Teaching the Physics of Light Through Inquiry

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Academic Setting

This curriculum is designed for seventh grade students at Madison Middle School. The school is located in an area that is generally middle range in socioeconomic status. Madison has about an 80% Anglo population, 10% Hispanic and 10% other. Madison Middle School is one of twenty-five middle schools that make up the Albuquerque Public School district. It is part of the Sandia High School cluster. I teach physical science. Teaching the Physics of Light Through Inquiry is designed to motivate students by using a hands-on approach.

New Mexico Science Standards and Benchmarks

This unit is intended to fulfill the following New Mexico Standards and Benchmarks:

Standard 9: Physical Science Students will know and understand the concepts of energy and the transformation of energy.
A. Apply knowledge about energy and energy transformation to science problems.
2. Investigate wavelengths and energies in the visible part of the electromagnetic spectrum.
3. Demonstrate how waves interact with barriers and with each other.

Standard 1: Unifying concepts and processes. Students will understand science concepts of order and organization.
B. Apply prediction to scientific problems and events.
2. Relate the outcome of a simple science experiment to a process that happens in the world. Explain how science experiments help us understand processes that occur in nature and processes that occur in society.

Standard 5: Science as Inquiry: Students will acquire the abilities to do scientific inquiry.
A. Use the scientific method within the classroom and school environment.
1. Design and conduct investigations including adequate number of trials, unbiased sampling and accurate measurement and record keeping, and comparison to control.
B. Employ equipment, tools, a variety of techniques and information sources to gather, analyze, and interpret data.
4. Use basic and advanced tools to observe and measure natural and artificial objects and events.

Standard 6: Science as Inquiry: Students will understand the process of scientific inquiry.
A. Use different kinds of methods, including observation, experiments, and theoretical and mathematical models to answer a variety of scientific questions.
1. Use various mathematical and investigative procedures to determine patterns and relationships, and make predictions.
F. Describe the results of investigations with teacher, peers, parents, and others.
1. Explain findings of investigations to the class in several ways (individual and group presentation, logbook, etc...)
2. Understand that scientists examine other scientists work, that scientific findings need to be communicated and confirmed, and that some scientists may develop new or different explanations for the same set of observations.

Context and Background

Why should the science of light be taught? Optics, the science of light, was once at the forefront of physics, and as such it was an important part of every introductory course and every curriculum for physics majors. Unfortunately, this no longer appears to be the case. Recently, optics has moved to the forefront of technology and the number of physicists engaged in optical research has increased markedly in recent years. Yet, many physics students do not study light on the intermediate or advanced levels, and even in introductory courses this subject fails to receive the attention it deserves.

Light is a very attractive and understandable subject for students in elementary and middle school, and the study of light is becoming a part of many science courses designed for future elementary and secondary science teachers. Obviously light and color have many important applications in the visual arts. Professional artists agree that an understanding of light and color at an early stage contributes a great deal to the education and development of visual artists. It also contributes a great deal to the appreciation of art by the lay person. So much of modern technology is based on light and color, studying it contributes to the understanding of these new technologies that our leaders, as well as informed citizens, need.

In this unit, I would like to focus on how learning takes place, concentrating on students perception of the scientific concepts of light. Results from research, documented by McDermott and DeWater indicate that at all levels of instruction the difference between what is taught and what is learned is often greater than most instructors realize. During the last 15 years, an increasing number of physicists have been contributing to the growth of a new area of scholarly inquiry within the field of physics: the learning and teaching of physics.

Traditionally instructors teach from the general to the specific. Generalizations are fully formulated when they are introduced. Students are not actively engaged in the process of learning. Very little inductive thinking is involved. Instructors present general principles and show students how to apply them in a few special cases and hope students will be able to do the same in new situations.

In order for students to grasp the concept being presented, they need to develop a working understanding. Students need to use equipment and materials so they can "see" what is being taught. A useful way to do this is to present a "discrepant event" for the students to analyze, and then guide them through the scientific concepts. More than one experience is usually needed for students to understand the concepts involved. Without this type of activity-based approach, students tend to simply memorize information and answers. They are unable to generalize and apply the concept to other situations.

Questions that uncover students' thinking help instructors discover the intellectual status of the students. They reveal where they are with regard to the necessary conceptual understanding. Students need to encounter some difficulties, to resolve conflicts and inconsistencies, so as to grow intellectually from these experiments. It is important that they do not wander aimlessly. Teachers need to support their intellectual insecurity. Teachers must question and listen carefully. Sometimes the best strategy is to ask a question such as, "What would you need to do to find out?"

It is also necessary to think about the engagement of students and the developmental appropriateness of the selected activities. Science is naturally engaging. Students are intrigued by the world around them and have already begun to develop their own explanations of how and why things work. Teachers must use this curiosity and channel it so that students develop more appropriate explanations for basic phenomena.

I intend to develop curricula that will incorporate some of McDermott's theories of how students learn physics. L.C. McDermott is a professor of physics at the University of Washington. She has done extensive work with college students in pre-testing, tutorials and post-testing. What follows is an example that shows the physics of light using an inquiry approach.

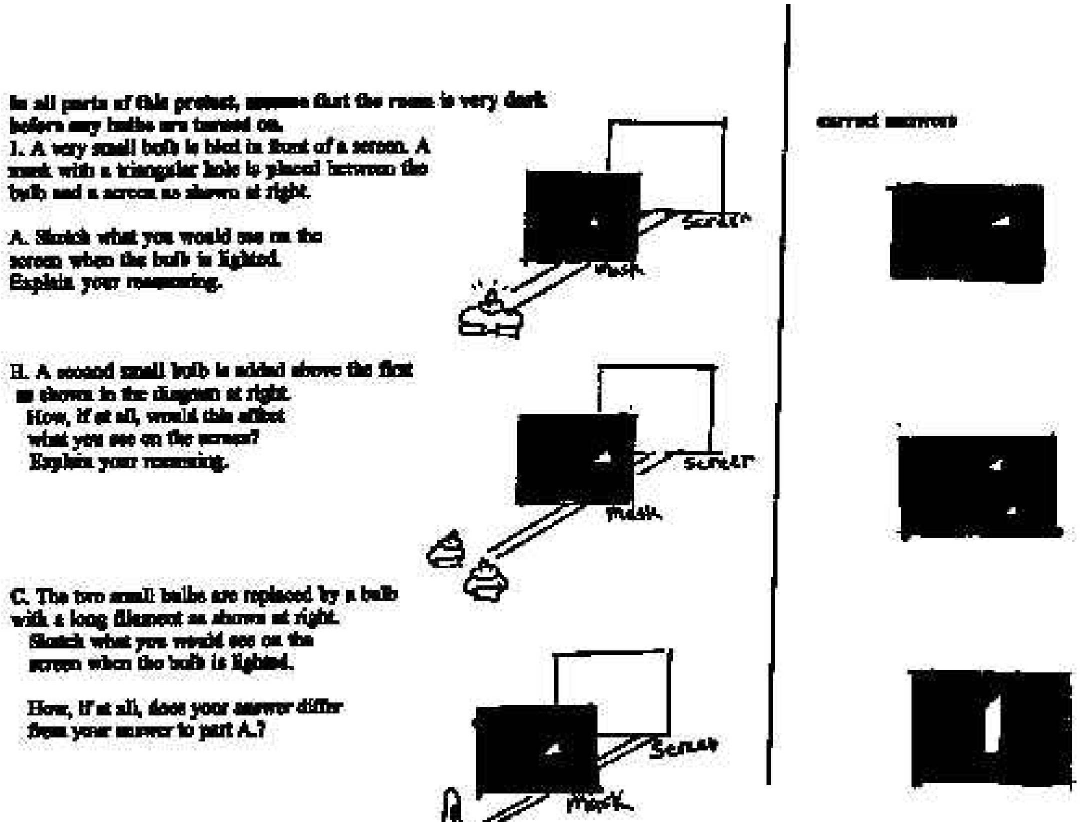

Figure 1

A tutorial sequence on light and shadow (Wosilait, Heron, Shaffer and McDermott) begins with a pre-test based on a simple optical system consisting of a light source, a mask with a small triangular hole (~1 cm) and a screen. The pretest shown in Fig. 1 contains three questions. A correct response requires that students recognize that light travels in a straight line and that a line source can be treated as a series of point sources. Students are required to explain their reasoning for their answers on the test. A correct answer for the wrong reason earns no credit. This version of the pre-test was given to more than 1200 students from many classes in the optics portion of an introductory calculus-based sequence. In some classes, there had not yet been any instruction in geometrical optics; in others the students had completed a laboratory on ray tracing with plane and curved mirrors. In still others, both this laboratory and the relevant lectures had already taken place. Although the amount of instruction varied, the results did not. 90% of all the students correctly predicted a single triangular image for the single small bulb. For the second question (two bulbs) about 60% of the students gave a correct response The third question was answered correctly by only 20% of the students.

After the pretest was administered for the first time, it was clear that most students were unable to apply their knowledge of how light travels. Using the results from the pre-test as a guide, a tutorial on light and shadow was designed.

The tutorial begins by helping students develop and apply the concept that light travels in straight lines. The students make several predictions similar to those asked for on the pre-test. After they have made predictions and given explanations of their reasoning, they check their answers and try to resolve any inconsistencies. In the first experiment, students predict what they would see on a screen when a mask with a small (1 cm) circular hole is placed between a small bulb and the screen. They also predict what will happen when the hole is triangular. They are then asked to predict what will happen to the image when the bulb is moved either slightly upward or away from the screen. The students often do not know how to represent the physical situation in a side-view diagram. As they become better able to draw and interpret such diagrams, they make use of this representation in trying to resolve inconsistencies between their predictions and observations.

The students then add a second bulb in front of the mask with the circular hole and predict how the appearance of the screen will change. Next, they predict what would appear on the screen if a string of closely spaced small bulbs were used. When they are then asked what would happen with a long filament bulb, many students recognize the similarity between the two situations and think of the image as being formed from a series of closely spaced, point-source images. As was shown on the pre-tests, however, some students obtain the correct answer by using incorrect reasoning. We ask students to predict what they would see if the hole on the mask were triangular. As on the pre-test, students who use a stretching model predict an elongated triangular image for the long-filament bulb. They recognize that their prediction is incorrect when they observe the distinctive image formed in figure 1B. in which the shape of the triangular hole can be clearly identified at one end. The use of a triangular hole helps the students to confront their mistaken belief about how the image is formed. They resolve their confusion as they begin to recognize that each point on the line source produces an image like that of the point source. Some students note that the brightness of the image is not uniform but varies with the amount of overlap among the triangles that combine to form the image. This experience reinforces their understanding of superposition.

Later exercises ask students to consider both up-down and left-right inversions between asymmetric light sources and their images. Students predict what they would see on the screen when a mask with a small triangular hole is placed between an L-shaped light source and the screen. In this case, the image is inverted both left-right and up-down. Students who fail to predict one of these inversions can usually recognize the flaw in their thinking. They note that the basic L shape of the light source has a more pronounced effect on the shape of the image than does the shape of

the triangular hole. When they try apertures of different sizes and shapes, some begin to generalize that a very small hole forms an invert image of the light source that is relatively unaffected by the shape of the hole. These exercises show that the size and shape of the source, the size and shape of the aperture, and the distances involved all can all have a pronounced effect on the image.

Post-test #1, which is depicted in figure 2, was given on examinations to approximately 415 students in three different classes to assess the effectiveness of the initial version of the tutorial. The student were asked to sketch the shape of the lighted area on a screen when a light source in the shape of an exclamation point is placed in front of a mask with a small T-shaped hole. The correct answer, which is shown in Figure 2b, can be found by treating the long-filament bulb as a continuum of point sources, each of which generates a T-shaped image. The small bulb produces a T-shaped image above the image due to the line source. About 45% of the students gave a completely correct response. Some neglected to include the image formed by the single bulb, or they put it below the image produced by the long-filament bulb.This result is an improvement over the 20% who correctly answered the corresponding question about a long-filament bulb on the pre-test.

Post-test- Students were asked to sketch what they would see on the screen when the bulbs were turned on. B is the correct answer to the post-test question.

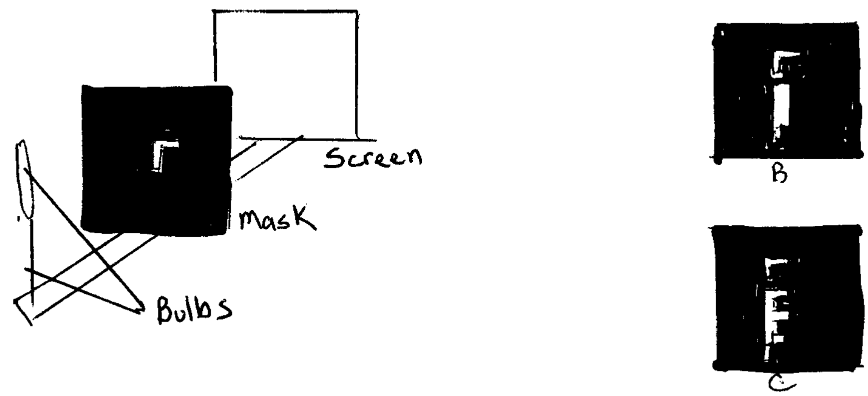

Figure 2

McDermott's work provides a framework for teachers to plan successful units, teaching physics. Teachers also need an understanding of basic physics concepts before teaching a unit on wave and light. The basic wave topics include observing wave motion, describing the basic characteristics of waves, identifying basic wave interactions, and relating wave speed to frequency and wavelength. Light topics include describing the properties of electromagnetic waves, describing the nature of light ray, comparing regular and diffuse reflections, describing the process of refraction, explaining how the human eye sees, and comparing transparent and opaque objects.

Waves and Wave Optics

A wave is a "wiggle" of something in time and space, a disturbance that repeats regularly in space and time, and that is transmitted progressively from one place to the next with no net transport of matter. In general, a wave is a propagating disturbance of some equilibrium.

Light is not a vibration of matter but a vibration of nonmaterial electric and magnetic fields. These fields create a force. This force is represented by an electric field. Even if no positive charge is nearby, the negative charge has an electric field which is ready to pull or push on any charge that enters into its region. This determines electric field lines which create an arrow tangent to the line points in the direction of the push or pull that a positive charge would feel at each point in space. These field lines can exist in a vacuum. If the electric field associated with the light is always parallel to a fixed line, then the light is said to be linearly polarized and the direction of polarization is the direction of that line. If the electric field direction changes so randomly that no direction of polarization is preferred over any other, we call the wave unpolarized. Most "natural" light, such as sunlight, moonlight, and bulb light is unpolarized.

A sine wave represents the simplest type of wave, but there are many other shapes of waves. The top of the wave is called the crest and the bottom the trough. The wavelength of a sine wave is the distance from the top of one crest to the top of the next one. The wavelengths of waves at the beach are measured in meters, the wavelengths of ripples in the pond in centimeters, and the wavelengths of light in nanometers (billionths of a meter). A wave is periodic and has a repetitive pattern. The time between repetitions of a wave is a period. Frequency describes how often a vibration occurs. Frequency is the number of times each second that an oscillation occurs at any fixed point in space. To oscillate means to move back and forth between two points.

Wave motion allows energy to be transferred from a source to a receiver without the transfer of matter between the two points. It is through wave motion that sound come to our ears, light to our eyes, and electromagnetic signals to our radios and television sets. The speed of wave motion is related to the frequency and wavelength of the waves. Wave speed = wavelength x frequency. It also equals how far a crest travels in a second. Amplitude tells us how great the disturbance is from the inactive state. Amplitude tells us how "big" the wave is. Amplitude is proportional to the rate at which energy is transferred by all waves.

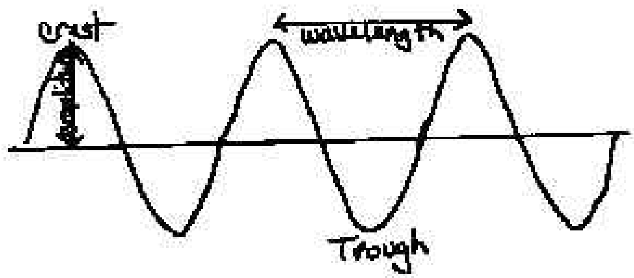

Figure 3

There are two main types of wave motion: transverse and longitudinal. In transverse waves, the motion is at right angles or is perpendicular to the direction of the wave’s motion . Strings, water and light demonstrate this type of perpendicular movement. With light it is the electric and magnetic fields which are perpendicular to the direction of the motion. In longitudinal waves, the motion of the medium is parallel to the direction of the wave. With sound waves, it is the molecules which oscillate back and forth along the direction of the motion of the wave. When air molecules are crowded together, the space in the medium in which they are crowded is called a compression. As energy is added, the particles collide with the particles next to them. The first set of air molecules moves to the left while the second set of particles begins to vibrate and moves to the right. This leaves a space in the medium in which there are few particles. A space in which there are few particles is called a rarefaction. Each layer of particles pushes the next layer as the compressions move forward through the medium. Each compression is followed by a rarefaction. As the layers of particles move back and forth, compressions and rarefactions develop and move in a regular repeating way. Energy is transmitted as a longitudinal wave.

When multiple waves are produced and overlap they form an interference pattern. Within the pattern, wave effects may be increased, decreased or neutralized. When more than one wave of the same type occupies the same space at the same time, the displacements of the medium add at every point. This is the superposition principle. When the crest of one wave overlaps the crest of another, their individual effects add together to produce a wave of increased amplitude. This is called constructive interference. When the crest of one wave overlaps the trough of another, their individual effects are reduced. The high part of one wave fills in the low part of another . This is called destructive interference.

Interference patterns in light can be seen when two sources of waves are placed side by side. In 1801 Thomas Young performed his famous interference experiment. He found that coherent light directed through two closely spaced pinholes recombined to produce fringes of brightness and darkness on a screen behind. The bright fringes of light resulted from light waves from the two holes arriving crest to crest, while the dark areas resulted from light waves arriving trough to crest. Interference patterns can be shown with a diffraction grating, a multitude of closely spaced slits. Interference fringes can also be produced by the reflection of light from the top and bottom surfaces of a thin film, such as the light reflected from a CD. Thin films will produce a spectrum of beautiful colors. The colors are produced by the interference of light waves. This is called iridescence and is seen in soap bubbles. A soap bubble appears iridescent in white light when the thickness of the soap film is about the same as the wavelength of light. Light waves reflected from the outer and inner surfaces of the film travel different distances. When illuminated by white light, the film may be just the right thickness at one place to cause the destructive interference of yellow light. When yellow light is subtracted from white light the mixture left will appear as the complementary color of yellow, which is blue.

Huygens' principle proposes that wave fronts of light waves spreading out from a point source can be regarded as overlapped crests of tiny secondary waves. Wave fronts are made up of tinier wave fronts. Plane waves can be generated in water by successively dipping a horizontally held straightedge, such as a meter stick, into the surface. Place wooden blocks in the ripple tank to create an opening for the waves to go through. Where the opening is wide, you will see the plane waves continue through the opening without change, except at the corners where the waves are bent into the shadow region, as predicted by Huygens' principle. As the width of the opening is narrowed, less and less of the incident wave is transmitted and the spreading of waves into the shadow region becomes more pronounced. As the opening gets smaller it can be seen to act as a "point" source of the new waves that fan out on the other side of the barrier. We say the waves are diffracted as they spread into the shadow region. Any bending of light by means other than reflection and refraction is called diffraction.

When light passes through an opening which is large compared with the wavelength of light, it casts a shadow. We see a rather sharp boundary between the light and dark area of the shadow. But if we pass light through a thin razor slit in a piece of opaque cardboard, we see that the light diffracts. The sharp boundary between the light and dark areas disappears, and the light spreads out like a fan to produce a bright area that fades into darkness without sharp edges. The light is diffracted.

Vibrating electric and magnetic fields regenerate each other to make up an electromagnetic wave which moves outward from the vibrating charge. In a vacuum, all electromagnetic waves move at the same speed but differ from one another in their frequency. The classification of electromagnetic waves according to frequency is the electromagnetic spectrum. The electromagnetic spectrum is a continuous range of waves extending from radio waves to gamma waves. Violet light has nearly twice the frequency of red light and half the wavelength. A phoon is a localized corpuscle of electromagnetic radiation wherein the energy is proportional to its radiation frequency: E~ hf, h = 6.6 x 10-34 Joules per second. It can be thought of as a "particle" of light. A photon in a beam of red light carries an amount of energy that corresponds to its frequency. Another photon of twice the frequency has twice as much energy and is found in the ultraviolet part of the spectrum.

Light is an energy-carrying electromagnetic wave that emanates from vibrating electrons in atoms. When light is cast upon matter, some of the electrons in the matter are forced into vibration. The way a receiving material responds when light is cast upon it depends on the frequency of the light and the natural frequency of the electrons in the material. Visible light vibrates at a very high rate, more than 100 trillion times per second. If a charged object is to respond to these ultra fast vibrations, it must have very little inertia. Electrons are light enough to vibrate at this rate. Materials such as glass and water allow visible light to pass through in straight lines. We say they are transparent to light. Electrons in glass have a natural vibration frequency in the ultraviolet range. When ultraviolet rays shine on glass, resonance occurs as the wave builds and maintains a large amplitude of vibration of the electrons. The energy the atom receives may be passed on to neighboring atoms through collisions, or it may be re-emitted. Resonating atoms in the glass can hold onto the energy of the ultraviolet light for quite a long time (about 100 millionths of a second). During this time the atom makes about one million vibrations, and it collides with neighboring atoms and gives up its energy as heat. Thus, glass is not transparent to ultraviolet. With visible light, electrons in the glass are forced into vibration at less amplitude. The atom holds the energy for less time, with less chance of collision with neighboring atoms, and less energy is transferred to heat. The energy of vibrating electrons is re-emitted as light. Clear glass is transparent to all visible light waves.

Objects that absorb light without re-emission are opaque. Vibrations given by light to their atoms and molecules are turned into random kinetic energy . They become slightly warmer. Metals are opaque. Metals are also good conductors of electricity. They have a lot of charges that aren't attached to individual atoms, but which are free to move around in the metal.. The charged electrons set up their own electric field. In response to an electromagnetic wave hitting the metal, the electrons move until the field they set up exactly cancels the electric field of the incident wave. Once the field is canceled, there is no further force to move any more electrons. If there is no electric field inside the metal, there is no electromagnetic wave, therefore no transmitted wave. Almost all the energy in the incident wave goes into the reflected wave. That is why metals make very good reflectors.

Geometric Optics

Optics is the study of electromagnetic waves. Visible light is in the electromagnetic spectrum. Geometric optics is used to understand simple problems, and concentrates on light rays only. Geometric optics are useful as long as the objects with which light interacts are much larger than the wavelength of light.

The ray model of light assumes that light travels in straight line paths called light rays. The ray model of light assumes that a luminous object sends out light rays that spread out in all directions in straight lines. An image is formed where the light rays, leaving the object from the same point, meet. A pinhole camera demonstrates this model. The light is traveling in straight lines. The image produced by the camera is inverted. The light from the top of the object travels in a straight line through the pinhole to the bottom of the "screen" of the camera. The bottom of the image is produced at the top of the "screen" by the pinhole.

A thin beam of light is called a ray. A shadow is a region where light rays cannot reach. The best shadows come from point sources, like a small light bulb or candle. Before photography, people traced shadows as silhouette portraits. Today shadows help artists represent objects more realistically. An unsupported object in mid-air is portrayed as being detached from its shadow. Shadows used on a human face gives it a more three dimensional appearance.

If we are close to our shadow it is sharp-edged because the sun is so far away. Either a large far away light source, or a small nearby light source, will produce a sharp shadow. A large nearby light source produces a somewhat blurry shadow. There is usually a dark part on the inside and a light part around the edges of a shadow. The total shadow is called an umbra and the partial shadow a penumbra. A penumbra appears where some light from one part of the source is blocked, but where light from other parts is not. It can also occur where light from a broad source is only partially blocked. Two point sources of light will result in two shadows being formed.

When re-emitted light is returned into the medium from which it came, it is reflected and the process is called reflection. When light travels from one place to another it will take the path that requires the shortest time and travel in a straight line. The law of reflection states that when a light ray traveling in a given direction hits a smooth surface obliquely, it is reflected in a different direction. The angle measured from the perpendicular of the surface to the ray of reflected light is the angle of reflection. The Law of Reflections tells us the direction of the reflected light. The most common surface from which light is reflected is a mirror. A plane mirror is a mirror with a perfectly flat surface. When rays of light encounter the mirror, they are reflected at angles equal to their angles of incidence. The rays diverge from the image and on reflection diverge from the mirror. These divergent rays appear to come from a particular point behind the mirror. The light rays do not actually come from this point., so the image is called a virtual image. The image is as far behind the mirror as the object is in front of the mirror, and image and object have the same size.

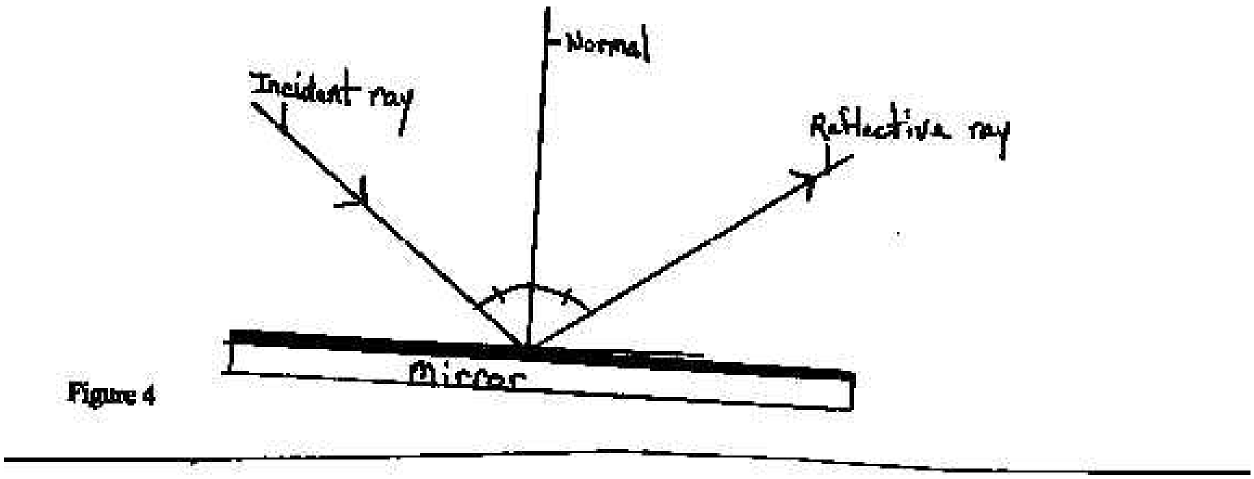

Figure 4

The amount of light that is reflected depends on the material and the angle the light hits the interface. For example, if you look straight down in to a clear lake, you'll see the bottom of the lake. However, if you look from further away, at a greater angle, you will see the reflected light from the sun and sky. The amount of reflection increases the farther away the incident ray is from the perpendicular.

There are two types of reflections: specular and diffuse. Specular reflections are reflections off smooth surfaces like mirrors, glass, and water. Diffuse reflections are reflections off a rough surface like cloth. Only the brightness of the surface is reflected. There is no mirror image. The reflected light scatters in all direction. When you're are driving at night in darkness, the difficulty of seeing the road is caused by diffuse reflection. When it's raining and your headlights are reflecting light off the road's now smooth surface, that is an example of specular reflection

Light travels at different speeds in different media. It travels at 300,000 kilometers per second in a vacuum, at a slightly lower speed in air, and at about three-fourths that speed in water. Light rays bend when they pass from one medium to another in which the speeds are different. The bending of the transmitted light at the interface between two media is called refraction. The index of refraction is obtained by dividing the speed of light in a vacuum by the speed of light in that material. In refraction, the angle of incidence is always greater than the angle of reflection when the light rays go from a fast to a slow medium. Some of the light from the incidence ray is reflected while some is transmitted.

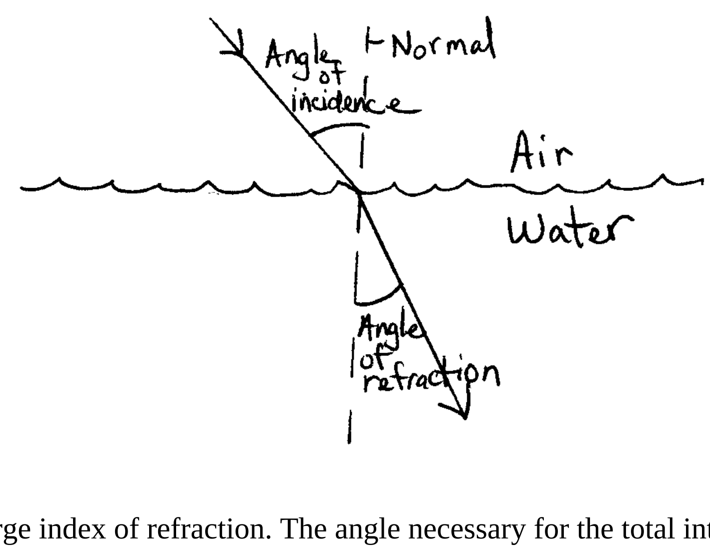

Figure 5

A diamond has a large index of refraction. The angle necessary for the total internal reflection is 24.5 degrees, much smaller than for glass. This accounts for the brilliance of diamonds.

Almost any ray of light that hits a diamond from the front, strikes the rear surface at more than 24.5 degrees and is internally reflected to another surface, eventually being reflected out the front. If you look through the back of a cut diamond it will appear almost black.

Refraction occurs when light passes through lenses. Light is refracted as it enters a lens and again as it leaves the lens. The amount of refraction depends on the degree to which the lens is curved. In air, a very curved glass or plastic lens will refract more than a lens the surface of which is only slightly curved. Lenses that are thicker in the middle and converge the light rays are called converging lenses. When the middle of the lens is thinner than the edges, the light rays are diverged. These lenses are known as diverging lenses. The principal axis of a lens is the line joining the centers of the curvatures of its two surfaces. The focal point in a converging lens is the point at which beams of parallel light rays, parallel to the principal axis, converge.

The first cameras had no lenses and admitted light through a small pinhole. Long exposure times were required because of the small amount of light admitted by the pinhole. A converging lens is used to form an image the same way a pinhole does, however, the lens doesn't require the long exposure time that a pinhole camera does. The opening in a camera through which light enters is called an aperture.

The simplest use of a converging lens is a magnifying glass. Magnification occurs when an image is observed through a wider angle with the use of a lens. When we use a magnifying glass, we hold it close to the object we wish to examine. This is because a converging lens provides a larger right-side up image only when the object is inside the focal point.

In the human eye, light enters through the transparent cover called the cornea, which does about 70% of the necessary bending of the light before the light passes through the pupil. The light then passes through the lens, which is used only to provide the extra bending power needed to focus images of nearby objects on the layer at the back of the eye. This layer is called the retina and it is very sensitive to light. Different parts of the retina receive light from different parts of the visual field outside. The retina is not uniform. There is a spot in the retina where the nerves carrying the information exit; this is called the blind spot.

There are over a hundred million light-sensitive cells called rods and cones on the retina. The spot in the center of our field of view, called the fovea, has the most distinct vision. This is because it has a great number of cones and no rods. There are three types of cones: those that are stimulated by low-frequency light, those stimulated by light of intermediate frequencies, and those stimulated by light of higher frequencies. The rods predominate toward the edges of the retina. Color vision occurs mostly because of the cones. Rods respond primarily to lightness and darkness. The color of an object disappears if it is viewed from the periphery of our sight, although this area is very sensitive to detecting movement.

The lens of your eye is a convex lens that is soft and flexible. It can easily change shape to see clear images of objects both near and distant. If the eyeball is too long, the image forms in front of the retina. This is called nearsightedness. A nearsighted person has difficulty seeing objects at a distance, but has no trouble seeing nearby objects. If the eyeball is too short, the image is focused behind the retina. This condition is called farsightedness. A farsighted person can see distant objects clearly, but has difficulty seeing nearby objects.

In summary, this unit explores waves and light. McDermott's work shows how an inquiry approach can be used to instruct students. After examining this work, it seems clear that students learn best when using a hands-on approach.

Implementation of the Unit

This unit will take approximately one month to complete. Students will work in groups of two to four. They should keep a notebook of experimental results, notes and diagrams.

Lesson # 1: Waves and Energy

Objective: Students will explore how waves are related to energy. NM Standard 9A2.

Ask students to identify wave phenomena of which they have heard. List on board. Teacher demonstration: attach a string to a support and suspend a mass from it. Pull the mass down to stretch the spring and release it to start it bouncing. Students need to understand that you are giving energy to the spring, which is like the energy that a particle would encounter as a wave passes through it. The spring eventually returns to its rest position. As a wave travels through a medium, the particles of the medium are put into motion. Once the wave passes through the medium, the particles return to their resting position. Teacher demonstration: Set up a pan of water or an aquarium and float a cork in it. Explain to students that you can use a pencil or a ruler to create waves by moving it up and down. Ask students: "Will the waves make the cork move across the tank?" (No-unless the wave is violent enough.) Have the students suggest reasons why the cork does not move forward. Ask them "What does move forward?" Ask them where the energy comes from. Define a wave, with the students, as a traveling disturbance that carries energy from one place to another.

Lesson #2: Wave Characteristics

Objective: Students will describe the characteristics of waves. NM standard 9A2.

Begin by tying one end of a rope to a doorknob or other stationary object. Take the free end of the rope in your hand and stand so the the rope is not quite fully stretched. Quickly jerk the free end of the rope. Have students observe the rope's movement. Move your hand up and down continuously for several seconds. Move your hand up and down so the rope goes higher than before. Move your hand up and down faster than you did before. Ask students to observe each change. Discuss with students how some waves, such as sound waves and water waves, are created by vibrations. Vibrating objects give off some of their energy to nearby objects, causing them to vibrate. This movement creates a wave. We have observed waves being transmitted through a substance. The substance is called a medium. Examples are the air the rope, and water. These form mechanical waves. Other waves do not require a medium. They can be transmitted in a vacuum. They are called electromagnetic waves. There are a number of types of electromagnetic waves including radio, microwave, T.V., infrared, visible light, ultraviolet, x-rays and gamma rays. Show students pictures of waves. For electromagnetic waves, use pictures of objects that give off these waves like a T.V. and a microwave oven. Have them classify the waves as mechanical or electromagnetic. Activity: Have students work with a partner. One student should hold their hands about six centimeters apart and clap for five seconds. Their partner should count the number of claps. Have the partner repeat, but after each clap bring their hands out to their sides. Discuss: Which had the highest frequency? Why couldn't the student clap as many times when returning hands out to the side? Describe the relationship between the distance and the number of claps. Give each student a diagram of a sine wave. Duplicate on an overhead transparency or on the board. With the students, label and define the following: crest, trough, wavelength, amplitude and frequency of the wave shown.

Lesson #3: Waves- Transverse and Longitudinal

Objective: Students will classify waves as transverse or longitudinal. NM standard 1B2.

Ask students if they have ever been to a stadium event where the audience did "the wave." See if they can create a wave going from one end of the room to the other. Ask for ten volunteers to sit in chairs in the front of the room. Tell them they are going to create a special wave. Give each a card with a letter from the word TRANSVERSE. Hand the letters out so that when the students hold them up the word is correctly spelled. On your signal each student should stand up and display their letter, then sit down, keeping the letter visible to the rest of the class. Repeat with ten new students so all have a chance to see. Have students return to their seats and discuss the properties of transverse waves. Define transverse waves as waves in which the motion of the medium is at a right angle to the direction of the wave. Discuss what represented the medium. What direction did our wave travel? Next have ten students line up front-to-back about ten centimeters apart. Have them put their hands on the back of the person in front of them. Gently push forward on one student who will send the push down the line. Explain that some waves travel in this fashion, rather than up and down. These are longitudinal waves. Line students up to show rarefaction and compression of longitudinal waves. Repeat twice so all students have a chance to both participate and observe. Use a slinky on the floor to show transverse and longitudinal waves again. Have students to get out a piece of paper and sketch a transverse and a longitudinal wave. Have the students write down explanations for their sketches. Ask students to label any parts they can. After most students are done, ask for a volunteer to sketch their representation on the board and explain their sketch to the class. Discuss.

Lesson #4: Wave Speed

Objective: Students will relate wave speed to frequency and wavelength. NM standard 9A2.

Relate the speed of waves to the speed of other moving objects. Put equations on the board and have the students copy: Speed = distance/time. Wave speed = wavelength (d) / period(t) . Frequency = 1/period. Wave speed = frequency wavelength. Demonstrate wave speed by attaching straws together with string. Place straws parallel to each other about six cm. apart and attach with string at top and bottom of straw. The total length should be two meters. Have a student hold one end in place. Rotate the free end by turning your wrist. Have students observe the motion. Calculate the wave speed by timing how long it takes for wave to reach the end. Repeat after attaching paper clips to the end of the straw. How does the speed change? Give students a tray of water and a cork. Have them calculate the frequency of the waves they create.

Lesson #5: Wave Interactions

Objective: Students will identify examples of how waves interaction with other objects (reflection and refraction). NM standard 5B4 , 5A1 and 6F1 and 2.

Reflection demonstration: Materials needed are a rectangular piece of window glass and two identical candles. Mount the glass sheet vertically between four stacks of books. Fix one candle in front of the glass sheet on the table (ten centimeters on the perpendicular to the glass) Fix the second candle in the back of the glass sheet on the table exactly the same distance from the glass. Block the students' view of the first candle with a folder and light only this candle. Pretend to light both candles. Then remove the folder. Students should sit in places. From which they cannot see the second candle without looking through the glass sheet. Place your hand above the unlit candle for a very short time and withdraw. Increase this time by two or three seconds. Students must think both candles are lit. Both candles must be exactly the same distance from the glass. This shows that the image of an object in a mirror is located behind the mirror, exactly the same distance from the mirror as the object is in front of it. Discuss reflection with the students. Bounce a rubber ball against a wall at an angle. Introduce terms "angle of incidence" and "angle of reflection." Give students mirrors, flashlights and protractors to test the Law of Reflection. Have them measure the angles on paper under the mirrors. Have students complete a diagram of a store or shop that shows the best placement for security mirrors Check that rays can be traced between object, mirror and viewer, and that obey the law of reflection. Teacher demonstration. Flashlight and mirror. Discuss two different types of reflection: specular and diffuse. Use the flashlight to show how light is reflected differently on different surfaces, including a mirror.

Refraction demonstration: Materials needed are four glass stirring rods, two clear glass containers, one container of vegetable oil, and tap water. Fill one of the jars about half way up with tap water. Put two of the glass rods into the water. Look through the jar at the rods. You can see them fairly clearly. Next, fill up the other jar half way with the vegetable oil. Now put the glass rods into the jar. Look through the jar at the rods. Notice that they have disappeared. They are practically invisible in the oil .Discuss the concept of the index of refraction. This is a measure of how fast light travels in a material. If light goes from one material to another, and the two materials have different indexes of refraction, the light is bent. When two materials (like glass and air) are in contact and light shines through them, the light bends a little at the surface separating the images seen through the two materials. When the two indexes of refraction are not very different, the light does not bend very much. When the glass rods were in the water, you could still see them clearly because the index of refraction of glass and water are only slightly different. When the glass rodsd are put in the oil they are practically invisible, because the oil and glass have practically the same index of refraction. The light that is traveling through the jar into your eye is not bending at the surface of the glass.

Diffraction of waves: Materials needed are a small wooden dowel, wooden blocks and a pan of water. Use the dowel to create waves in the water. Place the blocks in the water about three inches apart and have students observe how the wave curves around the side. Keep repeating, but make the opening between the blocks smaller and smaller. Have students draw in notebook.

Scattering of light: Materials needed are an aquarium of water, flashlight, and Coffee Mate. Shine a beam of light through the aquarium water. Notice the blue tinge. Add Coffee Mate, Observe the yellow color of the projected light.

Refraction and lenses: Materials are convex lenses, concave lenses, lens holder, light bulb and socket, a blank sheet of paper, and a meter stick. Place the convex lens in the lens holder and position them in front of the lighted bulb. Position the paper behind the lens so a clear image of the bulb can be seen. Sketch the light bulb in your notebook. Measure the distance from the lens to the paper. This is the image distance of the lens. Record. Turn off the light bulb. Repeat with concave lens, noting how your observations differ (if at all) from those for the convex lens. What is the reason for the diffence?

The human eye: Materials needed are a picture of the human eye for students to label, and a model of the human eye. Hand out the diagram of the eye. Show students different parts and discuss what they do. Discuss and sketch on the board how the eye lens enables us to see. Discuss far and near sightedness.

Lesson # 6: Ray Model of Light (modeled after McDermott's work)

Objective: Students will explore and observe light and its shadows. NM Standard 6A1.

Materials needed are a small light, a battery and a cover to fit over the light with a slit in one side. Have students look at an unlighted bulb. Observe that even though it is not lighted, you can still see it. Suppose you took the bulb into a very dark closet. Would you still be able to see it? Discuss. Place a cover over the bulb. Where do you have to look to see it?

Student Activities: Arrange a very small bulb, a cardboard mask and a screen. Place a hole about one cm. in diameter in the center of the mask. Ask students to predict what they would see on the screen. Explain in words and with a sketch. Predict how moving the bulb upward would affect what you see on the screen. explain. Perform the experiments and check your predictions. Predict how each of the following changes would affect what you see on the screen. Explain your reasoning and include sketches that support your predictions. Replace the mask with the circular hole with one having a triangular hole. The bulb is moved further from the mask. Place a second bulb above the first. What do your observations suggest about the path taken by light from the bulb to the screen?

Shadow box: Materials needed are a shoe box, white paper, two small light bulbs and sockets, thread, and clay. Turn the box away from the window. Tape white paper to the back of the shoe box to serve as a screen. Hold a small lighted bulb in front of a clay ball suspended in the box. Describe. Draw a diagram. Predict how the shadow will change when you make the clay ball larger, make the clay ball small, and form the clay into a triangle. Sketch what you would expect to see if two small lighted bulbs are held side-by-side in front of the screen. How will the image change as the bulbs are moved closer together? Explain. Discuss how shadows are formed.

Assessment

Assessment will begin with student responses to a pre-test in their journals which will help the teacher determine how much information students have on each topic. Students will write observations and lab notes in their journals which will be collected and graded. Quizzes and tests will also be used to assess student learning.

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