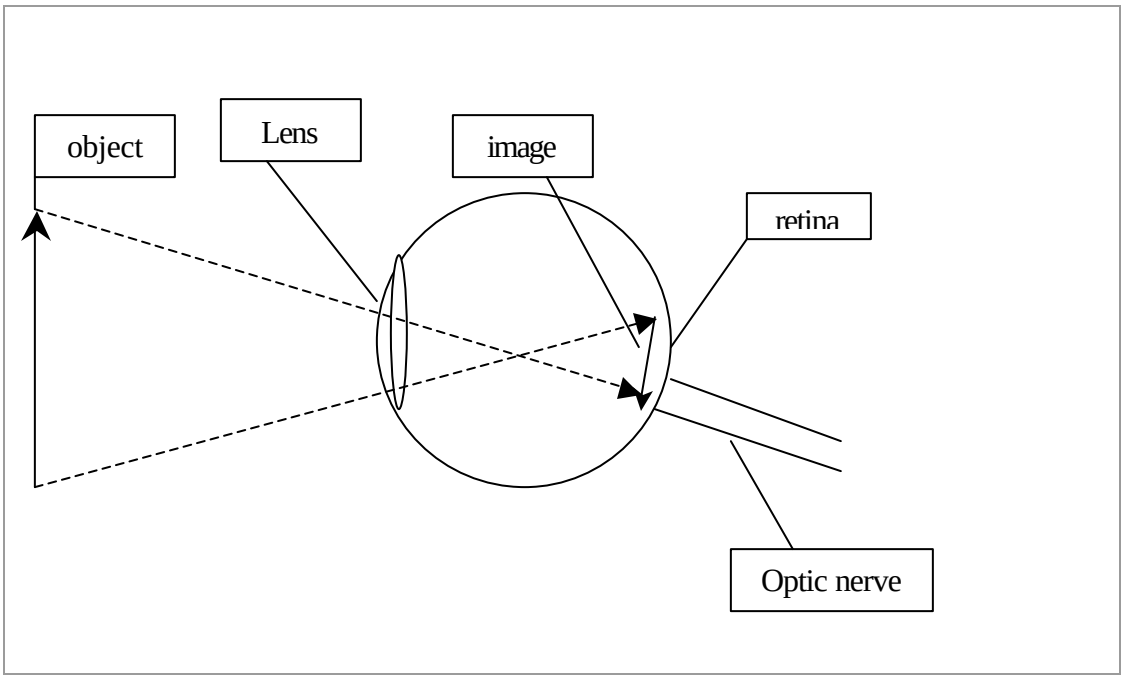
INTRODUCTION

I have always been amazed at the sheer beauty of some works of art and wondered why one painting excites me more than another. What are some the secrets that artist used to draw an observer into the artwork? We take our sight for granted, but when we see a certain painting, we are particularly moved.

Michael E. DeBakey High School for Health Professions, where I teach, is an all magnet high school. It specializes in introducing students to the wide field of the Health Professions. Our students are some of the brightest students in Texas. Therein lies the challenge. According to Jean Piaget, high school students are in the formal operational stage. In this stage there are three main characteristics: thinking abstractly, thinking systematically, and thinking hypothetically (Eggon & Kauchak, 2004). In the formal operational stage students are able to examine abstract problems. Although physics is a study of the world around us, to a great extent physics is very abstract. How do I show how the concepts in physics are used everywhere, even in art? It is the understanding of the basic concepts of light, forces, motion, and analytical geometry that make subjects seem to fly off a canvas and appear alive. The fun will be bringing the past to life and showing how the technology of today is based on some work of the artists of the past.

Physics is not the easiest of subjects; that is true. However we live physics everyday. I just want to show my students examples of how physics can be used to create beautiful art. I say to my students quite often that physics is more than algebraic manipulations of formulas; it is more important to understand the concepts that are studied. I find myself repeating that statement a lot in my classroom. Physics is more conceptual than it is mathematical. We use math in physics to allow us to construct models of real world situations. How is that fact related to art? Some, like my students, may say there is no relationship. I hope to show them there is. To do this we will look in particular at optics, the branch of physics that explains how light behaves. "The physicist, like any other scientist, sets out to break 'nature' down into its component parts to analyze the relationship of those parts. The artist on the other hand, often juxtaposes different features of reality and synthesizes them, so that upon completion, the whole work is greater than the sum of its parts" (Schlain, 1991).

We know that in our world everything is in three dimensions. Objects have length, width, and height. When painters want to represent what we see in everyday life, they have a major obstacle. The canvas that they work on can only be in two dimensions. Art and science are brought together again in needing to understand how the human eye works to interpret the beauty we see in nature. Men and women have wondered, researched, and measured to get the correct representation of the three dimensional world. Mathematician and scientist René Descartes used geometry to show how light hits the retina inside of the eye.



The eye is an amazing part of our body; it allows us to make meaning of the physical world through sight. Light travels into the eye through the lens. It travels through a liquid called the humorous. The humorous is a clear liquid that helps the eye keep its round shape. The lens bends the light traveling in to the eye so much so that when the lights strikes the retina in the back of the eye. The whole image can be interpreted by the optic nerve.

Philosophers spent a great deal of time in defining sight, "to know is to see" (Galison and Jones, 1998). Although the theories of vision were wide ranging of each other, they all agreed that to see an object is to establish with it an immediate relationship. This is where interpretation comes in, and this is why a group of people can look at the same piece of art and get different feelings. One of the older theories of sight reduced it to touch. The *atomists* believed that emanations from objects entered the eye through the iris and go directly to the soul. Plato and Aristotle had similar theories about sight and the connection to the soul. A look into the 17th century shows how vision became defined physiologically and psychologically. Johannes Kepler explained his idea about how vision works in his *Ad Vitellionem Paralipomena* (1604). He established a difference between the fixation of the image in the optical field and the grasping of this image by the soul. (Galison and Jones, 1998)) Kepler was able to begin the definition of optics by referring to the concave shape of the retina.

For example, when observing Leonardo da Vinci's *Virgin and Child with Saint Anne*, we can notice that it is very powerful and calm at the same time. Da Vinci understood how light behaves and he applies his knowledge in the beautiful portrait. Da Vinci uses colors to give the illusion of how light would play on his subjects as though the setting sun is behind the observer's shoulder. He shows how the body overcomes gravity when the Virgin reaches for her child. Without showing the muscles, the observer is made aware of the strength involved in that single move. Students will also see in this example the intense need to be creative and not a copycat. DaVinci had this to say about imitating another artist, "No painter should ever imitate the style of another painter because he will be called a nephew and not a child of nature with respect to art. Because nature provides so many things, we ought rather to rely on nature than on those masters who have learned from her" (Townsend, 2001). This statement is important because in physics we study the world around us.

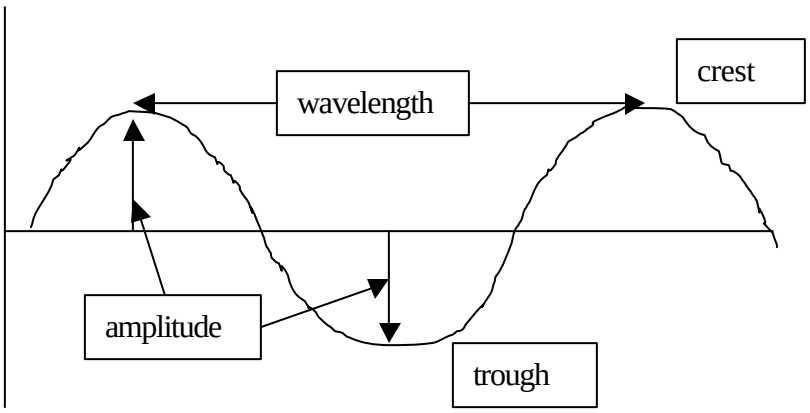
Da Vinci will not be the only artist studied in this unit. This unit will use examples of Monet and other artists who show how they understand how light behaves. This understanding helps them to create art that is greater than what they may have used as a model. How do artists use this knowledge about vision to trick our minds to see more than just shapes on paper? In this unit we will look at three great artists, Leonardo da Vinci, Claude Monet, and Diego Velazquez, and discuss very specific areas of their work.

Claude Monet is one the most well known artists of the twentieth century. Monet became particularly interested in reflections, and two-dimensional imagery. At his home in Giverny, Monet would spend hours at a time studying the fields, ponds and even the haystack, paying close attention to the way light behaved. What the students will see is that even when Monet painted the same subject, the results were still very different. This is because of the angle of reflection of the sun; the light would bounce totally differently off of the water and than off the surrounding trees. Monet also understood refraction. It is the bending of the sun's light as it passes through the earth's atmosphere that makes so many different patterns and textures. Monet was able to paint these haystacks in different seasons and different times of the day. Even though the subject did not change, how it was painted was always different. Sunrises and sunsets are beautiful, and they are wonderful examples of refraction. They are such good examples because the atmosphere is the densest at the horizon. When Monet did his work on the haystacks around him, he painted the changes as subtly as they may be. His work is defined as Impressionism, a traditionally French art movement based on the law of optics (*Masterpiece Technologies*, 2004). Monet's studies in reflection become obvious when the students see *Poplars* and *Water Lilies*. The students will use examples like these to draw Geometric Optics using ray diagrams. When the students are able to understand how geometrical optics work they will be able to appreciate some of the more subtle examples of reflection.

The third artist of this unit has done some amazing work with reflection of subjects in a flat mirror. His name is Diego Velazquez. The name of the work that we will study in this unit is *Las Meninas*. This painting is amazing for many reasons that we will dissect in our class. Velazquez gives us the observers of this painting a behind-the-scenes look at a studio session for a painting of a young model. At first glance the observer is led to believe that there may be some strange things going on in this studio. First of all, is it a painting of an artist and the model and the attendants in the frame? This portrait will be the focus of my lessons on reflection. The fact of the matter is that Velazquez has painted this painting by putting the observer in the position of the large mirror he himself is looking into. Velazquez also keeps the proportions of the people in the studio correct; he could only have done this with a strong understand of reflection using a flat mirror.

UNIT BACKGROUND

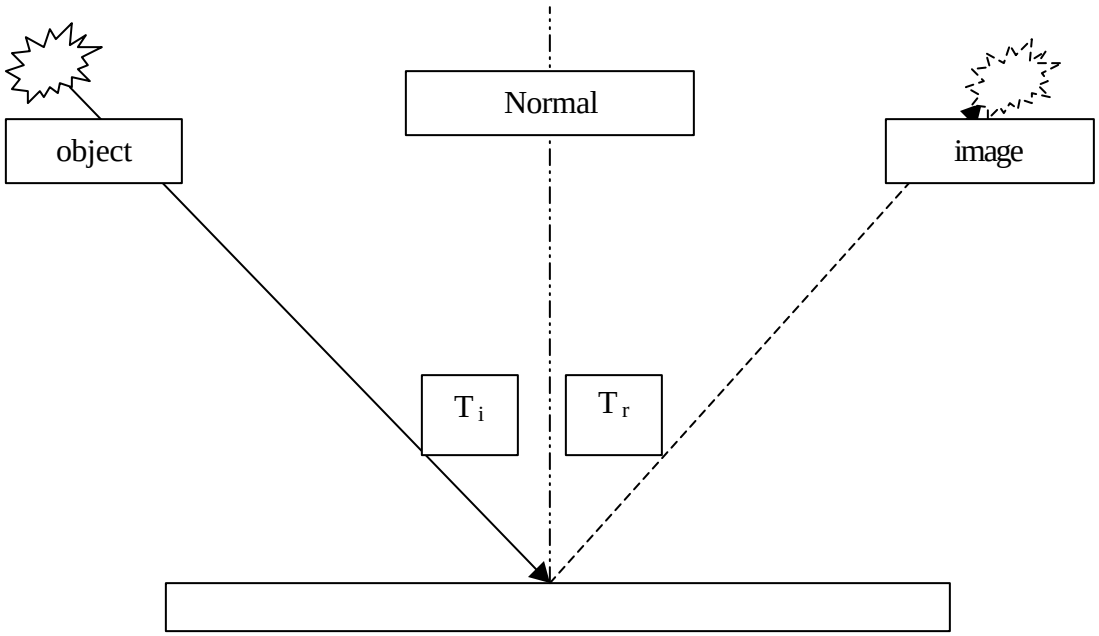
Optics is the foundation of this unit. What is exactly is optics and how does it help the artist? Let's start by defining light. Light is a form of electromagnetic energy. It has many different frequencies that allow the eye to interpret color. Light has properties of both waves and particles. Although there are an infinite number of frequencies there is still only one speed that light travels at and that is roughly $3.00 \text{ X } 10^8$ meter per second. Light travels as a wave. There are several properties of waves that will be explained to the students to help them analyze what they are measuring.



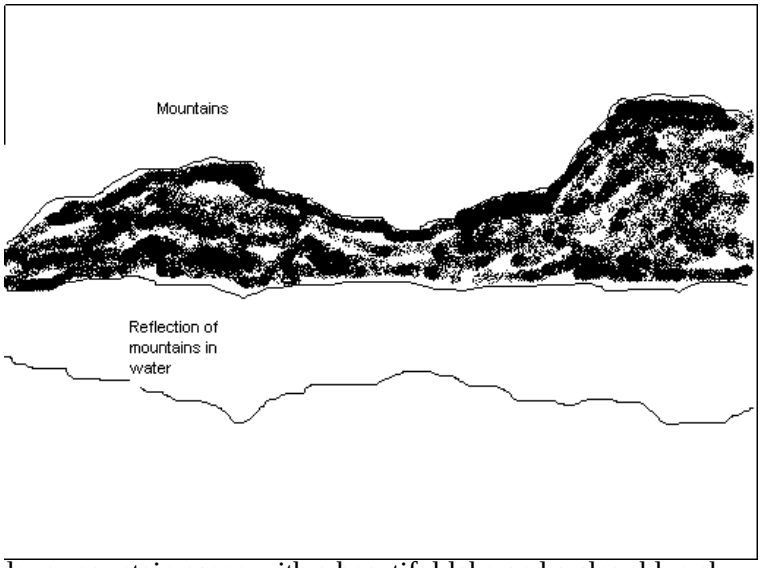
Wavelength is the measure in meters from one wave crest to the next or wave trough to the next. The amplitude is the height of the wave; this term applies to the intensity of the wave. Once light is defined the students can begin studying how it behaves in our world.

HISD has adopted the CLEAR curriculum as the foundation upon which all of our lessons are developed. There are three objectives in CLEAR that speak to the necessity of a unit like this. The first is PHYS.03.C: Evaluate the impact of research on scientific thought, society, and the environment. The second is PHYS.03.E: Research and describe the history of physics and contribution of scientists. The third is PHYS.08.B: Identify the characteristics and behaviors of sound and electromagnetic waves (CLEAR Curriculum, 2002). There is a need for students and teachers as well to see a link with science and society. Art and physics being connected is an unexpected pleasant surprise in the understanding of the concepts of light and how it behaves. Using CLEAR as the framework allows the unit to grow and constantly be up to date and fresh without growing out of control. This unit will also challenge the students to think conceptually about physics and less about the "plug and chug" method of physics.

Conceptually, there are two main concepts in optics that are addressed in this unit. One is reflection. The other is refraction. Reflection is something that students are familiar with. Every morning when a student goes to school it is their reflection they check before going out of the door. Physics asks the student to imagine, especially in the concept of light. Although we are constantly in light and we use it to see the world, what is light? Light is only part of the electromagnetic wave spectrum. The electromagnetic spectrum is made up of transverse waves that consist of oscillating electric and magnetic fields at right angles to each other (Serway & Faughn, 2002). Now that simplifies everything, but what is light?! Light is electromagnetic radiation that can produce a visual sensation. In order to make measurements of reflection, we need to understand ray geometry. Ray geometry is a practical application of geometry that used extensively in reflection. There are two worlds in a mirror, the real and the virtual. The virtual is the reflected image. When using geometrical optics the angles are what are important. There is the angle of incidence, which coincides with the real image, and the angle of reflection. There is a law of reflection that states that the angle of incidence ($?_r$) is equal to the angle of reflection ($?_i$) (Halliday, Resnick, 1988).

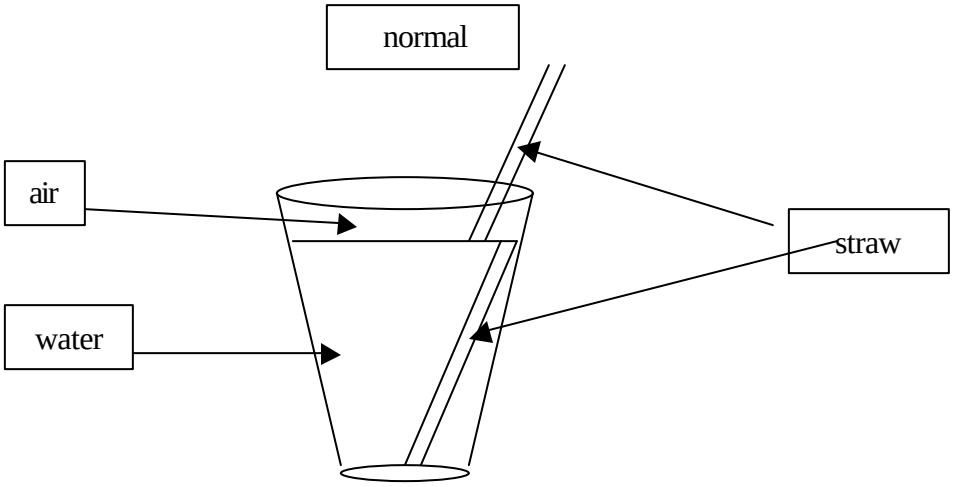


When the artist understands how reflections can be used, then the artist can use reflection to convey certain feelings or perceptions of a subject or subjects. This can be done subtly; for instance, an artist could paint a portrait of someone sitting in a parlor with a mirror in the frame. As the artist develops the picture he may use the reflection of the room to give the observers of the painting a reverse view of the room. This could extend the observer's view and cause the observer to think that the room is larger and only after studying the painting for some time does the secret of the window become revealed. Reflection can also be used bluntly to cause a shift in the understanding of what is up and what is down. When an artist uses reflection this way a momentary loss of the observer's own definition of up and down has been snatched away by the artist.



For instance, consider a mountain scene with a beautiful lake and a clear blue sky. If an artist takes the time and effort to line the angle of incidence and the angle of reflection, the effect is wondrous.

Refraction is the next objective of this unit. Refraction is the bending of light. Although the speed of light is constant, how it behaves is not constant depending on the medium it passes through. Light can be bent; for instance, if you look at a straw sitting in a glass of water from the side the straw will appear to be disjointed. This is because as the light from the object approaches the eye it passes through water, glass, and air. Each of these media has a different bending effect on light.



We can calculate how much water and air bend light by using another law of optics called Snell's Law. This law uses geometry and trigonometry to explain a physical event. Snell's Law uses a standardized index of refraction for materials. The index is noted by n. Snell's law relates the angles of the light as it goes form one medium to the next and the index of refraction of each media; $n_1 * \sin(?_1) = n_2 * \sin(?_2)$

This unit will allow my students to see creativity in action. The unit is designed to give the students insight to the fact that artists have to research their subject. This research can either be by writing or even sketches before the final product is made. When we have come to the end of the unit, the students should be able to produce creations based on one or several physics concepts that will be displayed in the library along with sketches and explanations. Examples might include paintings, sculptures, or maybe even photographs. We will let the student body decide if it is art.

UNIT

This unit will take students on a two-week journey through the beauty of physics and the science of art. As mentioned earlier, the objectives of research are the basis of this unit. The students will spend time finding out about different artists who were also scientists and their contributions to both worlds. Then the students will discover and share how the contributions are related.

The next step is introducing the science of light or optics. We will begin with simple reflection and how it is important to understand the geometry of reflection. The lesson will use a painting that uses reflection of a scene in nature and the students will draw ray diagrams to show how the artist had to be exact in order for the effect to work.

How does the eye focus the light of the outside world? We have lenses that focus light and help to define what we see. How do artists use this knowledge to help convey messages? This lesson will show how lenses work. There are two types of lenses we will study; concave and convex. Concave spherical mirrors are used whenever a magnified image of an object is needed, as in the dressing-table mirror. The concave spherical mirror is an outwardly curved, mirrored surface that is a portion of a sphere and that diverges incoming light rays (Serway & Faughn, 2002).

Refraction is the last segment of this unit. Once we have defined what light is and how our eyes allow us to see this light, building the bridge between art and physics will be a little easier. The works of Claude Monet will be used for this part of the unit. We will look at several reproductions of his work in the hayfields and on the water.

IMPLEMENTATION STRATEGIES

The plan is to introduce students to optics by first reviewing what they have learned about energy and the law of conservation of energy. The students will also review heat. This may seem strange to review heat. After all you cannot see heat; however, it is a form of energy. That leads me into introducing light. The students will then see how to measure light in the form of waves and their properties. I plan to get a few examples of different artists' work to help explain two main properties discussed earlier.

We will spend about a week on ray diagrams. We will focus on reflection first and the students will have hands-on laboratory activities to allow them to use protractors, rulers and graph paper to trace the paths that light takes. Once the students have gone through that lab, I will give them a chance to draw ray diagrams on a photograph of a pond that shows examples of reflection. The final step is for the students to produce their own example of art using reflection. The project will have three steps. The first step will be to brainstorm and come up with an original idea. In the next step the student will have to make a sketch of their idea using ray diagrams and the law of reflection to prove the validity of the idea. The final step is to develop their idea into a finished product, either in color or black and white. The important objective is that the students will connect art with science.

LESSON PLANS

Lesson Title: What is Light?

Overview and Purpose

Optics and how it applies to art, specifically reflection and refraction. This lesson will define what light is and how we interpret it.

Objectives

CLEAR Objective PHYS.03.C
Evaluate the impact of research on scientific thought, society, and the environment.
CLEAR Objective PHYS.03.E
Research and describe the history of physics and contribution of scientists.
CLEAR Objective PHYS.08.B
Identify the characteristics and behaviors of sound and electromagnetic waves.

Student Materials Needed

1. Paper
2. Pencils
3. Text

Teacher Materials Needed

1. Overhead projector
2. Colored markers
3. Light sources; incandescent, fluorescent, and Ultraviolet

Information

Start out by drawing a sketch of a wave reminding students of the properties of waves. Light is part of the electromagnetic wave spectrum and follows the same rules, to great extent, as all waves follow. Once it is established that visible light has wavelength and frequencies, show the students graphically that visible light is a small part of the EM spectrum. Teachers will be able to find the specific numbers in their teacher's manual. Define the speed of light as the wavelength of light times its frequency. As mentioned earlier in unit background the speed of light is constant.

Verification

It is always a good idea to do several examples of wavelength and frequency problems. It is also necessary that all steps and units are shown. Dimensional Analysis is a weakness among the high school students I have taught.

Activity: Light Demonstration

Use the different light sources as examples find out what the frequency is for each source and have the students find the wavelengths. Have the students put light sources in order from low to high.

Summary

This lesson is the link between textbook definitions of wavelength, frequency, and electromagnetic wave spectrum. The students will be shown that the wavelength and frequency of a light source always equals the speed of light.

Lesson Title: Reflection

Overview and Purpose

The lesson is design to continue with the focus on light and how it behaves. This lesson will use works from Claude Monet and Diego Velazquez. The lesson will start with the students reviewing a reproduction of Da Vinci's *Virgin and Child with Saint Anne*.

Objectives

CLEAR Objective PHYS.03.C
Evaluate the impact of research on scientific thought, society, and the environment.
CLEAR Objective PHYS.03.E
Research and describe the history of physics and contribution of scientists.
CLEAR Objective PHYS.08.B
Identify the characteristics and behaviors of sound and electromagnetic waves.

Student Materials Needed

1. Notebook paper
2. Graph paper
3. Colored pencils red and blue
4. Ruler

Teacher Materials Needed

1. Reproductions of Diego Velazquez's *Las Menina* and Leonardo da Vinci's *Virgin and Child with Saint Anne*
2. Overhead projector, colored pens and a ruler

Information

This lesson may take two 85 minute block days. The lesson will open with students viewing the painting by Leonardo da Vinci to ask the question, "How does light behave in this painting?" Is it all the same brightness? What about the background of the picture; why is not as sharp as the foreground? These questions will be used to focus students into thinking more about how light behaves in different surroundings. It is important to note how Leonardo da Vinci used shadowing to convey power and emotion.

The next step in this lesson involves the one of the simplest behavior of light reflection. Before bringing the law of reflection into the picture, the students will look at a reproduction of Diego Velazquez's *Las Meninas*. Review the unit background to help break down the charm of this painting. This is a good time to bring in the law of reflection.

Verification

Student input is very important in this lesson. Allow them to discuss what they see. Ask them if what they are looking at are the real or virtual images. Call on students who do not normally participate in Physics class.

Activity

The students should be in groups of two or three and have each group look at the painting of *Las Meninas*. Have each group try to come up with a photograph that they set up that show the magic of reflection. The students have to be able to show what the object is and what the reflected image is**.**

Summary

The pictures that the small groups create should be different even though they may use the same areas around their surroundings. This will allow the students to take ownership of the subject matter.

Lesson Title: Refraction: Bending Light

Overview and Purpose

This is the final lesson of this unit it will span two 85 minute class periods. The main artist focused on is Claude Monet.

Objectives

CLEAR Objective PHYS.03.C
Evaluate the impact of research on scientific thought, society, and the environment.
CLEAR Objective PHYS.03.E
Research and describe the history of physics and contribution of scientists.
CLEAR Objective PHYS.08.B
Identify the characteristics and behaviors of sound and electromagnetic waves.

Student Materials Needed

1. Paper
2. pencils
3. Graph paper
4. calculator

Teacher Materials Needed

1. Overhead Projector
2. Works by Claude Monet on haystacks and his ponds.
3. Suggestion: A computer with internet connection and a projector would be really good to use during this unit.

Information

Refraction is a good subject to help foster the students' imagination. Use the example of a pencil in a glass of water and have the students observe the glass. Question the students on why they cannot believe everything the eye sees. Show the students examples of Claude Monet's work, specifically the haystacks and lily ponds.

Discuss how when Monet was painting the same thing over and over, he showed how light from the sun changed how the objects appeared. The air the light shines through near the horizon during sunrise and sunset is denser and bends the light more than when the sun is at its zenith.

Verification

It is important that students be allowed to discuss Monet's work and hopefully the question will come up, "What does this have to do with physics?" The students should be allowed to ask questions that are challenging so that refraction becomes something they can understand. Then introduce Snell's Law as a part of the pictures. Look at the shadows on the pictures ask the students about the angle of the shadows. Also ask the students about the length of the shadows.

Activity

The students should be in small groups of two or three. Ask the students to take pictures of sunrises and sunsets. Have the student groups present their pictures to the class. Ask the groups to present their pictures to the class and explain when it was taken and why the picture was chosen.

Summary

This lesson allows more involvement by the students, and the teacher should let the students use their imagination within limits of course. The most important part is that the students make the subject of refraction theirs.

Lesson Title: Student Photography Show

Overview and Purpose

This is the chance for the students to show their work school-wide. By giving the students a chance to display their different photos, they will have a more personal ownership of basic optics.

Objectives

CLEAR Objective PHYS.03.C
Evaluate the impact of research on scientific thought, society, and the environment.
CLEAR Objective PHYS.03.E
Research and describe the history of physics and contribution of scientists.
CLEAR Objective PHYS.08.B
Identify the characteristics and behaviors of sound and electromagnetic waves.

Materials Needed

1. Group photos of reflection and refraction
2. Explanation of pictures including:
   A. Location
   B. Time of Day
   C. Type of picture (reflection or refraction)
3. A suitable place for viewing all of the students' work

Information

The purpose of the presentation is to bring together for the students art and physics. The size of the photo should be no smaller than a 5X7. 8X10 is preferable because it will allow students and other observers to see the detail of each group's work.

Verification

Ask for teachers to come and view the students' work and give feedback to you. Share the remarks with the students.

Activity

The students will have a Photo Gallery show where each group presents and explain how they did their photos. Most importantly, the students will relate their photos to reflection or refraction.

Summary

This lesson is an excellent assessment of the level of understanding of optics. Presenting their work and explaining how it applies to the subject matter is at the highest level of Bloom's Taxonomy.

Conclusion

This unit is designed to bring the science of light and the art of light together. The most important thing to realize is that we as teachers must find ways to make the information we are teaching more personal to the students. When we prepare lessons the question must be asked, "Why would I want to learn this subject?" When students can look at the work of other students and their own, that automatically draws them in and the memory of this work may stay with them for years. My hope is that this unit will allow teachers to bring more beauty into physics.

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Lori Dr. What Is Impressionism 2005. <http://www.drloriv.com/lectures/impressionism.htm>.
An excellent website that is straightforward and helpful for a novice in the art world.

Virtual Museums

MuseumLinks Museum of Museums. <http://www.museumlink.com/**virtual**.htm>.
An excellent place to look for reproductions of the works mentioned in this unit.