Inquiry into Physical Phenomena

(Physics 111 Student)

30 May 2013
Physics 111

A sophomore Human Development and Family Science major wrote this course paper. The instructor provided the organization of the paper by supplying headings and subheadings. As part of the homework assignment each week, the students wrote "their own textbook" to document their activities for that week by using these headings and subheadings as guidelines. The instructor provided detailed feedback each week. The students then submitted the revised weekly sections as a course paper during the ninth week of the ten-week term, along with the final section reflecting upon their science learning experiences in the course.

Course description: **Physics 111 Inquiring into Physical Phenomena (4)**
Development of conceptual understandings through investigation of everyday phenomena. Emphasis is on questioning, predicting, exploring, observing, discussing, and writing in physical science contexts. Students document their initial thinking, record their evolving understandings, and write reflections upon how their thinking changed and what fostered their learning.

Units: Nature of Light Phenomena
Nature of Thermal Phenomena
Influence of Light and Thermal Phenomena on Local Weather
Influence of Light and Thermal Phenomena on Global Climate
Nature of Astronomical Phenomena
Reflection on Science Learning and Teaching

Each unit has the following structure:
Identifying Resources
Developing Powerful Ideas Based on Evidence
Using Powerful Ideas to Develop an Explanation of an Intriguing Phenomenon
Developing Mathematical Representations of the Phenomena
Using Mathematical Representations to Estimate a Quantity of Interest

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Development of this course was partially supported by National Science Foundation grant No. 0633752-DUE, Integrating Physics and Literacy Learning in a Physics Course for Elementary and Middle School Teachers, Henri Jansen, PI, Department of Physics, Emily van Zee, co-PI, Department of Science and Mathematics Education, College of Science and Kenneth Winograd, co-PI, Department of Teacher and Counselor Education, College of Education, Oregon State University.

Introduction

The sun is a critical aspect of everyday life. Without the sun, plants would not be able to photosynthesize and create sugars from which to survive. Without the sun, important processes, such as the water cycle, would not be able to properly function. Without the heat and light from the sun, our world would be cold, harsh, and unlivable. Finally, without the sun, we would not be able to see anything, ever. Our world would be completely different if the sun did not shine upon the Earth. But what exactly happens when light from the sun shines on the Earth? What processes are at play that make this ball of gas so crucial to our everyday activities? In order to discover the answers to these questions, we must first discover critical aspects of the nature of light itself.

As the sun heats the Earth, it is interesting to explore and note certain aspects of thermal phenomena as well. Heat and temperature, while different concepts, both act in interesting manners. When the light and heat from the sun interact with the thermal phenomena to be explored later in this text, certain everyday occurrences exist. The afternoon cool breezes experienced on the beach can be explained by the interactions of light and heat from the sun and applications of thermal phenomena.

Phenomena regarding visible light and heat from the sun, along with interesting phenomena regarding other types of light and their properties can be used to explain recent issues of Global Climate Change. There are many efforts now to combat against some of the effects of climate change.

The sun is not the only interesting celestial body that we can readily observe when we look to the sky. The Earth's own satellite, lovingly known as the moon, can be observed over a period of time. In making diligent observations of the moon, interesting moon phenomena can be explored as well.

The Nature of Light Phenomena

In exploring the nature of light, it is important to observe natural occurrences regarding light. Everyday experiences can all contribute to the development of knowledge and powerful ideas about the light. By really observing natural phenomena and recording evidence, powerful ideas regarding light can be determined. Collecting these powerful ideas allows us to further our knowledge about light and reach a final conclusion to our main question.

Identifying Resources

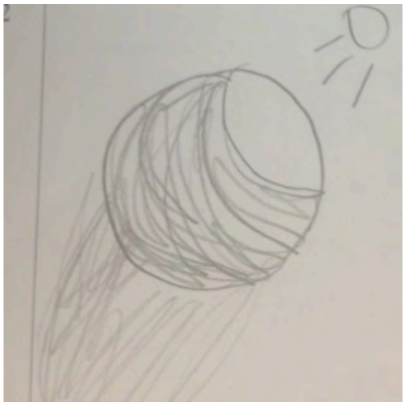
Even young children are at least subconsciously aware of some of the powerful ideas related to light and its normal functioning. For instance, when they draw pictures of suns, they draw rays of light coming from its source. Other observations can include small notations about the sizes and shapes of shadows and objects when the sun is out. Children also draw another light source, the moon, in its many different shapes and stages—this shows a basic understanding of the moon's phases, or at least that the moon does not always look the same in the night sky. Also, children can observe rainbows when the conditions are right—even if they do not fully understand why they see what they see, when they view a rainbow, children make the connection between the combination of sun, clouds, and rain. All of these experience and everyday observations contribute to one's understanding of how light works.

Developing Powerful Ideas Based on Evidence

Light acts in many specific, interesting ways, but there are five particular observations about light that are most important to our exploration. These are our powerful ideas that help us to understand and explain what exactly happens when light from the sun travels to the Earth. *See Table 1.*

Table 1:
Evidence for Powerful Ideas About Light Phenomena

Day	Set Up	Evidence	Powerful Idea	Vocabulary
1		The light from the single bulb lit up all areas of the board, table, and our surrounding faces.	Light travels in all directions from its source	Filament: the inside part of a lightbulb that emits light
1		A shadow was cast on the table and screen, as well as on the backside of the barrier.	There are two kinds of shadows—1 formed behind the object and 2 on the backside of the object itself.	Barrier: item that casts a shadow Screen: the white backdrop in our set up Shadow: the absence of light
2		Light hits the barrier, but is not stopped there—light can be seen cast on the table around the barrier.	Light bounces off surfaces and goes in all directions.	
2		When we hold a ruler from the source to directly flush with the barrier and screen, we can see that the shadow ends right where our straight edge is. This is a way to concretely visualize a straight ray of light.	Light travels in straight lines.	Straight: As it pertains to rays of light, straight simply means that the beam continues in a flat direction—this flatness could be angled in any direction.

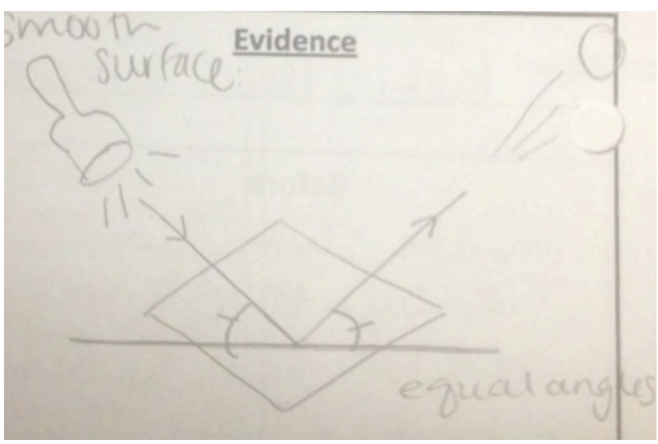
1/2		When observing the basketball in dim light, the reason we could even see it at all is because there was light shining on it that bounced off and carried to our eye. In complete darkness, we would not have seen a single thing.	In order for us to be able see something, light has to bounce off of it and go back to the eye.	Bounces: This just means that when light hits a barrier, it is not able to continue on its path, so the direction changes in all directions from the point on the barrier where the light hit.

Light leaves a source in all directions. When we turned on a lightbulb, light from the filament lit all areas surrounding the bulb—the screen, the table, our faces, the walls, etc.

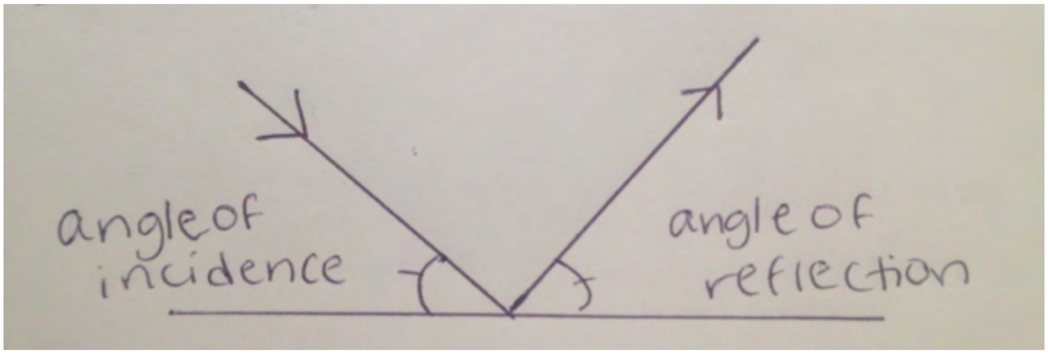
Light rays travel in straight lines. When we turned on the same bulb, but with an object in front of the screen, the object obstructed the path of light and cast a shadow on the screen behind it. When we held a straight edge from against the light source to against the edge of the object to the screen, the edge of the object's shadow was reached. Thinking about the straight edge as a representation of a ray's path, we observed that this path went straight from the light to the object to the edge of the shadow on the screen.

Light rays reflect from smooth surfaces such as mirrors in a regular way. This is called reflection. When we shined a beam of light onto a mirror, the light beam changed direction. It still traveled in a straight direction, but in such a way that when observing the two light beams, the angle of incidence equaled the angle of reflection. No matter what angle we used to shine the light on the mirror, the resulting beam always created these two important and equal angles.

Ray Diagram explaining the physics of the phenomena:



Light from the source bounces off of the smooth surface (such as a mirror) in such a way that the angles created by the light are equal. These angles, called the angle of incidence and the angle of reflection, are equal.



If you draw a perpendicular line to the vertex (called the normal to the surface), the angle formed by the perpendicular line (normal to the surface) and the incident ray is called the angle of incidence. The angle formed by the perpendicular line (normal to the surface) and the reflected ray is called the angle of reflection. The angle of incidence equals the angle of reflection.

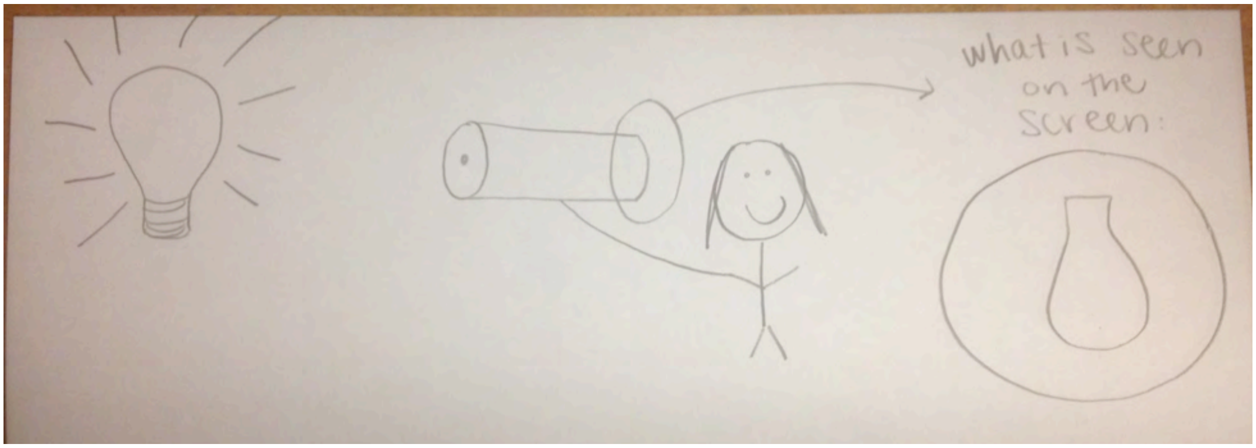
Light bounces off of rough surfaces in many directions. When we turned on a lightbulb, the light was cast in many directions, including to our TA's nose. We each could see Kortney's nose, even though we were standing in different parts of the room. Because of this, it is clear that the light bouncing off her nose traveled in all different directions in order for it to be possible to reach multiple eyes in different places at the same time.

For someone to see something, light has to reach the eye. As in the previous powerful idea, had there been no light hitting Kortney's nose, no one in the classroom would have been able to see it. In complete darkness, we cannot see anything, but when there is even the slightest bit of light, we are able to see objects because the light bounces off of them.

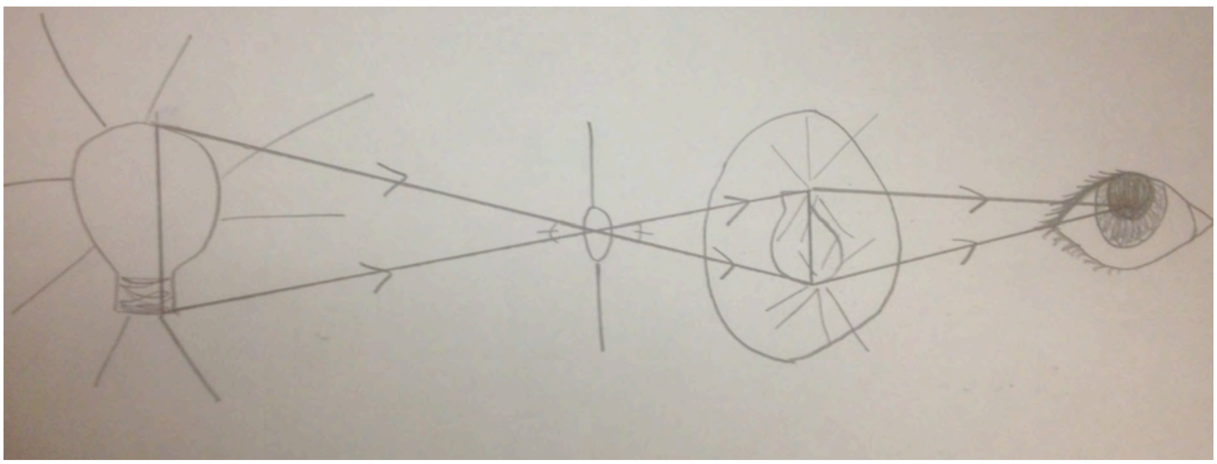
Using Powerful Ideas to Develop an Explanation of an Intriguing Phenomenon

When light travels from its source through a tiny pinhole and to a screen past the pinhole, the image of the light source is flipped. In exploring pinhole phenomena, I predicted at first that the light I would see through the pinhole would be concentrated as one small circle of light on the wax screen. I was very surprised when I actually saw an upside down light bulb. When I looked through the pinhole, the visible light that I saw shining on the screen was a small, inverted lightbulb shape. In order to explain why this happens, we can use our powerful ideas, particularly that light travels in <u>all</u> directions from its source, light can be envisioned as straight rays, and that light from the lightbulb travels in straight rays going in all directions. Some of these rays enter the pinhole, and continue in their straight path to be shining on the screen. Some rays from the top of the bulb travels in a straight line, through the hole, and to the bottom of the screen, forming an image of the top of the bulb. Some rays from the bottom of the bulb travels in a straight line, through the hole, and to the top of the screen, forming an image of the bottom of the bulb. There are also rays coming off of all parts of the bulb, so the shape of it can be seen inverted on the screen.

Sketch of what is seen:



Ray Diagram explaining the physics of the phenomena:



Developing Mathematical Representations of the Light Phenomenon

H_{object} = h_{image}

$D_{pinhole}$ = $d_{pinhole}$

As seen in the ray diagram above, two similar triangles are created by the paths of the rays. We know that with two similar triangles, we can set up and use a ratio to compare corresponding sides from the triangles (relevant lengths that relate to one another).

Using Mathematical Representations to Estimate the Diameter of the Sun

When we draw a Ray Diagram of the pinhole phenomena, we are able to see that the rays from the top and bottom of an object form two similar triangles. Because the triangles are similar, we can use them to compare relevant lengths and set up a proportion. For instance, we used a pinhole to estimate the Diameter of the sun. The pinhole we created consisted of a board with a tiny hole cut out of the center, a meter stick, and a piece of paper as a screen. We held the board with the pinhole at a 1 meter distance from the screen, and angled ourselves so that light from the sun traveled through the pinhole and onto our screen. We knew the values for the distance from the pinhole to the screen, the distance from the sun to the pinhole (approximated to be 100,000,000 miles), and the length of the diameter of the image of the sun on the screen. Using this information, we were able to solve for our unknown value: the diameter of the sun. We did so by setting up the following proportion and solving for our unknown value.

Diameter of the Sun = diameter of the Image

Distance from sun to the pinhole distance from image to the pinhole

H_s = diameter of the sun
h_i = diameter of the image
D_s = distance from the sun to the pinhole
d_i = distance from the image to the pinhole

This is our equation using the symbols defined above:

$$\frac{H_s}{D_s} = \frac{h_i}{d_i}$$

When we solve the equation for our unknown value (the diameter of the sun), we get:

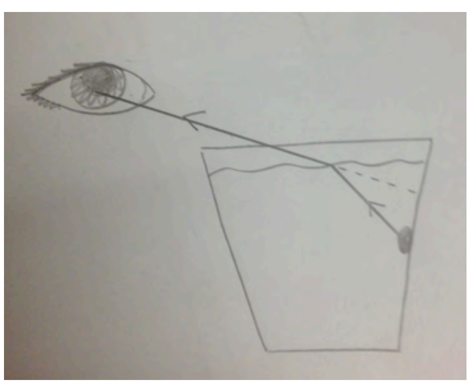
$$H_s = (D_s)\frac{h_i}{d_i}$$

In our exploration, we found the following values:
D_s = estimated to be about 100,000,000 miles
h_i = measured to be 1 centimeter
d_i = set up in the experiment as one meter stick, so 100 centimeters

H_s = (100,000,000 miles) (1 cm / 100 cm)
H_s = 1,000,000 miles

Developing an Additional Powerful Idea Based on Evidence

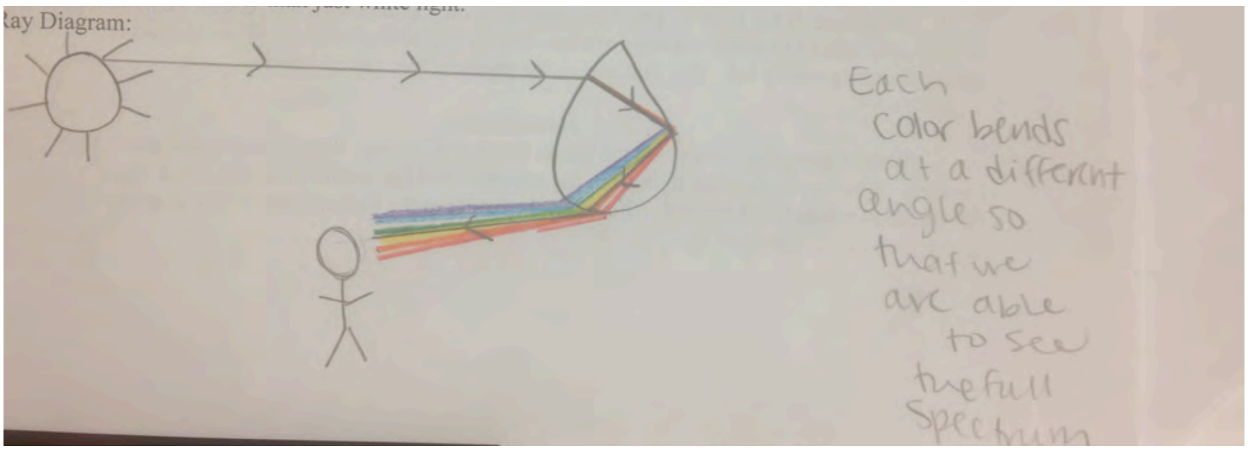
Light rays bend at a surface when moving from one medium to another (such as from air into water or from water into air). This is called refraction. When we poured water into a cup with a dot drawn on one of its inside faces, it appeared as though the dot rose along the cup's face as more water was added. This was our perception because the light from the dot changed paths, or refracted, when it transferred from the water medium to the air medium on its path to our eye.
Ray Diagram:



Using Powerful Ideas to Develop an Explanation of an Intriguing Phenomenon

Light bends when it travels from one medium to another. When we pair this powerful idea with our other powerful ideas regarding light, we can explain how rainbows are formed. In order for us to be able to see a rainbow, our back must be to the sun (we must be standing between the sun and the water droplets in the air that will play a key role in rainbow formation). Light travels in straight lines and in all directions from its source, which in this case is the sun. Some of the beams of light travel in a path that hits a raindrop from a cloud or in the air. When this happens, the direction of the light "bends" because of the change in medium from air to water. This is called refraction, and the colors that make up the spectrum in light each bend at a slightly different angle. Because of this, the “bend” in a sense separates out each color. The colors and the light's path still continue to travel in straight lines. Next, the light reaches the other end of the rain droplet, where it is reflected back across to the other end of the raindrop. When it crosses from water to air a second time, the light once again refracts, and the result is a rainbow of the colors of the spectrum each “bending” at different angles so that we can see the individual colors rather than just white light. The reason we are able to see different colors is that they come from different rain drops. Sunlight reflects and refracts through rain drops that are higher in the sky at a different angle than for rain drops lower in the sky. The full rainbow that we are used to seeing exists because each color bends at the many different angles of the different raindrops in the sky. We see red light coming from raindrops higher in the sky and we see indigo light from raindrops lower in the sky.

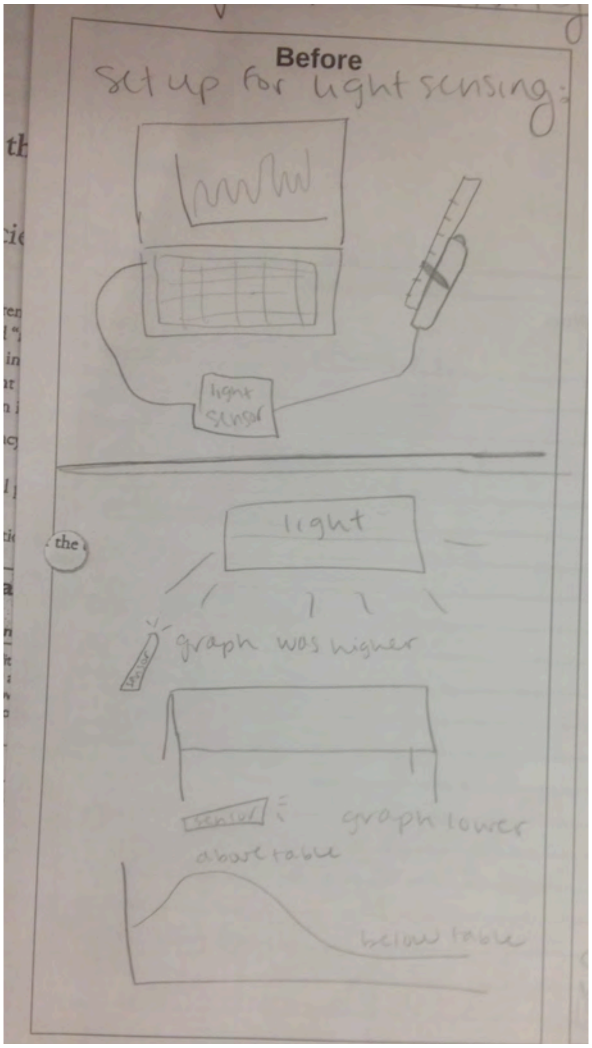
Ray Diagram:

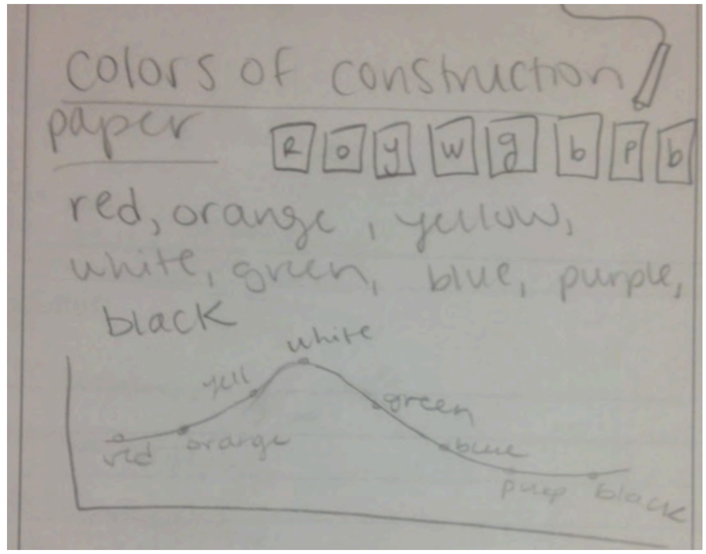


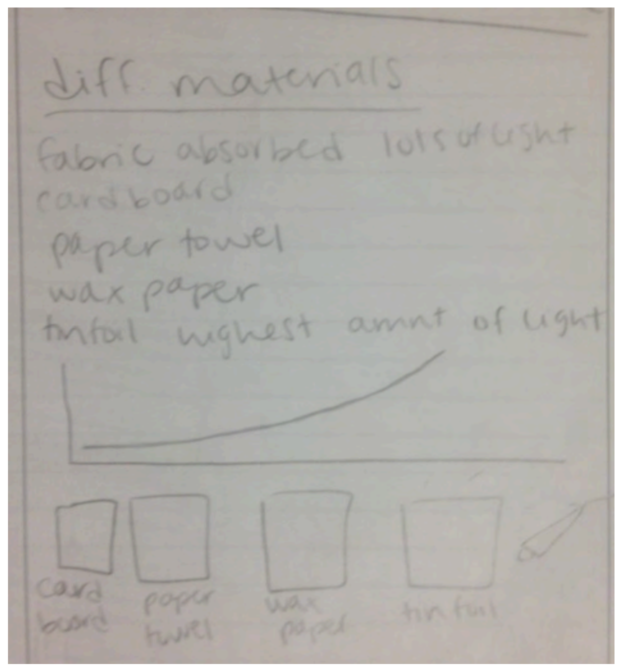
Developing an Additional Powerful Idea Based on Evidence

Light rays are reflected by materials of different colors and by different materials at different levels. When we used the light sensor, the graph of the amount of light sensed changed depending on the materials at which we pointed the sensor. When pointed at white, yellow, orange, and red paper, the graph was higher, whereas green, blue, purple, and black papers let off lower intensities of light. As for other objects, when arranged from the most amount of light absorbed—the least amount of light absorbed (a graph of low levels to high levels of light sensed), our order of objets was fabric, cardboard, paper towel, wax paper, tinfoil.

Sketch of the Setup:







The Nature of Thermal Phenomena

There are many powerful ideas related to thermal phenomena that can help explain why certain occurrences happen the way that they do. Heat is an important aspect to everyday life, so knowledge of the following thermal phenomena can be very beneficial.

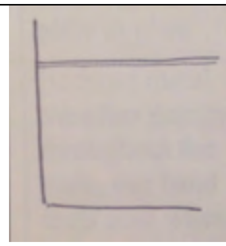
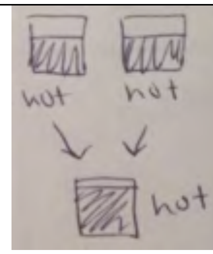
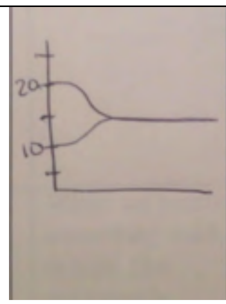
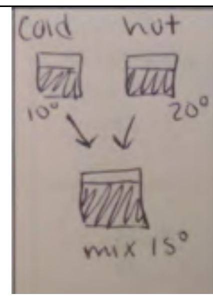
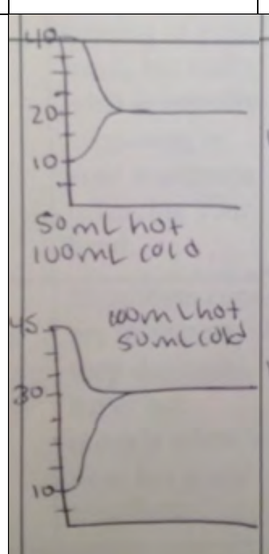
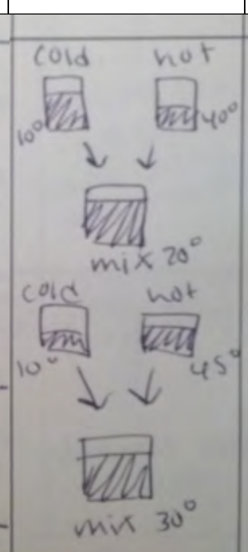
Identifying Resources

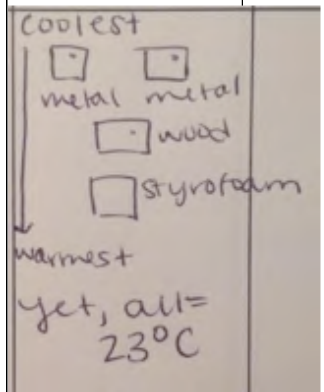
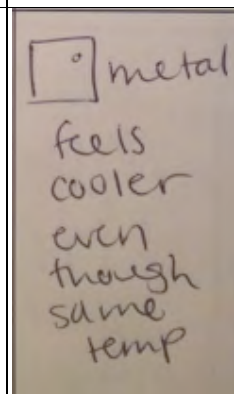
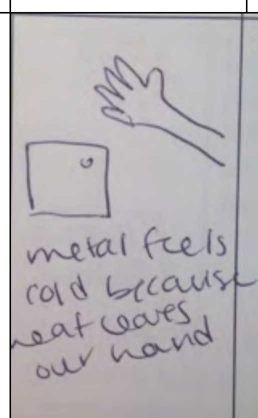
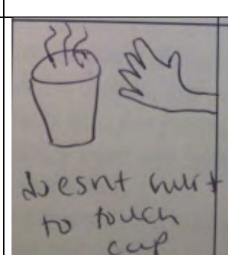
In order for humans to happily and healthily survive, it is important to maintain a stable body temperature. Certain materials are conductors of heat, and certain materials are insulators. Hot and cold water each serve different uses in everyday life. These three different examples or everyday applications, along with countless others can be further explored and explained when we look at the powerful ideas that relate to thermal phenomena. These everyday experiences are thus very relevant to the exploration of thermal phenomena.

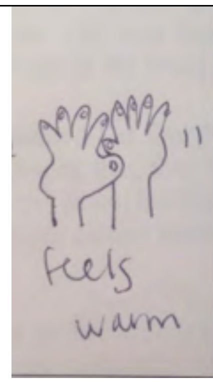
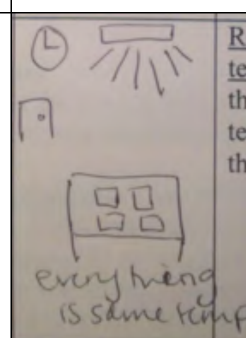
Developing Powerful Ideas Based on Evidence

There are some important powerful ideas that relate to heat and thermal phenomena. We are able to develop these ideas when we explore different relationships with heat and when we observe evidence of thermal occurrences. *See Table 2*

Table 2:
Evidence for Powerful Ideas About Thermal Phenomena

Day	Powerful Idea	Evidence	Sketch of set up(s)	Relevant Vocabulary
7/8	When mixing water of the same temperature, the resulting mixture will be the same temperature (doesn't matter how much of each is mixed)			<u>Equilibrium temperature:</u> point at which objects become the same temperature
7/8	When mixing 2 waters of different temperatures but of the same volume/mass, the resulting mixture will have an equilibrium temperature that is exactly halfway in between the 2 starting temperatures			
7/8	When mixing 2 waters of different temperatures and of different volumes/masses, the resulting mixture will have an equilibrium temperature that is closer to the temperature of the starting temperature of the larger amount. (If there was more hot than cold water, the equilibrium temperature will be warmer. If there was more cold than hot water, the equilibrium temperature will be cooler).			

8	Heat and temperature are different concepts	The temperatures of the plates were all the same, yet they felt different because the transfer of heat from the hand differed plate to plate		
8	Different materials differ in their properties, such as thermal conductivity.	Because metal transfers energy throughout the plate, our hand feels cold when we touch it		<u>Thermal conductivity:</u> how well/how quickly items transfer heat energy (# that tells you how readily an object will transfer heat energy)
8	Heat is a flow of energy from a source—from <u>hot object toward cold object</u>	When we touch something cold, it feels like coldness is coming to your hand, but really, what is actually happening is your warmness is leaving your hand.		
8	Some materials are insulators (low thermal conductivity, so heat does not flow through them as quickly)	Styrofoam cups are insulators, so they don't get super hot quickly when we pour hot water into them.		
8	Some materials are conductors (high	Metal and wires are possible examples of		

	thermal conductivity)	conductors		
8	Materials conduct heat energy at different rates	Combination of powerful ideas: 1)different materials differ in their properties and thermal conductivity, 2) some materials are insulators, 3) some materials are conductors		
8	Friction between 2 objects results in the objects getting warmer	When we rub our hands together, they feel warmer. Our group at first had temperature readings that were different for each plate, possible due to some friction.		
8	Objects left for a long time without a heat source will come to an equilibrium temperature.	The four blocks had been sitting in the room for a while, so they all reached the same equilibrium temperature that was equal to the temperature of the room	 (that temperature is room temperature)	Room temperature: the temperature of the room

Materials differ in how hot or cold they feel to the touch. We observed and felt with our hands four different plates of the same shape and volume—2 metal plates, a wooden plate, and a styrofoam plate. The temperatures of the plates were all measured as being the same, yet they felt different when we touched them because the transfer of heat from the hand differed plate to plate. This is because the materials of each plate were different—some plates, such as the metals, are conductors and have high thermal conductivity, so heat from our hands flowed quickly and easily into the plates. The styrofoam on the other hand, is an insulator, and has low thermal conductivity, so heat energy from our hand did not travel into the plate as quickly. This is why the metal plates felt so much colder to our touch.

Temperature is measured by a thermometer. We can measure temperatures of materials with an instrument called a thermometer. In our explorations, we used a thermometer that had alcohol inside of it. When the alcohol is heated, it expands, so we can read the temperature as the line where the alcohol inside of the thermometer reaches. When it is cooler, it contracts, so the temperature reading is lower. We also used digital thermometers, that gave us very accurate readings of temperature. Both of these thermometers gave us temperature measurements in Celsius, though Fahrenheit and Kelvin temperature systems do also exist. In Celsius, the boiling temperature of water is at 100 degrees and the freezing point of water is at 0 degrees.

Materials left for a long time without a heat source or sink in the room come to the same temperature, room temperature. This is called an equilibrium temperature. We saw this occur when we took the temperature readings of the four different blocks—they all read at a temperature of around 23 degrees Celsius. This is because they were all stored in the same room, which probably is the same temperature of 23 degrees Celsius. Thus, we can say that the blocks were all at room temperature.

Materials differ in their thermal properties such as how fast they conduct heat. Materials with a high thermal conductivity are conductors and materials with a low thermal conductivity are insulators. The metal block felt cold to our hand because the heat energy from our hand flowed very quickly into the material that conducted, or let in easily, the heat. The styrofoam block felt warm because the heat energy from our hand did not flow as quickly because as an insulator, the styrofoam does not easily let heat transfer from object to object. This is why styrofoam-like materials are used to insulate, and keep our houses warm.

Heat energy flows from hot objects to colder objects. The metal blocks felt colder than the wood and styrofoam blocks because heat from our hand flowed into the different blocks at different rates. Because metal is a conductor, the heat from our hand flowed quickly throughout the entire block, so we lost a lot of heat from our hand which made it feel colder. The eat from our hand also flowed into the styrofoam, but at a slower rate that did not spread throughout the block, so we did not feel as if we were losing as much heat from our hand. Our bodies, and in extension, our hands, are much warmer than the temperature of the room. Because of this, when we touch anything in the room, heat travels from our hand to the objects. This is why certain objects feel differently to our touch, depending on the amount of heat flowing either away from our hand, or towards it in cases where the object has a greater temperature than our hand. These observations allow us to develop the idea that heat energy always flows in the direction of the colder object.

Heat energy and temperature are different ideas. The four blocks that we touched were all in the same room, and all read the same temperature when measured with a thermometer. Despite that, they each felt to be different temperatures because of their properties—conductors versus insulators. The temperatures were all the same, but the interactions between the heat from our hand and the different materials is what differed and made certain materials feel colder and certain materials feel warmer. Heat is the energy that flows from object to object in order to spread evenly through the objects. Temperature is the specific measurement of how hot or cold an object is.

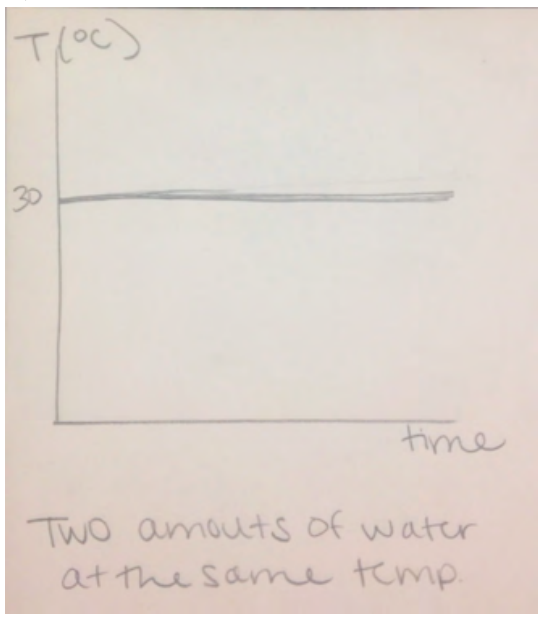
Using Powerful Ideas to Develop an Explanation of an Intriguing Phenomenon

When we sit on metal bleachers or tough the metal parts of chairs, they feel much colder than when we sit on a plastic seat. This is because our body heat energy will flow with greater ease into the metal verses the plastic. Metal is a conductor, so heat energy flows very easily into it. Plastic, on the other hand, does not have this same property, so our body's heat energy does not leave us to flow into the chair at such a fast rate. Thus, we perceive the metal chair to be colder than the plastic chair when we sit on it.

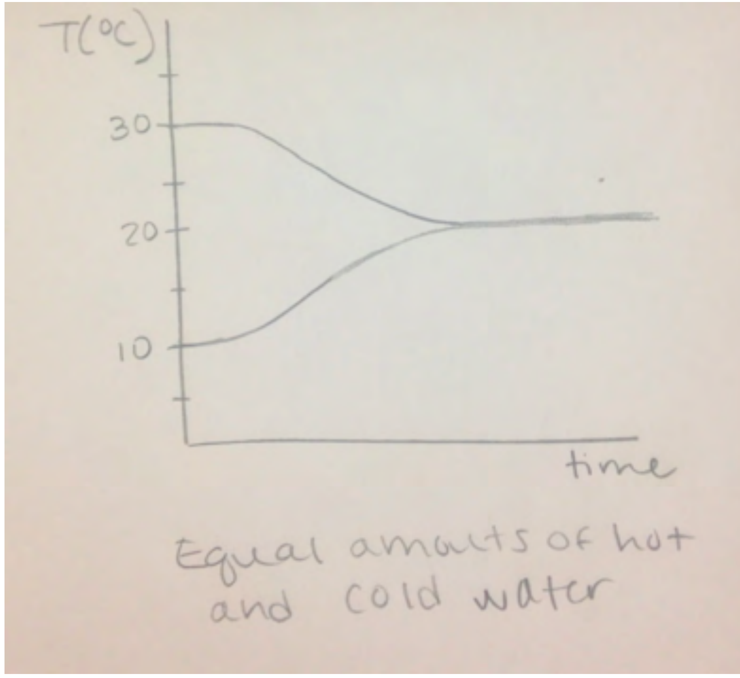
Developing More Powerful Ideas Based on Evidence

In another exploration of temperature and thermal phenomena, we mixed different amounts of hot and cold water and observed what happened to the temperature graphs. We first mixed equal amounts of water of the same temperature, and saw that the temperature line on the graph remained at the same height. When we mixed unequal amounts of water at the same temperature, the same thing happened to the graph. We then mixed equal amounts of two different temperatures of water—one hot and one cold. For this graph, we started with two lines—one at the initial temperature of the hot water and one at the initial temperature of the cold water. When we mixed the waters, these lines met on the graph at a point exactly between our two different initial temperatures. Finally, we mixed unequal amounts of waters of different temperatures. When we had more hot water, the two temperature lines on our graph reached the same equilibrium temperature that was closer to the initial temperature of the hot water. When we had more cold water, the two temperature lines on our graph reached the same equilibrium temperature that was closer to the initial temperature of the cold water.

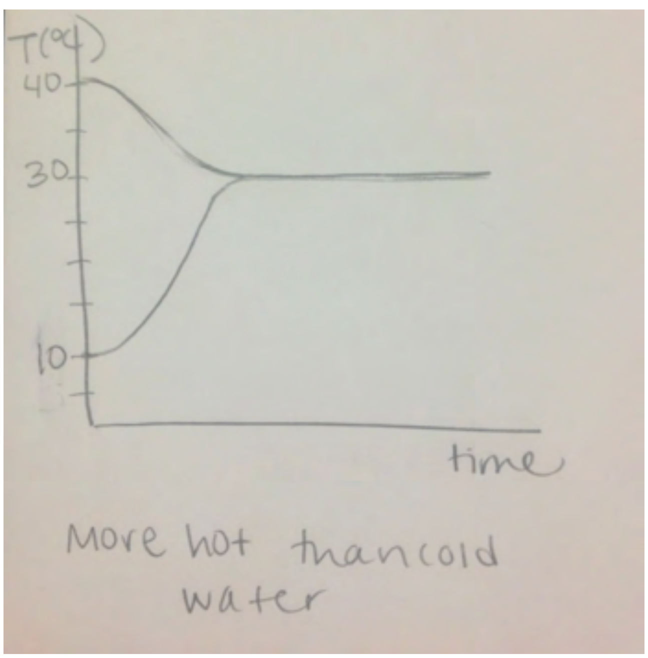
When two amounts of water at the same temperature are mixed, the equilibrium temperature of the mixture is the same as the initial temperature. When we mixed equal amounts of water of the same temperature, the temperature lines on the graph remained at the same height**.** Even when we mixed unequal amounts of water of the same temperature, the temperature lines on the graph still remained at the same height.

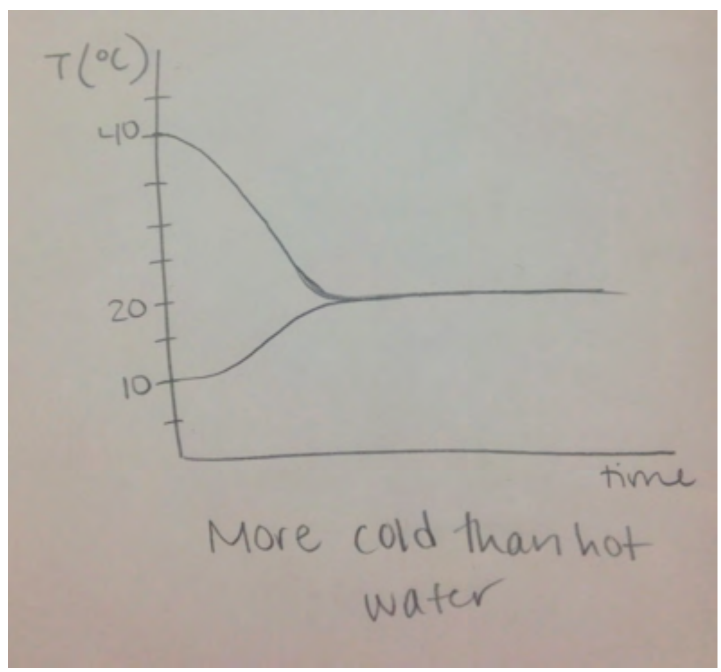


When equal amounts of hot and cold water are mixed, the equilibrium temperature of the mixture is the average of the initial temperatures. When we mixed equal amounts of two different temperatures of water—one hot and one cold, we created a graph of two different lines meeting together at the same temperature. For this graph, we started with two lines—one at the initial temperature of the hot water and one at the initial temperature of the cold water. When we mixed the waters, these lines met on the graph at a point exactly between our two different initial temperatures. This point is the equilibrium reached once the heat from the water completely dispersed throughout the mixture of the two waters.



When unequal amounts of hot and cold water are mixed, the equilibrium temperature of the mixture is closer to the initial temperature of larger amounts of water. We also mixed unequal amounts of waters of different temperatures. When we had more hot water, the two temperature lines on our graph reached the same equilibrium temperature that was closer to the initial temperature of the hot water. When we had more cold water, the two temperature lines on our graph reached the same equilibrium temperature that was closer to the initial temperature of the cold water.





Developing Mathematical Representations of Thermal Phenomena

In analyzing the results of what we observed when we mixed our different water and temperature scenarios, we noticed that the ratio of the amount of water was the inverse of the ratio of the change in temperature of the water. So, if we used 100 mL of hot water and 50 mL of cold water

(2:1 ratio), the ratio of the change in temperature of the hot water to the change in temperature of the cold water was 1:2. We considered that heat lost equals heat gained (the Law of Conservation of Energy), so the amounts of water had an inverse relationship to the change in temperature of that water.

When unequal amounts of hot and cold water are mixed, the ratio of the amount of hot water to the amount of cold water is equal to the ratio of the change in temperature of the cold water to the change in temperature of the hot water. In our experiment, we mixed 100 mL of water that was 38 degrees Celsius with 50 mL of water that was 6 degrees Celsius. When we did this, we ended up with 150 mL of water that reached an equilibrium temperature of 33 degrees Celsius. The ratio of the amounts of hot water to the amount of cold water that we used was 100:50, or 2:1. The ratio of the change in temperature of the hot water to the change in temperature of the cold water was 12:20, or approximately 10:20, or 1:2. These two inverse ratios show an important relationship between mass of objects and change in temperature of those objects. We can express this relationship mathematically as:

$$\frac{\text{mass of hot water}}{\text{mass of cold water}} = \frac{\text{Change in temperature of cold water}}{\text{Change in temperature of hot water}} \qquad \frac{m_h}{m_c} = \frac{\Delta T_c}{\Delta T_h}$$

This equation is justified by the findings from our experiments in class.

The more water one has and the bigger the temperature change, the more energy is lost (or gained).
Larger masses of material, such as water, will have more heat energy spread throughout the entire mass. This is why when there is more hot water mixed with a small amount of cold water, the temperature change for the hot water is not very significant. More heat energy transfers from the hot water to the cold water, so more energy is lost by the hot water (and gained by the cold water).

heat lost = $M_h \Delta T_h$ makes conceptual sense because the amount of the hot water multiplied by the change in the temperature of the hot water is the total amount of heat energy that was transferred by the hot water, or the amount of heat lost.

heat gained = $M_c \Delta T_c$ makes conceptual sense because the amount of cold water multiplied by the change in temperature of the cold water is the total amount of heat energy that was transferred from the hot water, or the amount of heat gained by the cold water.

The heat lost or gained also depends upon a property of the material, its *specific heat*.
Specific heat is the amount of energy (either lost or gained) that is needed to raise the temperature of 1gram of material by 1 degree Celsius. Different materials have different specific heats, so it is important to take this value into account when we consider the equation that relates to the idea that heat lost equals heat gained. Water, for instance, is the standard, so its specific heat is 1—it takes one calorie of energy to raise the temperature of one gram of water by one degree Celsius.

Energy is conserved: When hot and cold water are mixed, energy lost by the hot water equals energy gained by cold water (assuming the environment (cup, air) does not gain any energy during the mixing). This idea is called the law of conservation of energy. Energy cannot be created or destroyed, so when we mix two objects of different temperatures or varying levels of heat energy, the energy is transferred between the materials but is never destroyed. This is why it makes sense that the heat lost by one object is equal to the heat gained by the other—the energy transfer that occurs results in an equilibrium temperature where this is the case. (This is conceptually true if we were experimenting in a completely closed system. Because in our lab setting some of the heat energy could have escaped to the air, there are some possibilities for mistakes and we must consider this experimental error). This idea can be expressed mathematically as:

Heat energy lost by hot water = Heat energy gained by cold water

(mass of hot water)(specific heat of water)(change in T of hot water) = (mass of cold water)(specific heat of water)(change in T of cold water)

$$m_h\, c_w\, \Delta T_h = m_c\, c_w\, \Delta T_c$$

where c_w represents the specific heat of water, which is the same for hot and cold water, so:

$$m_h\, \Delta T_h = m_c\, \Delta T_c$$

This equation is justified by the theoretical statement of the Law of Conservation of Energy

Using Mathematical Representations to Estimate a Quantity of Interest

How much hot water is needed to be added to 100 g of cold water in order to create a mixture of water that is the perfect temperature for a baby's bath?

- Amount of hot water X
- Amount of cold water 100g
- temperature of the hot water 50 degrees Celsius
- temperature of the cold water 5 degrees Celsius
- ideal temperature/ equilibrium temperature 25 degrees Celsius

$$M_{hot} = M_{cold} \frac{\Delta T_{cold}}{\Delta T_{hot}}$$

$$M_{hot} = 100\text{g} \frac{(25—5) \text{ degrees Celsius}}{(50—25) \text{ degrees Celsius}}$$

$$M_{hot} = 100\text{g} \frac{20 \text{ degrees Celsius}}{25 \text{ degrees Celsius}}$$

$$M_{hot} = 80 \text{ g}$$

An Example of the Influence of Light and Thermal Phenomena on Local Weather

If you have ever visited the beach, you have probably observed firsthand the breezes and clouds that roll in each afternoon. These interesting weather patterns are created by the interactions of the heat from the sun and its effect on the sand and water at the beach. The properties of the sand and water, along with the powerful ideas about interactions with the light and heat from the sun are what create this interesting phenomena of the weather patterns at a beach.

Identifying Resources

Living on the planet Earth means that we will experience many different weather patterns. Sometimes, it is hot and sunny. Sometimes, there are clouds in the sky. Sometimes, more severe weather, such as rain or snow storms, will form. Sometimes, there is wind and sometimes there is not. All of these weather types follow specific patterns that are formed by the interactions of other components of weather cycles and patterns. We will explore one such weather pattern—that of an afternoon ocean sea breeze.

Developing Powerful Ideas Based on Evidence

Materials differ in many properties. There are many different properties of materials that affect they way in which those materials act under certain situations. Some specific properties that are relevant to light and thermal phenomena include density, thermal conductivity, specific heat, and reflectivity. Density is the amount of mass a material has per one unit of volume. Thermal conductivity is how well and how quickly items transfer heat energy. It is a number that indicates how readily an object will transfer heat energy. Specific heat is a number that indicates how much heat energy is needed to raise the temperature of one gram of material by one degree Celsius. Finally, reflectivity is a measurement of how much light is reflected back when it bounces off of an object.

Density. Density can be defined as how much mass there is for each unit of volume. Water is the standard, so the mass of one gram of water has a volume of one cubic centimeter., and water thus has a density of 1 g/cc. In our experiment, when we measured out equal masses of sand and water using a balance, the water cup ended up having a greater volume. This means that sand is more dense than water because the mass of sand fit into a smaller volume than that same mass of water. Also, if some sand was placed into the water, it would sink, because of its greater density. The density of sand is about 1.6 g/cc.

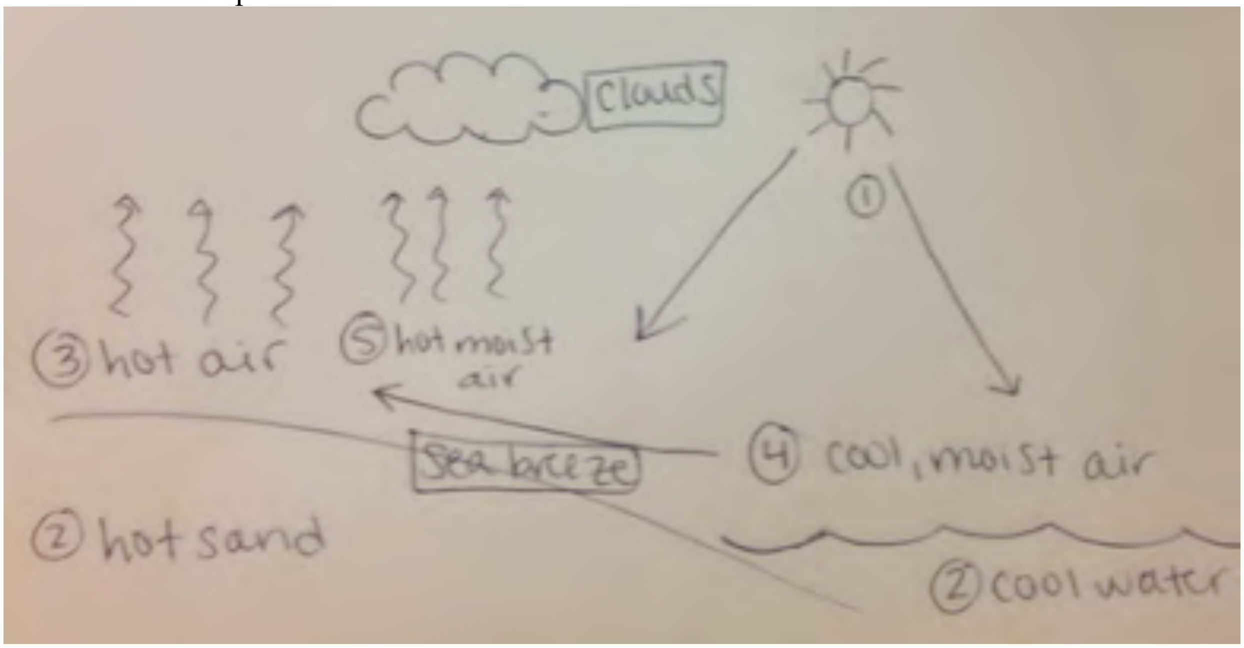
Thermal conductivity. Thermal conductivity can be defined as how quickly a material transfers heat energy. When we felt the four blocks of different materials, even though the blocks were all the same temperature, the metal blocks felt colder to our hand. This is because metals are conductors, and have high thermal conductivity. They easily allow heat energy from our hand to flow into them, so our hand feels cool as it loses heat energy. The styrofoam, on the other hand, felt a lot warmer to our touch. This is because styrofoam is an insulator and does not easily allow heat energy to flow into it. Similar to this experience, the water felt much colder to touch than the sand after we had heated both up under a light. However, the sand was only hot at the top layers—when we moved the temperature probe deeper into the sand, it was much cooler. This allows us to infer that the water had a greater thermal conductivity because the heat from the lamp spread throughout all of the water, rather than just the top layer of the sand.

Specific heat. Specific heat can be defined as the heat energy (in calories) needed to change the temperature of a mass of one gram of a material by one degree Celsius. Water is the standard, so one calorie is needed to change the temperature of one gram of water by one degree Celsius. The specific heat of water is 1 cal/g ºC. The specific heat of sand is about 0.2 cal/ g ºC. If the same amount of heat energy is absorbed by equal masses of sand and water, the sand will change its temperature more. This is because it takes more energy to raise the temperature of the water than the sand.

Reflectivity. Reflectivity can be defined as an indication of how well a material reflects light that is shining upon it. The more light that is reflected, the higher the reflectivity of the object. When we pointed the light sensors on materials with high reflectivity, our graph was much higher than for materials with low reflectivity. In our explorations of the creation of ocean sea breezes, it is important to note that water is more reflective than sand.

Using Powerful Ideas to Develop an Explanation of Weather Phenomena

These powerful ideas about light and thermal phenomena can be used in conjunction to describe local weather, such as that which exists on beaches. At the coast, one typically experiences hot sand, cool water, sea breezes, and clouds in the afternoon. This occurs due to a cycle that relates to light and thermal phenomena. Light from the sun travels in straight rays in all directions, and heats the sand and the water throughout the morning. By the afternoon, the sand is much hotter than the water. This is because the water reflects more of the sun light back than the sand, and also because the water is more thermally conductive than the sand, so the heat energy spreads throughout the entire body of water. On the sand, the heat energy remains concentrated only on the top exposed layer. This is why you can dig down into the sand, and it will feel cool. Because the sand is warm, the air about the sand is warm. Because hot air rises, this air rises, and the cold air above the water flows into this space. This cool air also contains some moisture from the water, and as it sits over the hot sand, it begins to heat up itself. Following the cycle, this cold but now warm, moist air rises, and is it rises into the cooler atmosphere, the moisture condenses and forms clouds. The sea breeze that is felt is created by the movement of the cold air into the space left by the risen hot air. This pattern continues, so that each afternoon, clouds and breezes can be experienced at the beach.



Using Mathematical Representations to Estimate a Quantity of Interest

In order to make predictions about weather trends and patterns, meteorologists use mathematics to build complex computer models that they use to predict the weather. This is beneficial to us when trying to plan for the week's weather by looking at a forecast.

Examples of the Influence of Light and Thermal Phenomena on Global Climate and Its Implications

Identifying Resources

If you have ever gotten into a car that has been sitting out in the sun for a while, you have probably experienced some discomfort from the warm seats and seat belts. Also, if you have ever been inside of a greenhouse in the middle of winter, you may have been curious as to why it was so warm inside the tiny glass house when the outside temperature was quite cold. These examples of everyday experiences are relevant to ideas surrounding global climate, which can be explained through the knowledge of certain light and thermal phenomena.

Developing Powerful Ideas

Liquids expand when heated. When we use alcohol thermometers, the reason the red line increases with an increase in temperature is because liquids expand when heated. When we warmed the thermometers using our hands, heat energy from our hands transferred to the alcohol in the thermometer. This caused the liquid to heat, and in turn, expand. We saw evidence of this expansion when the red of the alcohol went up and the thermometer read a higher temperature.

Visible light can be represented as a wave and is part of a broad spectrum of such waves. The way that we are used to thinking about light is only a small piece of the whole picture. The light we encounter and are fully aware of is known as visible light—it is the light that is visible to the human eye. This light, though it travels in a straight direction, can be represented as a wave with a certain length. However, on the electromagnetic spectrum, there are many other different waves that we are not able to see, with varying wave lengths. For instance, there are ultraviolet rays, radio waves, micro waves, x rays, and infrared waves. According to an image from the site http://missionscience.nasa.gov/ems/01_intro.html, radio waves are the longest and gamma rays are the shortest wavelengths. Visible light is towards the middle of the electromagnetic scale, and only makes up a very small portion of the scale. How surprising and interesting it is that we are unable to see a majority of the electromagnetic energy that exists. Also, the site http://science-edu.larc.nasa.gov/EDDOCS/Wavelengths_for_Colors.html , explains that light waves that are too short for the visible eye to see are described as "bluer than blue" and light waves that are too long to see are described as "redder than red".

Hot objects emit energy as infrared radiation. According to the information provided by Dr. Michelle Thaller, who works with NASA and the Spitzer Space Telescope, infrared light can be emitted by hot objects as energy or radiation. Infrared light is invisible to the human eye, but with special infrared cameras, it is possible to see some interesting aspects of this type of light. For instance, looking through an infrared camera, hot objects appear red or orange in color and colder objects appear as blue or purple. These cameras and this type of light energy is useful because one can distinguish infrared light through walls or smoke. However, infrared light energy cannot pass through glass at all. Finally, Thaller noted that the higher the energy of the light, the shorter its wave length will be. (http://www.youtube.com/watch?v=2--0q0XlQJ0.)

Materials differ in whether visible light and infra red radiation can pass through the material or are blocked. As mentioned above, Dr. Michelle Thaller explained that certain materials let infrared light pass through them and certain materials do not. Smoke and plastic bags, which normally do not let visible light through, are very easily passed through by the infrared light. The infrared cameras can clearly see the heat of objects cloaked in smoke or plastic. However, glass is a specific material that does not let any infrared light past it.

Using Powerful Ideas to Develop Explanations of Intriguing Phenomena

Greenhouse effect. The Greenhouse effect is the way in which the Earth's atmosphere traps certain wave lengths of energy which contributes to the planet's heating. Light, envisioned as wavelengths, travels in straight lines from the sun to the Earth. Some of the energy from this visible light is absorbed by the land and water, and some of it gets reflected back into the atmosphere and then back outside of the sphere of the Earth. The energy that is absorbed into the Earth somehow gets translated into some infrared energy, which is also then emitted back away from the Earth. Some of this energy leaves the atmosphere, but because infrared light cannot easily pass through atmospheric gasses such as carbon dioxide (similar to the glass example above), the infrared light is bounced back and forth within the Earth's atmosphere. Because it remains in the Earth's sphere, this infrared energy contributes to the Earth's natural heating, ensuring the planet does not get too cold to the point where it cannot sustain life. The site http://climatekids.nasa.gov/greenhouse-effect/ explains further how the greenhouse effect can be compared to what happens in an actual greenhouse. Visible light is able to travel through the glass/atmospheric gasses into the greenhouse/earth. The visible light is then absorbed and some of it is also reflected back out through the glass/atmospheric gasses. However, some infrared light is also reflected from the ground, which cannot pass through the glass/atmospheric gasses. Thus, the energy from this light which is trapped within the greenhouse/planet contributes to warming the greenhouse/Earth.

Rising sea level due to melting ice on land. In our lab exploration of this phenomenon, we used ice melting in a tray of water and ice melting on a rock in a tray of water (where the trays were filled to the brim before the ice melted) to model what occurs when that ice melts. In this experiment, we discovered that the ice in the water melted at a much faster rate than the ice on the land. We also discovered that when ice on water melts, it does not cause the water to overflow into the second tray. However, when the ice on the rocks melted, the water in the tray overflowed into the second tray. When comparing this to real world phenomena, ice and glaciers that sit on land have a much greater impact on rising sea levels when they melt and run off into the ocean. Ice from glaciers in the sea are not a concern to rising sea levels, but an increased melting of the ice that sits on land is a growing concern to rising sea levels. According to http://www.nasa.gov/topics/earth/features/grace20120208.html, satellite measurements from the NASA/German Aerospace Center Gravity Recovery and Climate Experiment were used to measure ice loss in all of Earth's land ice between 2003 and 2010. The researchers found that during the period, the glaciers lost about 4.3 trillion tons, which in turn added about 12 millimeters to the global sea level (enough to cover the United States 0.5 meters deep).

Rising sea level due to thermal expansion of oceans. In our explorations, we also looked at the impact of thermal expansion of oceans on rising sea level. We discovered the powerful idea that liquids expand when they are heated. We saw this firsthand when the levels of our thermometers were increased when we heated the bulbs with our hands. As the sun shines down on the Earth, it heats the land as well as the water. As it is a liquid, when the ocean is heated, some thermal expansion occurs, contributing to sea level rises. When melting glaciers are combined with this thermal expansion, rises in sea level are inevitable as the Earth becomes hotter. According to the site, http://ocean.nationalgeographic.com/ocean/critical-issues-sea-level-rise/, sea levels worldwide have been rising at a rate of 3.5 millimeters per year since the early 1990s. This recent increase in rate can possibly be attributed to issues of global warming, as we have significantly been putting more pollutants into the air that trap heat in (see infrared section above). Also, the EPA explains on their site (http://www.epa.gov/climatestudents/expeditions/sea-level/index.html) that the Maldives, a group of islands, are experiencing the impacts of rising sea levels. Because of this country's low elevation (at most 7 feet above sea level), the island is at risk from the melting land ice and from the natural thermal expansion of the ocean.

Developing Mathematical Representations of Relevant Phenomena

Currently, some scientists are developing computer models to predict sea level rise and other aspects of climate change. This work is vital due to the dramatic rises in sea levels in recent years. Models for predicting these aspects of climate change will be of benefit for future endeavors involving climate change and preventing dramatic results.

Local, State, National, and International Efforts to Address Global Climate Change Issues

Global Climate Change is an issue that affects every single individual living on this planet. Because in recent years, an increased rate of warming has been perceived due most likely to human influences, many groups of humans are now working to reverse the negative effects. There are efforts to address many global climate change issues that can be seen at local, state, national, and even international levels.

Oregon State University efforts. The Oregon Climate Change Research Institute (http://occri.net/) has recently been playing a role in promoting efforts to lessen the impact of humans on the warming of the Earth. According to the site, IPPC reports have found increases in average global air and ocean temperatures, rises in sea level, and a dramatic increase in the melting of ice and snow. As explained on one of the site's links (http://occri.net/climate-science/potential-impacts-of-climate-change/water-resources), one impact of climate changes is the availability of fresh water resources. As the climate changes and regional temperatures rise, less snow falls and at different times in the year than normal. In the winter, melting snow and more frequent rain contribute to wintertime flooding. In the summer, there is less water in the rivers, because more water ran off earlier in the year; leading to shortages of water.

Oregon state government efforts. The Oregon Department of Energy website at http://www.oregon.gov/ENERGY/gblwrm/climhme.shtml, explains some aspects of Oregon climate change. According to the site, the Oregon that we are used to could become very different due to climate change—we could see public health problems with an increase in heat-related illness, many species who have become accustomed to the current climate may not be able to adapt to warmer temperatures, and crops and livestock could be affected by diminished water supplies. However,

according to
http://www.oregon.gov/energy/GBLWRM/Pages/portal.aspx#Oregon_Climate_Change_Actions, the state of Oregon has been pursuing many efforts to try to combat the impacts of climate change. With the development of a low carbon fuel advisory committee, for instance, Oregon has adopted a standard that would reduce the average amount of greenhouse gas emissions per unit of fuel energy by 10 percent from 2010 to 2020. (http://www.deq.state.or.us/aq/committees/advcomLowCarbonFuel.htm)

US national efforts. Not only are there individual state efforts regarding global climate change, but the United States also has its own national efforts. The United States Global Change Research Program (http://www.globalchange.gov/) is a Federal program that integrates global change research among government agencies. It was mandated by the Global Change Research Act of 1990, and has since made scientific investments in climate science and global change research. The USGCRP pursues many efforts to assess US climate, and in turn use that assessment to further efforts regarding the prevention of increased levels of climate change. (http://www.globalchange.gov/what-we-do/assessment) The assessment informs the nation about already observed changes, the current status of the climate, and anticipated trends for the future. It provides input that helps US citizens work together to create more sustainable and environmentally sound plans for the nation's future.

International efforts. Finally, the Intergovernmental Panel on Climate Change (IPCC) (http://www.ipcc.ch/) is an international group concerned with climate change issues. The IPCC provides Assessment Reports of the current states of knowledge on climate change at regular intervals. For instance, they present a report that includes studies on sea levels every 7 years. The most recent report was Climate Change 2007, and the next report is due in 2014. According to the report on sea level, thermal expansion is projected to contribute more than half of the average rise. Land ice will also have an impact as it continues to lose mass at an increasingly rapid rate as the century progresses. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-5-1.html

Social Impact of Global Climate Change

Global climate change is an issue socially around the world, and particularly for low-lying countries. As the Earth heats and ice caps melt, and as thermal expansion causes ocean levels to rise, impacts on societies from low lying islands become greater. For example, the article http://www.guardian.co.uk/global-development/2013/jan/29/sea-change-bay-bengal-vanishing-islands, explains the impact of ocean levels on the islands of Bangladesh. Many of the small islands have been completely swallowed up and now rest many feet below ocean levels. This has led to an increase in refugees without a home. Another social impact of the rising sea levels, this increase in refugees creates issues in increased spread of disease and overpopulation. Because of these social issues, and because it is important to care for our planet and protect it for future generations, knowledge of climate phenomena is vital if we want to be knowledgeable about the best way to prevent further extreme impacts.

The Nature of Astronomical Phenomena

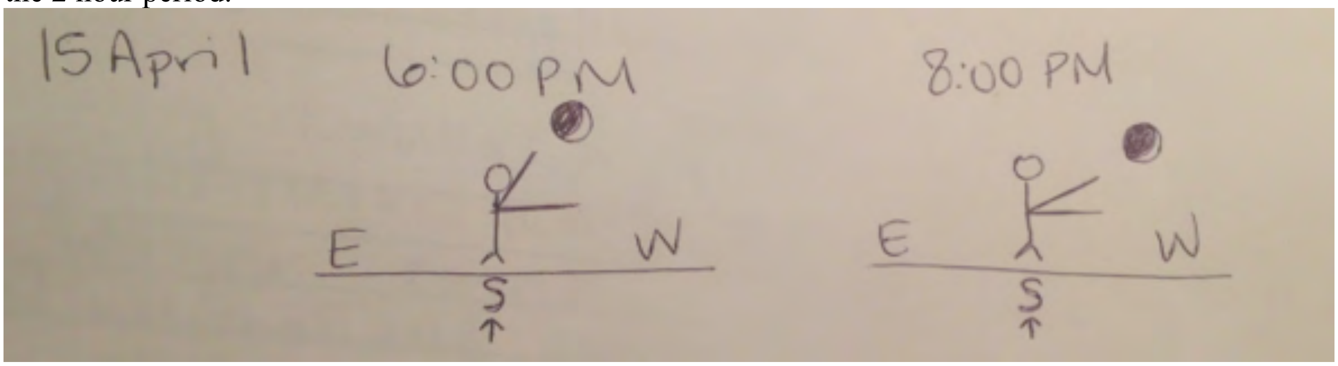
Identifying Resources

The moon is a very beautiful celestial body. When there is a full moon shining brightly in the night sky, many are drawn to its beauty. If one were to observe the moon on a daily basis, they would notice some interesting phenomena. They would see its shape change, they would see its position in the sky differ over hours and over days, and they would realize that the moon looks slightly different each night it is observed. Looking for the moon in the sky is the best resource for noticing these interesting phenomena. However, one could also look to see if their calendars provide moon information, or could research moon cycles and phases online in order to learn more about the moon.

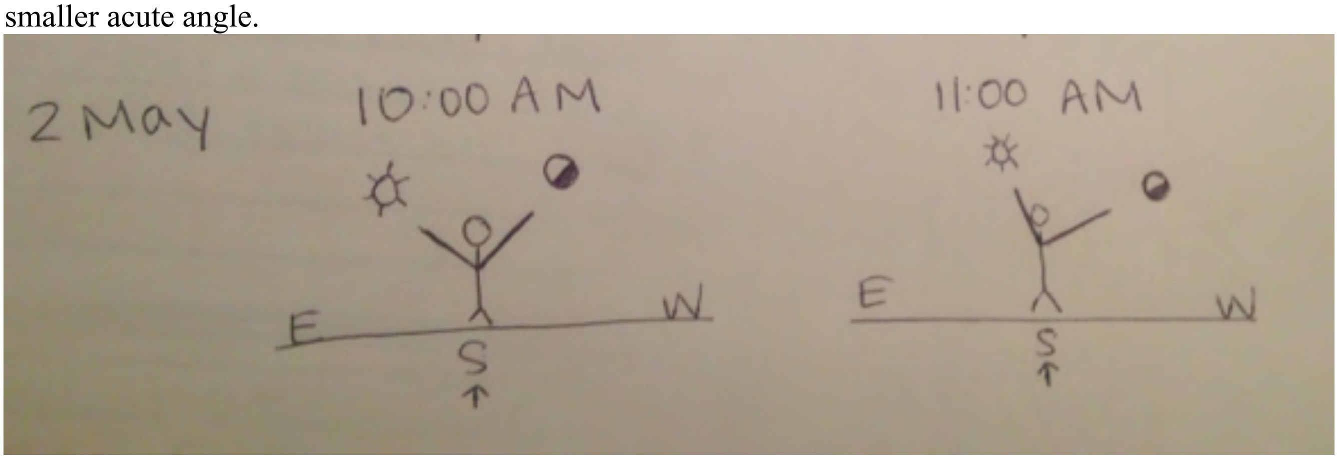
Developing Powerful Ideas Based on Evidence

The moon seems to move across the sky like the sun, east to west, during one day. When actively looking for the moon within a single day at certain hour intervals, one would see the moon's position in the sky change over time. It would start in the Eastern part of the sky, and over a few hours, its position would gradually become more towards the Western part of the sky. In using my moon journal, I observed exactly as described, so I can infer that over a few hours, the moon appears to move from East to West.

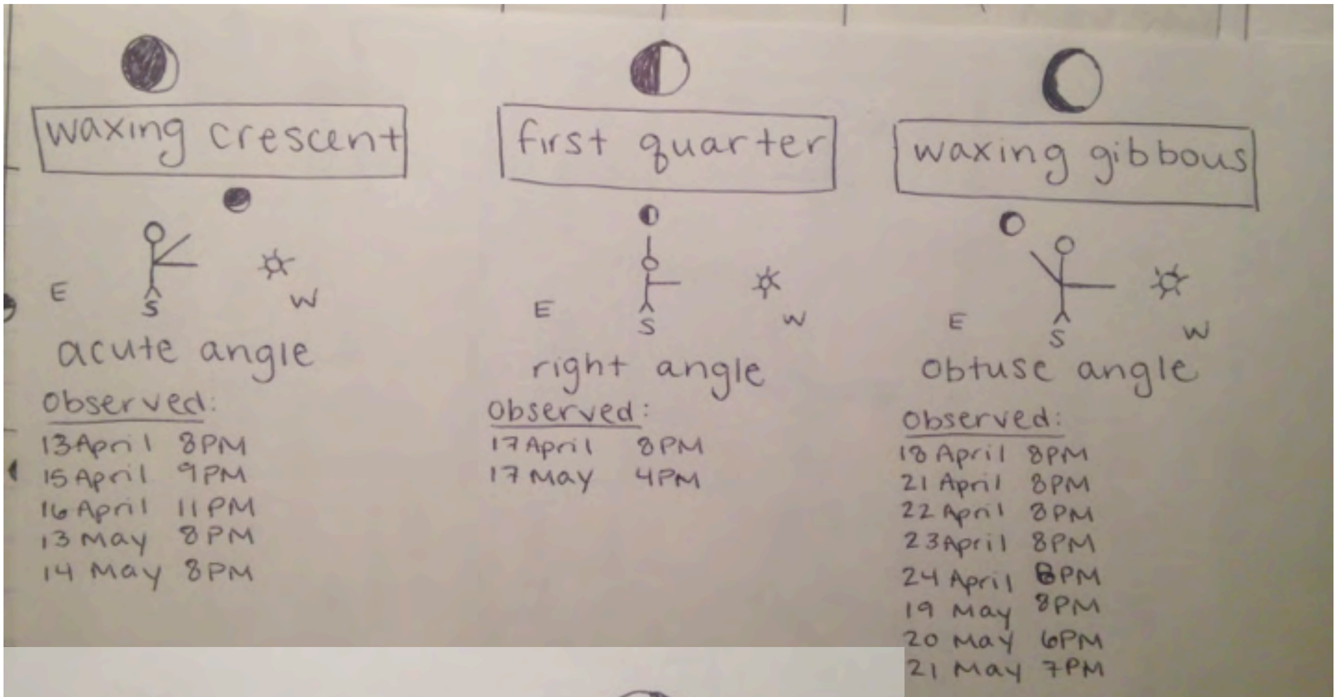
On April 15, 2013, I saw the moon at both 6:00 PM and 8:00 PM. When I saw the moon at both of these times, I pointed one hand toward the moon and one toward the Western horizon. The angle between my arms was smaller at 8:00 PM than at 6:00 PM because the moon appeared to move West in the 2 hour period.

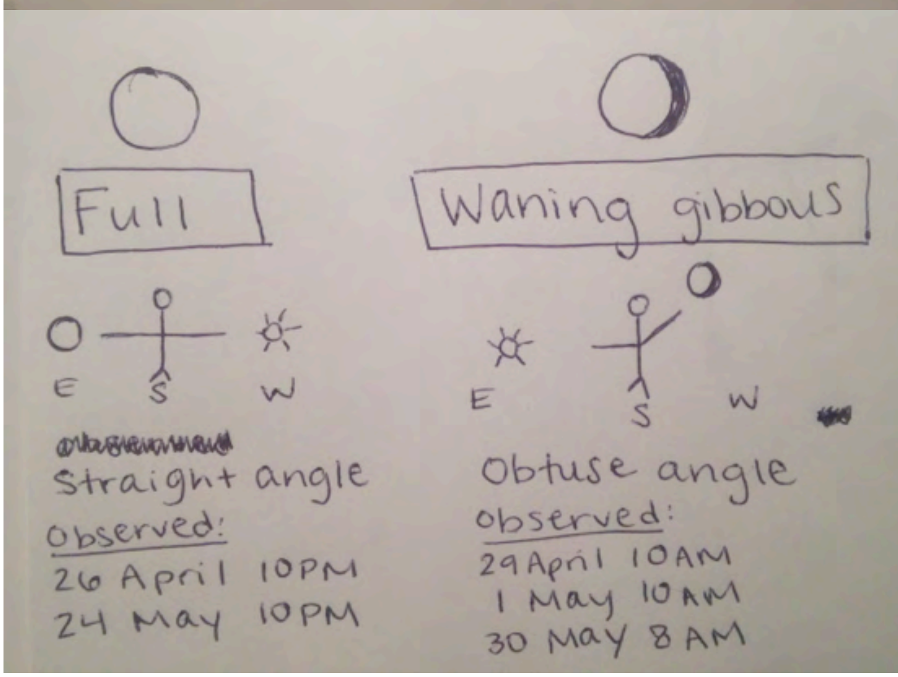


In class on May 2, 2013, we observed the third quarter moon at the beginning of class and then again at the end of class. The moon when we observed it on this day was half lit on the left side. When we looked at the beginning of class, the angle between our arms when we pointed one hand to the sun and the other to the moon was exactly 90 degrees. We also observed an acute angle between the sun and the Eastern horizon, and an acute angle between the moon and the Western horizon. When we looked at the end of class, the angle between our arms was still 90 degrees, and the moon was still half lit on the left side. However, both the sun and the moon were in positions that were West of their positions when we first observed them that day. Because the angle between them had not changed, we inferred that the sun and moon appear to move together in a 24 hour period, from East to West. Because of this movement, the angle between the sun and the Eastern horizon was still an acute angle, but the angle was much larger. The angle between the moon and the Western horizon was a much smaller acute angle.

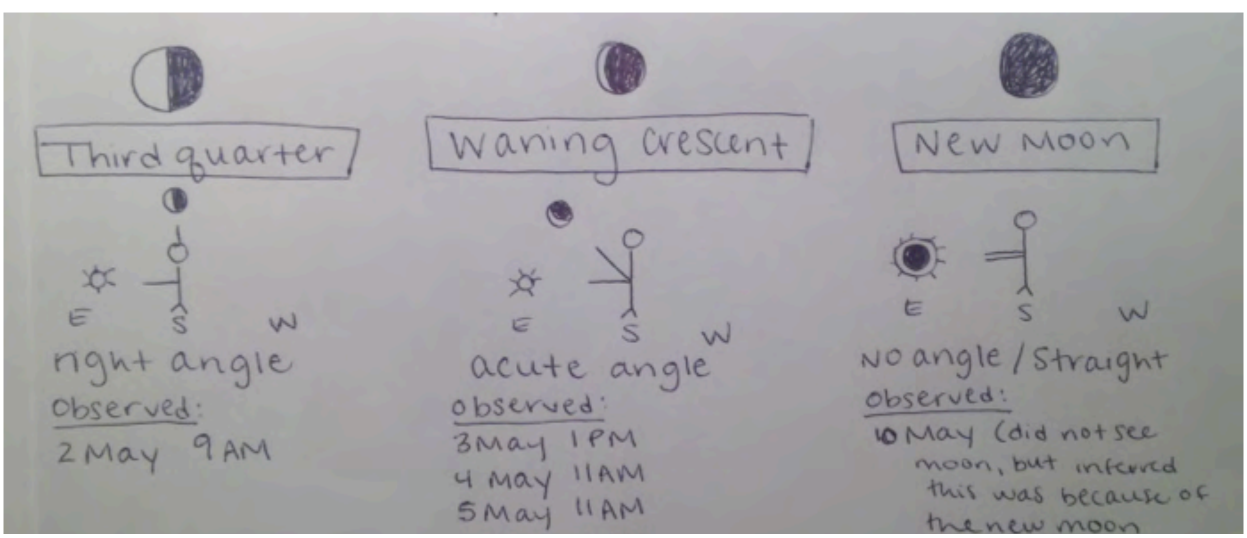


The shape of the lit portion of the moon that we see from earth changes in a regular pattern. Over many days, the moon appears to change shape in a regular pattern. This pattern is the different phases of the moon. Below are the phases of the moon in order, the angle between the moon and the sun when the phase is observed, along with the times and dates that I personally was able to observe and record in my moon journal that particular phase.

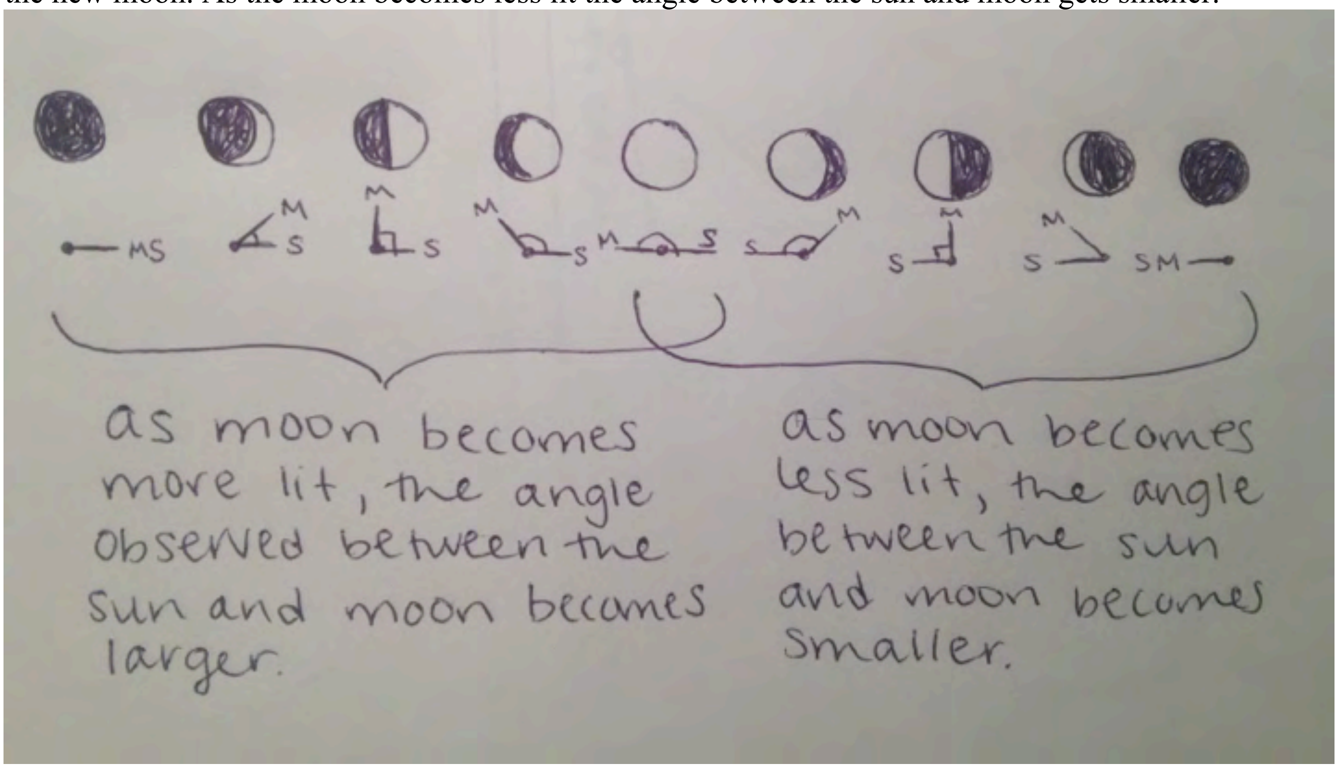




The angle formed by pointing one arm at the moon and one arm at the sun changes in a regular pattern related to the changing shape. By looking at the observations presented above, we

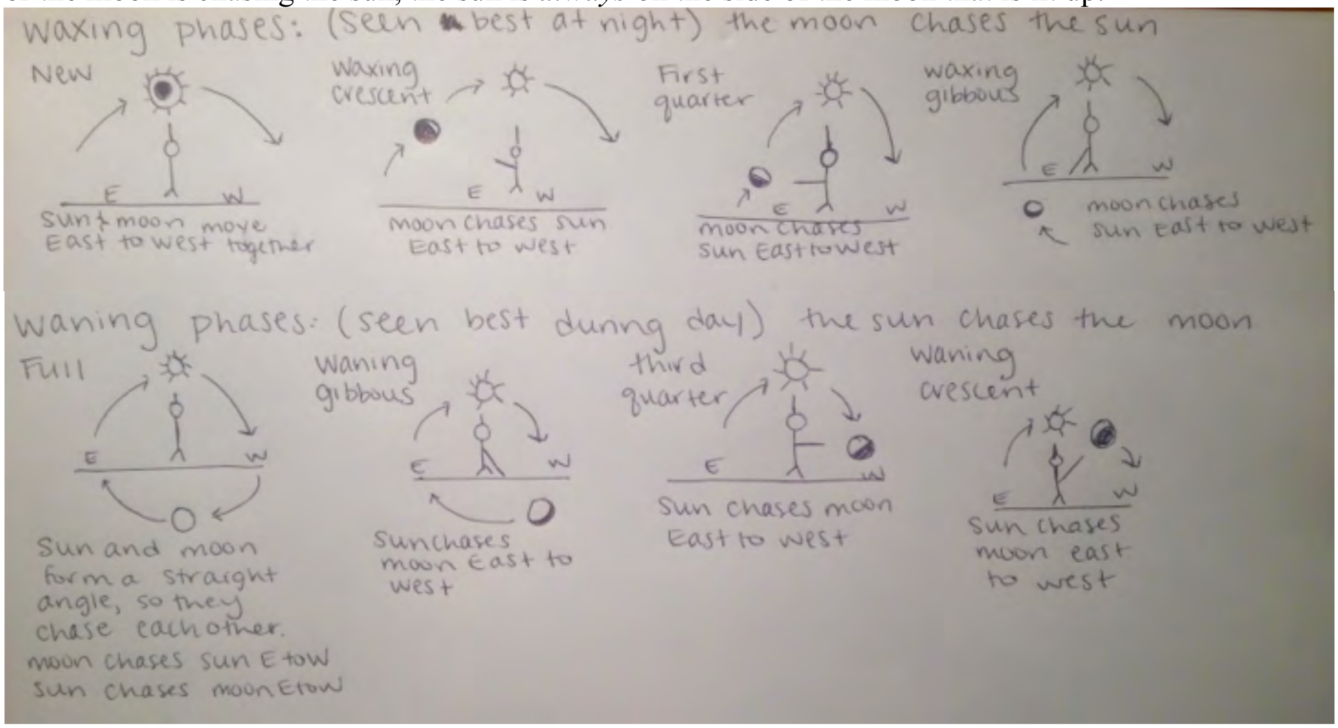


see that as the lit portion of the moon we see gets bigger, the angle formed by pointing one arm at the sun and one arm at the moon also gets bigger; and as the lit portion of the moon we see gets smaller, the angle formed gets smaller. As the moon goes from a new moon to a full moon, the lit portion of the moon on the right side is getting larger. As this occurs, the angle between the sun and moon also gets larger. We observe no angle with the new moon, an acute angle with the waxing crescent moon, a right angle with the first quarter moon, an obtuse angle with the waxing gibbous moon, and a straight angle with the full moon. As the moon becomes more lit the angle between the sun and moon gets larger. Conversely, as the moon goes from a full moon to a new moon, the lit portion of the moon on the left side is getting smaller. As this occurs, the angle between the sun and moon also gets smaller. We observe a straight angle with the full moon, an obtuse angle with the waning gibbous moon, and right angle with the third quarter moon, and acute angle with the waning crescent moon, and no angle with the new moon. As the moon becomes less lit the angle between the sun and moon gets smaller.

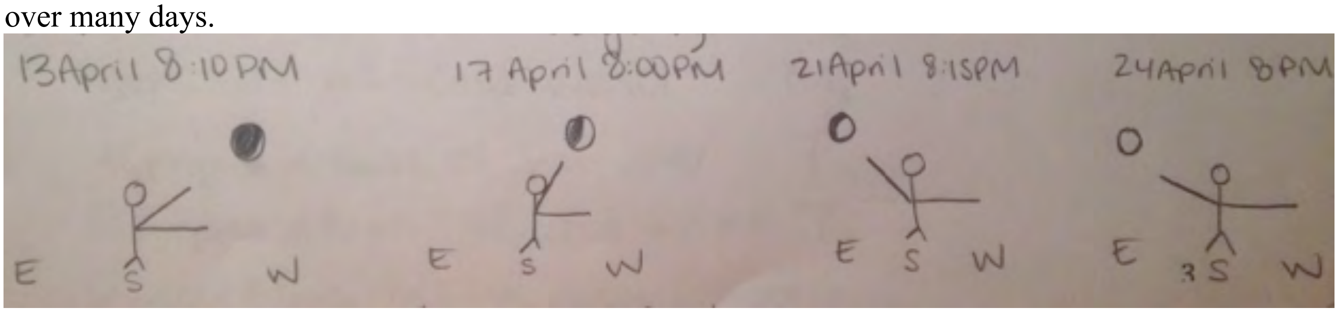


The sun is always on the lit side of the moon. However, we did notice a paradox—sometimes the moon seems to chase the sun across the sky but other times the sun seems to chase the moon. For example, when we observed the sun and moon together on May 2, the sun was to the left of the moon and both seemed to move toward the right (toward the West), with the sun chasing the moon. Yet, when I observed the moon on April 15, the moon was to the left of the sun and both seemed to move toward the right/West, with the moon chasing the sun.

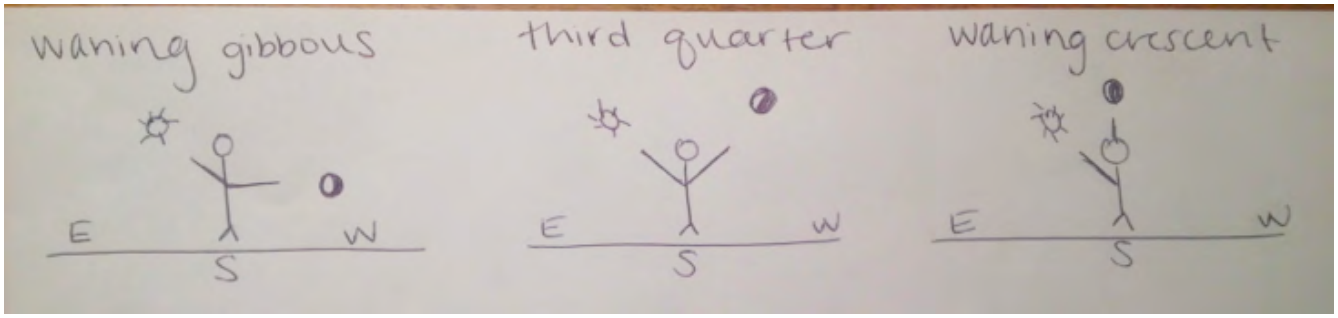
During the waxing phases, the moon appears to chase the sun. During the waning phases, the sun appears to chase the moon. But in both cases, the sun was always on the lit side of the moon. This paradox occurs because we observe the waxing and waning phases at different times of the day. The waxing phases are best observed at night once the sun has gone down because the moon appears to be chasing the sun. The waning phases are best observed during the day because the sun appears to be chasing the moon. This switch in the appearance of which celestial orb is chasing which occurs as the angle between the sun and moon changes. Also, while the moon does seem to move from East to West in a single day, over multiple days, it actually appears to move from the West to the East part of the sky. During the waxing phases, we infer this West to East movement because the angle between the sun and moon gets bigger. During the waning phases, we infer this West to East movement because the angle between the sun and moon gets smaller. In all of the phases, whether the sun is chasing the moon or the moon is chasing the sun, the sun is *always* on the side of the moon that is lit up.



Systematic observations indicate that the moon seems to move west to east over several days. We meticulously looked for the moon every night, and carefully recorded exactly what we saw in our moon journals. Over time, we noticed that while the moon does seem to move from East to West in a single day, over multiple days, it surprisingly actually appears to move from the West to the East part of the sky. When I saw the waxing crescent moon, it was in the West part of the sky, yet when I saw the full moon at the same time of night, it was in the East. The angle between the moon and the Western horizon got larger over a few days, suggesting that the moon appears to move West to East over many days.

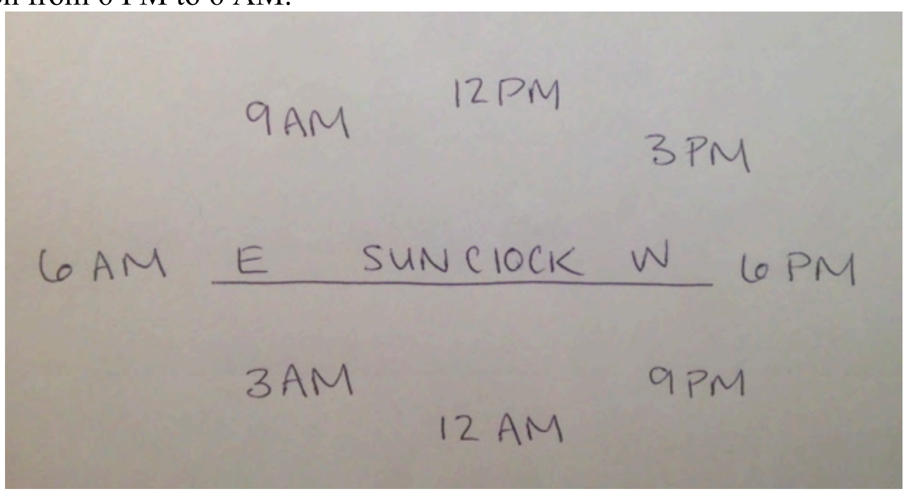


The apparent West to East movement can really be seen when one looks at the angles between the sun and moon for the waning gibbous, 3rd quarter, and waning crescent phases as seen when the moon is looked for at about 9:30 am over several days during these phases. The sun remains in the same place in the sky when looked for at 9:30, yet over the several days and the different phases of the moon cycle, the moon moves to a position that is closer to the sun or more towards the East.

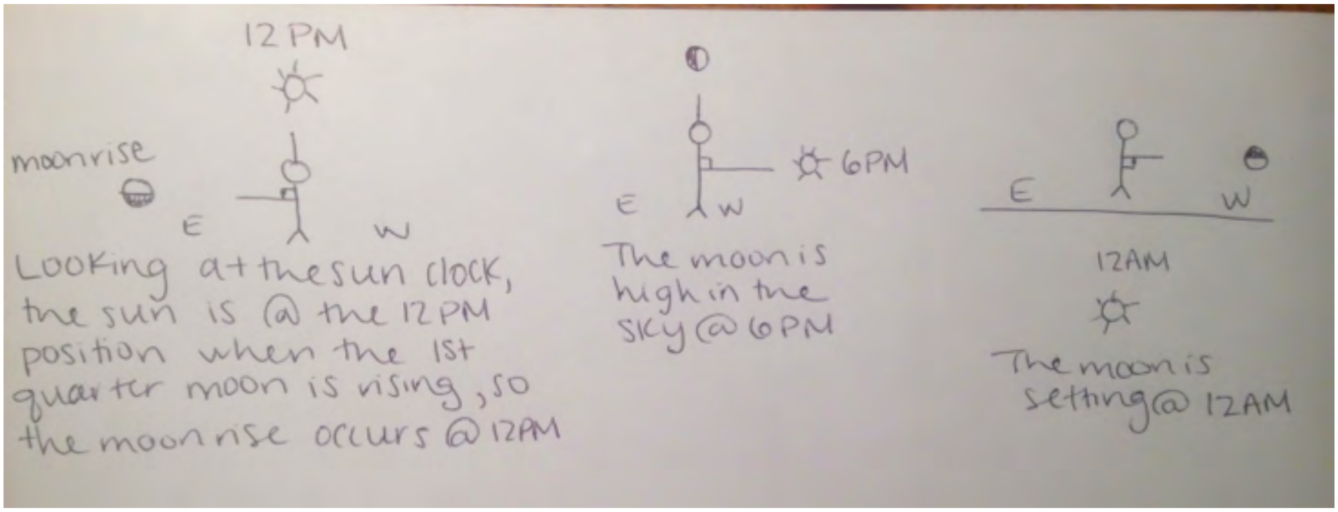


The angle formed by pointing arms at the sun and moon is a useful tool for predicting when and where to look for the moon. One of our early frustrations when we first started to meticulously look for the moon each night was that the moon often times was hard to find. At first, we did not know what time to look or what part of the sky to look at. The moon does not seem to be reliably up in the sky at night where one expects to see it, even when the sky is clear. After several weeks of trying to find the moon, students typically ask, how can I know where and when to look?

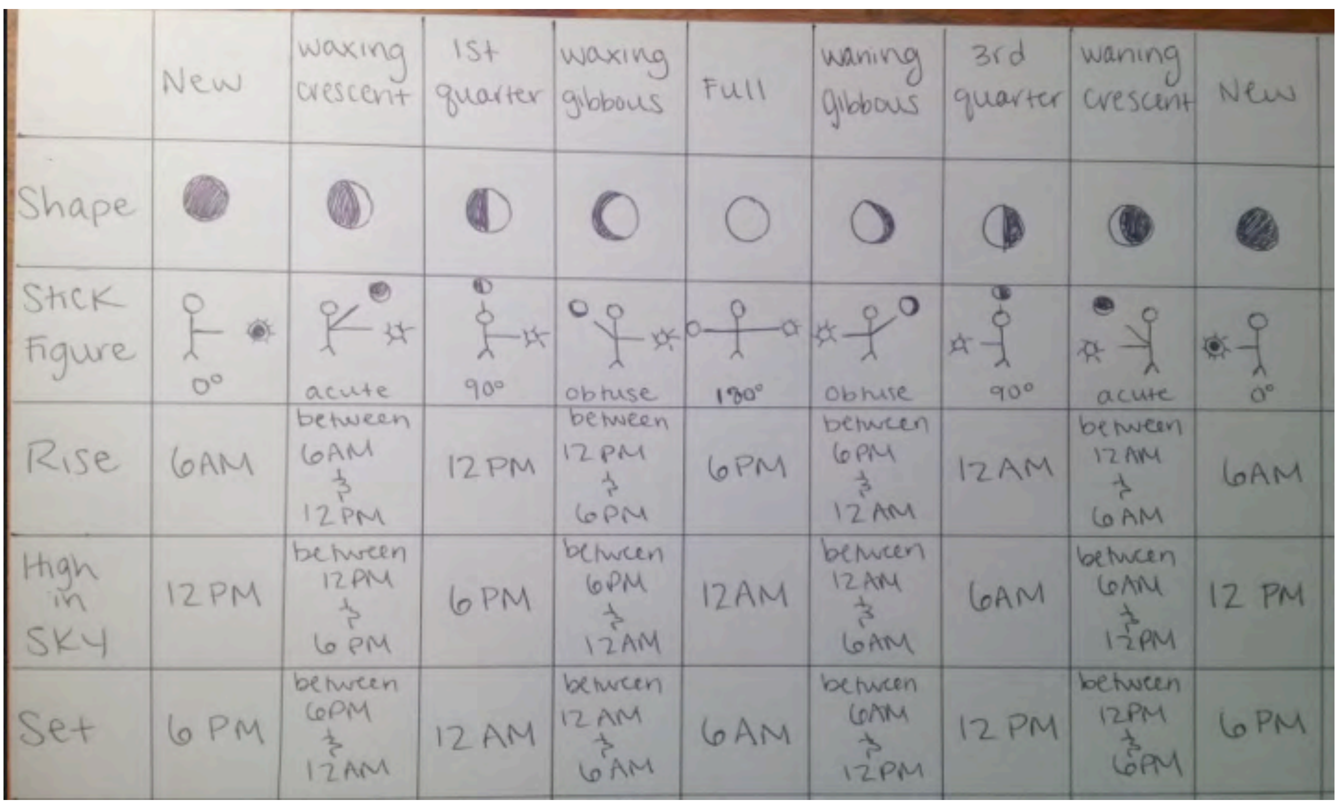
A 'sun clock' can be useful for answering that question. It shows how to 'tell time' based off of where the sun seems to be in the sky (or below the horizon) over a 24 hour period. Looking at the sun clock, we see that the sun rises at 6 AM and sets at 6 PM. It is high in the sky at 12 PM, and completely below the horizon from 6 PM to 6 AM.



This knowledge can be used along with knowledge of the angles between the sun and moon during different phases. We know that for a first quarter moon, there is a right angle formed between the sun and the moon. Using this, we can predict when the moon is rising, high in the sky, and setting. We know that the angle between the sun and moon must be 90 degrees, so when the sun is high in the sky, the moon would just be rising. This means the moon rise is at 12 PM. In order to maintain the right angle, when the sun is setting, the moon would have to be at its highest point. This means the moon is high in the sky at 6 PM. Finally, the sun would be at the 12 AM position when the moon sets, so we determine that the moon is setting at 12 AM.



The following chart shows the shape of the phase, name of the phase, a stick figure with arms pointing to sun and moon, and predictions for rising, high in the sky, and setting times for each phase of the moon. These predictions are based on assuming the sun rises at 6 am and sets at 6 pm, as it does during the equinoxes (days of equal daylight and darkness) in March and September.



	New	waxing crescent	1st quarter	waxing gibbous	Full	waning gibbous	3rd quarter	waning crescent	New
Shape									
Stick Figure	0°	acute	90°	obtuse	180°	obtuse	90°	acute	0°
Rise	6AM	between 6AM & 12PM	12PM	between 12PM & 6PM	6PM	between 6PM & 12AM	12AM	between 12AM & 6AM	6AM
High in Sky	12PM	between 12PM & 6PM	6PM	between 6PM & 12AM	12AM	between 12AM & 6AM	6AM	between 6AM & 12PM	12 PM
Set	6 PM	between 6PM & 12AM	12 AM	between 12AM & 6AM	6AM	between 6AM & 12PM	12 PM	between 12PM & 6PM	6 PM

The rising/setting/high in the sky times for the new, 1st quarter, full, and 3rd quarter phases are defined by 'moments' when the sun, moon, and earth are at particular angles. The angle between the sun and moon is 0 degrees for a new moon, 90 degrees for a 1st quarter moon, 180 degrees for the full moon, 270 degrees for the third quarter moon (because if we were to draw our stick figure with the sun in the West, the moon would be below the horizon at a 270 angle from the sun), and 360 degrees to get back to a new moon again. Waxing and waning phases occur over many days as the angle gets bigger or smaller, so there is no set rising/setting/high in the sky time. The time falls within a range, but varies as the angle changes.

Not only do our monthly calendars indicate that a full moon cycle occurs within a month, but our own observations also provide evidence for this claim. When looking at the moon each night, I saw a waxing crescent moon from April 11th through April 16th, or for around six days. I saw a first quarter moon on April 17th. I saw a waxing gibbous moon from April 18th through April 24th, around 7 days. I saw a full moon on April 25 which was about a week after I saw the 1st quarter moon. I saw a waning gibbous moon from April 27th through May 1st, around 6 days. I saw the third quarter moon on May 2nd, about a week after the full moon. I saw a waning crescent moon from May 3rd through May 9h, around 7 days, and finally, I "saw", or inferred that there was a new moon on May 10th. The entire cycle takes about a month (four weeks), with each waxing or waning phase taking about a week.

The history of the development of calendars based on the phases of the moon in various cultures is an interesting topic to explore if one wanted more information. This site, http://eclipse.gsfc.nasa.gov/SEhelp/calendars.html, explains the astronomical bases of calendars.

A useful URL for checking predictions for rising and setting times for a given day for a given location is http://aa.usno.navy.mil/data/docs/RS_OneDay.php This website also states the predicted phase and the percent of the moon that is lit as well as indicating the predicted time and date for new, first quarter, full, and third quarter moons. The website uses a complex mathematical model to make these predictions, which apparently are very accurate. The website is very helpful when planning when would be a good time to be able to observe the moon. This website can also be used to compare predictions for how the moon looks on the same date at different locations

Using Powerful Ideas to Develop an Explanatory Model for Intriguing Phenomena

We have observed that the moon seems to change its shape in a regular way. This happens based off of the moon's movement as well as its positioning around the Earth and in regards to the sun. We also have observed that the moon seems to move East to West during one day but West to East over several days. This is a very peculiar phenomenon, but it can be explained using the series of inferences that we have made based on the evidence provided by the above observations. The following are our powerful ideas and inferences regarding the moon.

The sun is the source of light from the moon on earth. The moon does not always appear to be fully lit, so we infer that the moon is not producing its own light. The light that we do see when parts of the moon are lit must then come from somewhere else. We infer that this light comes from the sun. The light from the sun travels to the moon, and bounces off of it. Sometimes, parts of the light bounce to where we are on Earth, so that the moon appears to be lit in places. On the basis of the above observations that the sun is always on the side of the moon that is lit we can strengthen our inference that the moon's light is coming from the sun. We infer that light rays from the sun are bouncing off the moon in all directions from the surface of the moon that is facing the sun and some of these light rays travel in the direction of Earth when some of the lit part of the moon's surface is facing Earth.

The phases of the moon are caused by the moon revolving around the Earth about once a month. To explain this, we developed an explanatory model for the phases of the moon in class. We held a ball in our hand as a representation of the moon. There was a light in our dark classroom to simulate the light from the sun. We envisioned ourselves as the Earth and we held the ball and saw certain parts of our "moon" lit up by the "sun". When we moved our arm around our fixed body (the Earth), we replicated the same changing phases we have seen for the moon in the sky. From this activity here on Earth we can infer that we see the changing phases of the moon in the sky because the moon is REVOLVING around the Earth. As explained in the above sections, this occurs during a time period of about one month.

This explanatory model for the phases of the moon also explains the apparent motion of the moon from west to east over several days. We infer that the moon actually IS moving over several days; it is revolving counterclockwise around the Earth as seen from our location.

The ‘shadow’ we see on the dark part of the ball is formed by the ball itself, the part of the ball facing away from the lamp. We can thus infer that the ‘shadow’ we see on the dark part of the moon is formed by the moon itself, the part of the moon facing away from the sun.

Thus we infer that the phases of the moon are NOT caused by the shadow of the Earth falling on the moon, a belief held by many people, including usually about a third to half of the participants in this course initially (of which I am a part). This is a reasonable belief to have, given that our experience with shadows typically involves seeing objects blocking light from falling on other objects rather than noticing that objects also have shadows on the back sides of the objects themselves, the sides facing away from the light source. Also we often hear on radio, TV or in the newspaper, about the moon moving through the shadow of the earth during a lunar eclipse. That this only occurs rarely, and only during a full moon, is not usually mentioned.

The moon is close to the earth and the sun is far away. To draw a representation of the Sun/Earth/Moon system, we need to decide whether the sun and moon are equally distant from earth, or whether the sun is close to the earth and the moon far away, or whether the moon is close to the earth and the sun far away.

We observed together on Thursday May 2 that when we saw a third quarter moon that was half lit, a right angle formed by pointing our left arm at the sun and our right arm at the moon. We used this observation in class to decide how to draw the arrangement of the Sun/Earth/Moon system. We modeled the sun, moon and earth in our classroom. The lamp was the sun, we were the Earth, and the basketball in our hand was the moon. We started with the “moon” in our left hand and our right hand pointing to the “sun” such that our arms formed a 90 degree angle. Our right hand was touching the “sun”, so we were modeling the sun and moon being equal distances from the Earth. However, when we modeled this in this way, we did not see a third quarter moon as expected. We had to move away from the sun (and keep the angle at 90 degrees), until we were finally able to see a third quarter “moon” on the basketball. This allows us to infer that the sun is farther away from the Earth than the moon is from the Earth.

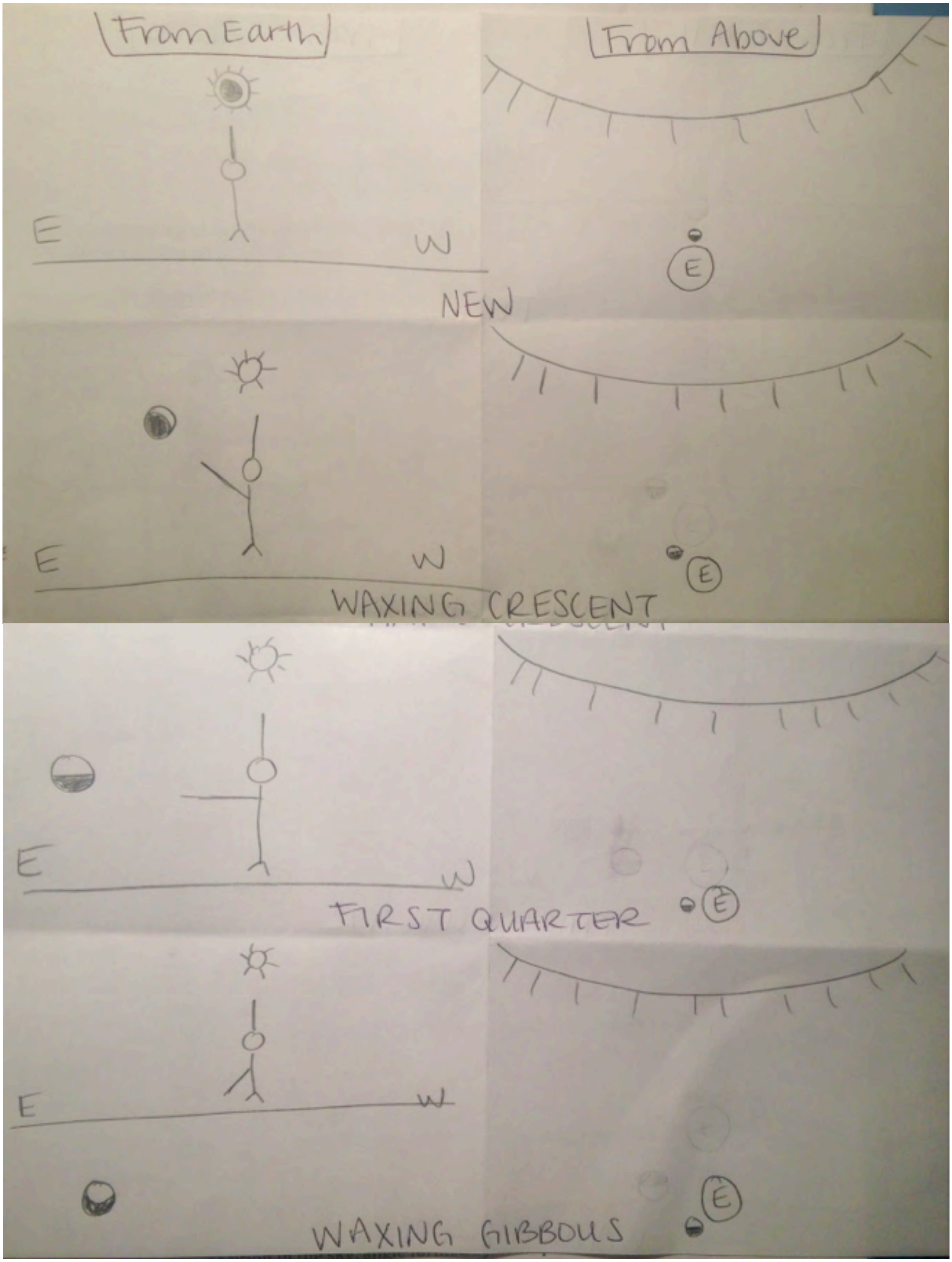
When I was close to the lamp holding the ball at a right angle, I saw a waning gibbous moon, not the expected third quarter moon. I had to step away from the lamp in order to replicate what we saw in the sky, a half lit moon with arms forming a right angle while pointing at the sun and the moon.

This replication in the lab of what we see in the sky is support for the inference that the moon is close to the Earth and the sun is far away.

The moon is small and the sun is very large. To draw a representation of the Sun/Earth/Moon system, we also need to decide what the relative sizes of the sun and moon are. Are they the same size as they appear to be as we view them here on Earth? Or is the moon big and the sun small? Or is the sun big and the moon small? In reasoning through these questions, we determined that the sun is quite large and the moon is small. The sun is very far away from the Earth (about 93 million miles away), which is why it looks so small when we see it from Earth. The moon is closer to the Earth, so it looks small as well, because it is small (compared to the sun).

To demonstrate this, we looked at a clock on the wall that was across the room from us. We then held our thumbs out so that we could no longer see the clock. The thumb and clock look like they are about the same size if we stand far away from the clock but we know that the thumb is very small compared to the clock if we stand close to the clock. From this, we can infer that if the sun and the moon look like they are about the same size as seen from Earth, but the sun is far away, then the moon must be small and the sun very large.

What we see depends upon our perspective. Using our inferences about the distances of the sun and moon from the Earth and the relative sizes of the three, we discover that drawings of what we see on Earth and what we infer we would see if we were able to look down on the Sun/Earth/Moon system from above for each phase of the moon are different. The same phases are being presented for two different perspectives.



From Earth
From Above
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NEW
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WAXING CRESCENT
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FIRST QUARTER
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WAXING GIBBOUS
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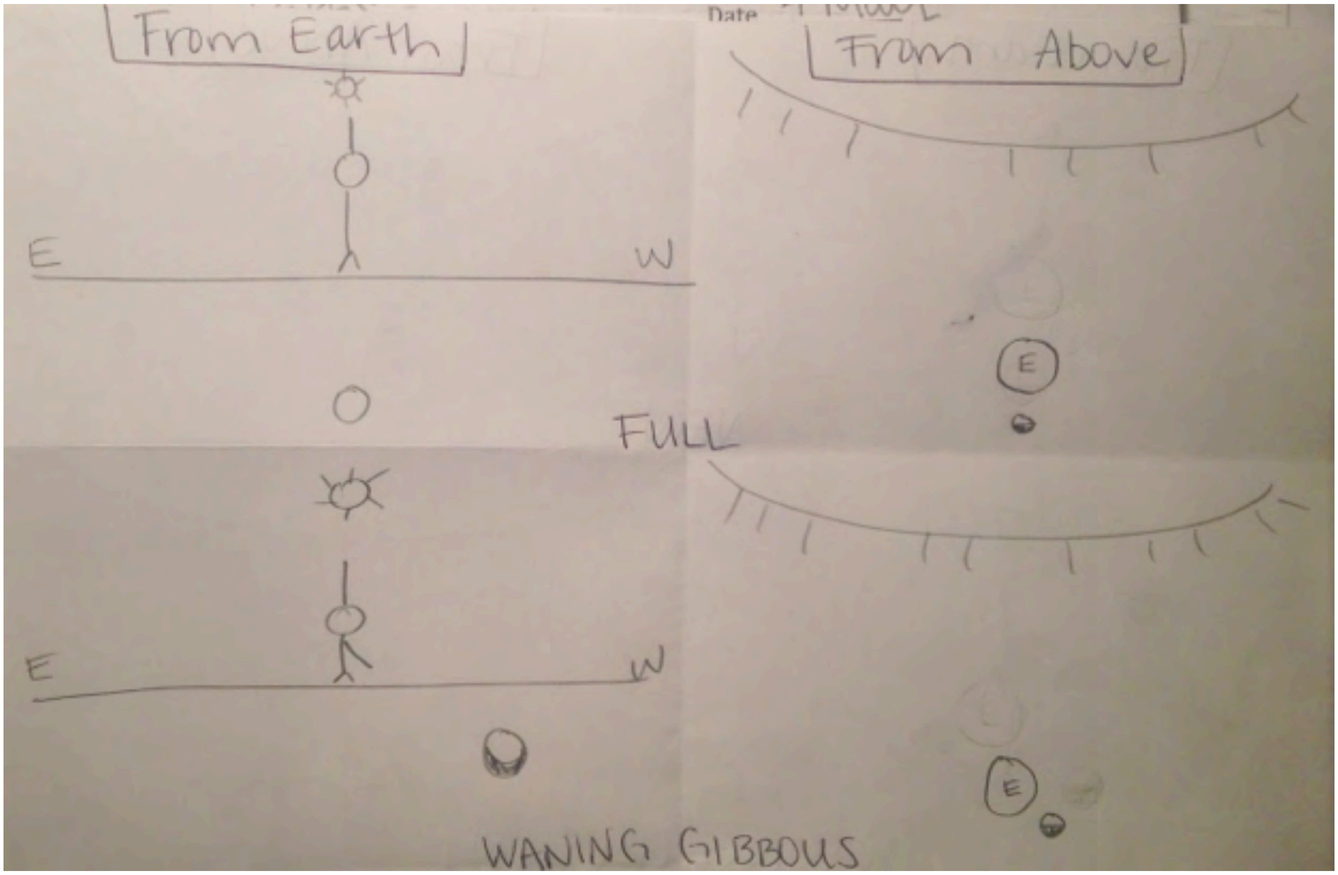
From Earth
From Above
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W
E
FULL
E
W
E
WANING GIBBOUS


E
W
E
THIRD QUARTER
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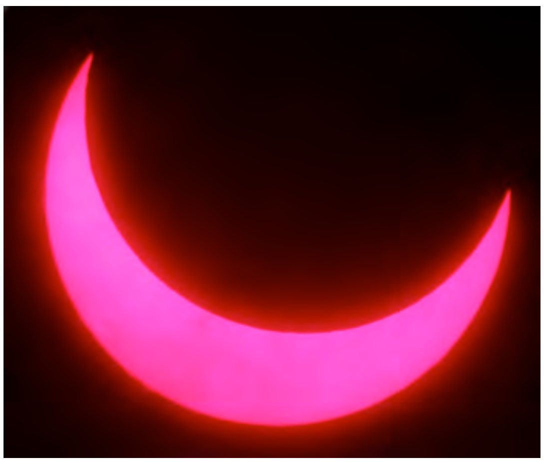
W
E
WANING CRESCENT

Eclipses occur when the moon is precisely in line with the Earth and Sun. A lunar eclipse may occur during full moon when the moon, Earth, and Sun are precisely in a line and the moon moves through the earth's shadow. A solar eclipse may occur during new moon, when the Earth, moon, and Sun are precisely in a line, and the moon's shadow falls on the earth. Usually the moon passes slightly above or below this precise line-up during full moon or new moon and an eclipse does not occur. More detailed explanations of eclipses can be found near the bottom of http://ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/skyappearance.htm. Look at http://eclipse.gsfc.nasa.gov/eclipse.html for dates of upcoming eclipses.

On May 9, 2013, there was a solar eclipse that could be seen in Australia. This site gives information about the eclipse: http://news.nationalgeographic.com/news/2013/05/130508-solar-eclipse-sun-slooh-space-science/#At the site http://events.slooh.com/, I was able to watch some of the eclipse, and took a few screen shots of the images of the shadow from the moon can be seen as it moves across the sun.



Using the ball and lamp in a darkened room, one can model eclipses of the moon and sun. One can 'eclipse' the ball by moving the ball into the full moon position but precisely in line with the lamp so that one is moving the ball through the shadow of one's head. One can 'eclipse' the lamp by moving the ball into the new moon position precisely in line with the lamp so that the shadow of the ball falls on one's eyes.)

Developing Additional Powerful Ideas

The Earth rotates on its axis every 24 hours. We have observed that the sun seems to rise in the east in the morning, move across the southern sky during the day, and set in the west in the evening. The moon seems to do this also, rising in the east, moving across the southern sky and setting in the west. (These rising and settings only occur precisely east and west during the equinoxes; at other times during the year they may occur slightly north or south of east and west.) One could infer from these observations that the sun and moon both move around the Earth every 24 hours.

In our culture, we are raised with the different view that the sun and moon are NOT moving around the Earth every 24 hours as seems obvious by merely looking at the sky. Rather, it is the Earth that is doing the moving, as it is spinning on its axis.

In order to model this alternative inference, we worked with a partner to develop a "moon dance" where we as the Earth spun around to model the Earth spinning on its axis. This caused the perception that the moon, held by our partners, was moving East to West, when really, we were rotating on our axis. We perceive that the moon and sun are moving East to West, but the apparent motion of the moon east to west during one day is NOT due to the moon moving around the Earth every 24 hours but rather due to the Earth ROTATING on its axis.

We infer that the apparent east to west movement of the moon during one day is due to the Earth ROTATING on its axis each 24 hours, rather than the moon moving around the earth each day, but that the apparent west to east movement of the moon over several days is due to the moon actually moving, in the process of REVOLVING around the earth about once a month.

The Earth revolves around the Sun in one year. As a class, we realized that different stars are visible in the night sky at different times of year. We replicated this in the lab by putting a lamp in the middle of the room, and personally ROTATing as we REVOLVED around the lamp. As we revolved around the lamp, we were looking at different walls depending on where we were in our revolution path. As the Earth revolves around the sun, different stars are seen because at night, we are looking out at a different part of the milky way (a different wall in our smaller model).

An interesting excursion, if one has time, is to explore the history of different cultures' views on the place of the Earth in the universe. (see http://earthobservatory.nasa.gov/Features/OrbitsHistory/) Both historically and currently, many people have held the view that the Earth does not move, that the Earth is the fixed center of the universe, with the sun and moon doing the moving, both moving around the Earth, and the stars moving around the earth as well, every 24 hours. This geocentric view was stated by an ancient Greek philosopher, Aristotle (384 BC – 322 BC) and elaborated later by a Greek astronomer, Ptolemy (c. AD 90 – c. AD 168) whose views were accepted for about another 1500 years. In the 1500's, a Polish astronomer, Nicolaus Copernicus, proposed an alternative sun-centered view, called the heliocentric model, that the earth and other planets moved around the sun, with only the moon orbiting the earth. In 1600, an Italian philosopher, Giordano Bruno was burned at the stake for espousing this (and other) controversial views. An Italian astronomer, Galileo Galilei (1564-1642) was investigated by the Catholic Inquisition and placed under house arrest for advocating the view that the Earth revolves around the sun. A modern Pope finally acknowledged in 1992 that the church was wrong to do this to Galileo (see http://www.nytimes.com/1992/11/01/world/vatican-science-panel-told-by-pope-galileo-was-right.html) This is an example of social issues concerning the relation between science and religion.

What keeps the moon in orbit around the Earth and the Earth in orbit around the sun? This is another interesting exploration, of the nature of gravity. An easy way to demonstrate (but not explain) what is happening is to attach a ball to a string and swing the ball around one's head. The string represents the force of gravity between the moon and the earth that keeps the moon in its orbit around the earth and between the earth/moon system and the sun that keeps us in our orbit around the sun. See http://starchild.gsfc.nasa.gov/docs/StarChild/questions/question30.html Sir Isaac Newton is credited with recognizing the connection between things falling to the earth and the moon revolving about the earth in its orbit, both due to the "force of gravity". See http://csep10.phys.utk.edu/astr161/lect/history/newtongrav.html

The Earth's axis is tilted. Globes that represent Earth are common in classrooms and show a tilted axis of about 23 degrees. We modeled this tilt in class while modeling the revolution of the earth around the sun by leaning toward the "sun" or away from it was we revolved around it. The Summer solstice occurs when the Earth is tilted toward the sun, and the Winter soltstice occurs when the Earth is tilted away from the sun. Our seasons are thus based off of the Earth's tilted axis!

One theory about how this tilt occurred is discussed on a NASA website (see http://spaceplace.nasa.gov/seasons/). Information about variation in the degree of the tilt is available at a NOAA website (see http://www.ncdc.noaa.gov/paleo/milankovitch.html)

Using These Powerful Ideas to Develop an Explanation of Intriguing Phenomena

In the Northern hemisphere, we are experiencing a cold winter in January because we are tilted away from the sun at that time. Meanwhile, the Southern hemisphere is experiencing a warm summer at the same time, in January, because they are tilted toward the sun. The Northern and Southern hemispheres are both roughly the same distance from the sun, given the scale of the distance of the sun from Earth, about 100 million miles, so the reasons for seasons can not be due to differences in how close the hemispheres are to the sun. Seasons occur depending on whether the portion of Earth is tilted towards the sun or away from it.

Using Mathematical Representations to Estimate a Quantity of Interest

When we see a third quarter moon we are looking at the place in space toward which we and everyone else on Earth are moving in our revolution about the sun. Using our knowledge and some mathematics we can estimate that we will get there in about 3 and ½ hours. When we see a first quarter moon we are looking at the place in space where we and everyone else on Earth used to be about 3 ½ hours earlier. See the attached handout at the very end of this paper for a detailed explanation of the mathematics involved in making this estimate.

Reflection on Learning and Teaching Science

Comparing Initial and Current Understandings

My initial and final responses to the diagnostic questions about light and shadows did not change. At the beginning of the course, I understood and observed the two shadows on the basketball and that another person in a different perspective would see a different portion of the ball lit up. However, by the end of the course, my diagram for how the light bounces off of the basketball and to my eye was more complete—my final response included rays traveling to my eye whereas my initial response did not. In my initial understanding of the sun and the moon, I said that, "the moon rotates around the Earth, and the sun's rays hit the Earth and cast a shadow on the moon" when explaining why the moon seems to have different shapes at different times. I now understand that this is completely incorrect and that the moon is always half lit by the sun when observed from space. When on Earth, however, we see different shapes for the moon based off of what portion of the lit moon is visible to us, which I explained in my final response. I initially thought the unlit parts of the moon were from the Earth's shadow, but now I understand they are just the parts of the moon not lit by the sun. This course also helped me gain enormous understanding of inquiry approaches to learning and teaching, and I feel very confident that I will be able to translate those ideas to my classroom. I have grown immensely as a learner of science through inquiry.

Reviewing the Learning and Teaching Process

The newly released *Next Generation of Science Standards* advocates for engaging students in learning science through the following practices. As I embarked on this course, I also experienced many of these practices.

Asking questions and defining problems. This course encouraged us to ask questions about what we were interested in. At the end of each class period, we shared ideas that we were still curious about, and asked questions that we could use to further explore.

Developing and using models. Our moon dance was an excellent model to help us further our understanding of the moon's movement—its revolution around the Earth, its position in regards to the sun and the Earth, and its own rotation around its axis. We developed this model as a dance to visualize what we were discovering about the moon.

Planning and carrying out investigations. We came up with our own moon investigations with our table groups. We asked a question, developed a plan for ways to observe and things to look for in order to answer that question, and we carried out our investigation by recording in our moon journals observations relevant to our question.

Analyzing and interpreting data. We used temperature probes to collect data about the temperatures of different materials. We found their temperatures to be equal, so we interpreted our data in order to come to the conclusion that the items were all at room temperature.

Using mathematics and computational thinking. We drew ray diagrams of pinhole phenomena and were able to set up proportions that aided us in estimating the diameter of the sun. We used our knowledge of mathematical principles in order to do this.

Constructing explanations and designing solutions. Throughout our explorations of many different phenomena, we worked to construct explanations for why the things we observed occur.

Engaging in argument from evidence. Through discussions with our table groups, we engaged in arguments based off of evidence.

Obtaining, evaluating and communicating information. During multiple class periods throughout the term, we learned about a new phenomenon, discussed and evaluated it as a group, and communicated the information to the rest of the class through posters, diagrams drawn on our white boards, and verbal explanations. We also communicated information about light phenomena when we created websites documenting our explorations and understandings.

Discussing Changes in Personal Views about Science and about Science Learning and Teaching

Before this course, I had absolutely no idea of how I would approach incorporating science learning into an elementary classroom. I also was completely unaware of the *Next Generation of Science Standards.* This course has been very beneficial in building my confidence regarding the actual content matter as well as how I would teach it. I think that this class was wonderful for explaining and utilizing aspects of inquiry learning and exploration in order to make science learning fun. I am very confident that I could incorporate much of what was learned in this class into my own classroom. I have always been interested in science and learning about scientific ideas, but in my past experience, have been discouraged by boring, impersonal, and difficult science classes. Now I have a renewed enthusiasm and positive outlook regarding exploring and learning about science.