The Phases of the Moon and Eclipses

v. Dec 2014

Next Generation Science Standards Supported

• Scientific Practices:
  o Developing and Using Models
  o Constructing Explanations

• Crosscutting Concepts:
  o Patterns
  o Cause and Effect: Mechanism and Explanation
  o Scale, proportion, and quantity

• Disciplinary Core Ideas:
  o Earth and Space Sciences: The Earth and the Solar System
    ▪ Earth and Moon have predictable patterns of movement
    ▪ The Moon’s orbit and the cause of eclipses
    ▪ The causes of the phases of the Moon

Lesson Objectives

Students will:

• Understand what causes the Moon’s phases and eclipses
• Be able to predict the phase of the Moon given a particular Sun-Earth-Moon configuration.
• Given a particular Moon phase, be able to predict where the Moon is in its orbit around Earth, relative to the Sun’s location.
• Understand how models can help us understand complex phenomena, but they can also introduce misunderstandings if we are not mindful of inaccuracies in the models.

Key ideas to highlight throughout lesson

These will be emphasized throughout and summarized at the end, but it’s preferable not to present these ideas all at once to students before beginning the lesson.

Phases:

• The Sun shines on HALF the Moon always.
  The Moon has a daytime/nighttime side just like Earth. The parts of the Moon we see are the daytime side.
• How the Moon appears to us (what phase we see) depends on how much of the lit side is facing the Earth.
• How much of the lit side is facing Earth depends on where the Moon is in its orbit around Earth.
Earth-Sun-Moon system:
• The separations between the Earth and Moon and Sun are much, much farther apart than most people imagine them to be.
• The Moon’s orbit around the Earth has a 5 degree tilt, making it rare for the Earth-Sun-Moon to lie in a straight line.
• When things happen to line up (roughly twice a year), you get solar and lunar eclipses. Most of the year, the Earth’s shadow plays no role in changing the Moon’s appearance.

Time required: Minimum three 45-minute class periods. (More if including extension discussions).

Materials Needed
• Day 1 (WWT Tour on Phases)
  o Enough computers with WWT installed so each pair of students (or each individual student) has one computer
  o If needed, headphones with splitters, so pairs of students can listen to the tour together
  o Put “Moon Phases Tour” on each desktop
• Day 2 (Physical Model)
  o Enough 1.5” Styrofoam balls for each student (to represent the Moon)
    ▪ The type of Styrofoam ball is important. Some Styrofoam balls from craft stores are extremely porous, and do not create distinct daytime/nighttime sides of the Moon. (The light shines right through).
    ▪ Polystyrene Balls work well and are available from: Molecular Model Enterprises
      116 Swift St., PO Box 250, Edgerton, WI 53334
      http://www.molecularmodelscompany.com/
      608-884-9877
  o One 6” Styrofoam ball (to represent the Earth)
    ▪ Type is not important here.
  o Lamp and light bulb
    ▪ The light bulb type is also important. Lights that are too faint do not provide sufficient light. Lights that are too bright and harsh scatter too much excess light around the room. We found Westpointe Eco-Halogen Soft White General Purpose 72 Watt bulbs to work well.
    ▪ Our pilot teachers really liked the simplicity of the lamp we used: Normande HN1-1482 Flager 60-Watt Polyresin Wood-Look Table Lamp with Fabric Shade, available on Amazon. Remove the shade for the model.
  o Toothpicks
  o If you have a classroom with uncovered windows: you will likely need to cover the windows (i.e., with black trash bags) to block out excess light. The room needs to be very dark for this activity.
Day 3 (WWT Tour on Eclipses)
  - Same as Day 1, but with “Eclipse Tour” on each desktop
  - Same as Day 2
  - Hula hoop

Day 1

Preparation/Classroom Set-Up
  - Not completely necessary, but it helps to push desks to the outside edges of room.
    - Students can sit at desks, but they should turn their chairs to face middle of room during discussion.
  - Optional: Administer Formative Assessment Probe:
    - Uncovering Student Ideas in Science, Vol. 1, Page Keeley, NSTA Press, pg 183, “Going through a Phase”

WWT Tour
  - Hand out “Day 1 WWT Activity Sheet.” Every student should have their own copy.
  - Make sure computers are turned on and are running “Moon Phases Tour” WWT tour.
  - The first slide teaches students how to navigate around the program, including how to pan around the view, and how to zoom in and out.
  - Once students have had about 5-6 minutes to explore and feel comfortable, advance to the next slide by pressing the <right arrow> key.
  - Students will have an opportunity to adjust the volume on their headphones before continuing the tour.
  - Students should view the tour, following all instructions for making “observations” within WWT, and recording their ideas in the Activity Sheet.
  - Help make sure students are correctly lined up in questions they’re answering versus what’s on their screens
  - Most students will need a whole class period (~45 minutes) to complete the activities. You might plan some extension activities for students who finish early. There is an optional bonus question, and students who finish early can also continue to explore WWT on their own.

Day 2

Preparation/Classroom Set-Up
  - Push desks to the outside edges of room.
    - Students can sit at desks, but they should turn their chairs to face middle of room during discussion.
  - Place the lamp on a small table in the middle of room. The height of bulb should be roughly even with head height of most students, or lower if necessary.
**Activities for the Day**

**Introductory Class Discussion on Models**
- Ask: What is a model? Why do we use models in science?
  - Eventually try to guide students to the idea that models represent some aspect of a phenomenon or system that we’re studying. They can be smaller than (model of our solar system; real thing wouldn’t fit in our room) or larger than the real thing (model of a bug; easier to see important parts).

**Thinking about the Activity**

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<thead>
<tr>
<th>Prompt</th>
<th>Ending Ideas</th>
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| We want to use a model to understand the Moon’s phases. What would be good things to put in the model? | **Moon**  
  Why? It’s the thing we are trying to understand                                |
|                                                                      | **Sun**  
  Why? It gives the Moon its light                                               |
|                                                                      | **Earth**  
  Why? It’s where we live, so it marks the location from which we are observing the Moon.  
  - Some students may say “the Earth blocks the light from the Moon, so we need to include Earth.” Emphasize that Earth blocks the Moon only rarely, and the Earth’s role is important because it is the observing location. |

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| What can we use to represent each of these things in our model?     | **Moon**  
  - The smaller Styrofoam balls.  
  - We put them on sticks to make them easier to hold. Does the stick represent anything we’re trying to model? No. |
|                                                                      | **Sun**  
  - Light bulb in the middle of the room.                                      |
|                                                                      | **Earth**  
  - the 6” Styrofoam ball; or, later, our heads  
  - One of our eyes can represent the place on the Earth where we live and where we observe from |
Discuss the Role of Scale in our Model

- Point out that there are two different sizes of Styrofoam balls: 1.5” and 6”
  - Ask students: Which represents the Earth and which represents the Moon?
  - Explain that our model will be “to scale,” meaning that the proportions in our model will be the same as the proportions in the real system.
    - The Earth’s diameter is 4 times that of the Moon, so the 6” ball and the 1.5” ball are in the correct proportions to be in scale. Your head is roughly the correct scale, too.
- Have students try to decide how far apart the “Earth” and “Moon” should be placed.
  - Ask students: How far away should the model Moon be placed to have the relative sizes correctly scaled AND the separation correctly scaled?
    - Let students guess. Give 4-5 students a 1.5” “Moon” and let them choose different distances from “Earth.” Have students vote on which distance is correct. (Students typically guess locations within 2'-3’ of the Earth ball)
    - The distance between the Moon and the Earth is about 30 times the diameter of Earth. Have students work out: 30 x 6” = 15 feet
    - Have one student hold the Earth ball. The teacher then takes the Moon ball and steps away 15 paces (it’s especially helpful if you have 1 square foot tiled floors). Have the students count this out.
- Have students think critically about this separation distance

Things to Ask/Sample Discussion

Why do most people not know that this is the true Earth-Moon separation?

- Most textbooks, diagrams, etc cannot show a true-scale image. Why not?
  - You wouldn’t be able to make them big enough to see and far enough apart to be in scale and still fit on the page

Discuss: Many people think the Moon’s phases are caused by Earth’s shadow. Put the Earth and the Moon close together again. If you think the Earth and the Moon really are this close together, then the idea that the Earth’s shadow causes phases seems to be pretty reasonable. But really, the Earth is THIS far away (walk back to 15 feet away with the Moon); is it going to be easy for the Earth to cast a shadow on the Moon from here? No. It happens very rarely, only about twice per year, when the Moon, Earth, and Sun are exactly in a line with each other.

Additional Discussion (likely won’t fit in 45 min class unless adding extra days): The distance between the Earth and the Sun is about 12,000 times the diameter of Earth. How far away should the lamp be placed?

- Approximately one mile
- The Sun is 100 times bigger than the Earth. The Model Sun would be 50 feet tall, as tall as a five-story building.
**Activity: Modeling the Moon’s Movement**
(Much of this is borrowed from the Project ASTRO Texas instruction sheet)

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<tr>
<td>Have one volunteer demonstrate the motion of the Earth around the Sun for the class (walk in a circle around the lamp)</td>
<td>This takes 365 days in real life. Our model is a sped-up version of reality.</td>
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</tbody>
</table>
| Have a volunteer demonstrate spinning on an axis, so that an observer on the nose would see night and day.  
  - To see the Sun rise in the east and set in the west, the volunteer has to spin to their left | This is how we get night and day  
*Optional:* If Earth in our model spins once per second, how long would it take to go all the way around?  
  - 365 seconds is equal to approximately 6 minutes |
| Have one student pretend to be the Earth  
  - The teacher holds the Moon to show a specific phase to the person pretending to be the Earth  
  - Ask Earth student: What do you see?  
    - Earth student describes the Moon as they see it  
  - Teacher: Ask students sitting around the room what they see  
    - It may be helpful to ask in clusters, so that students sitting near each other should see more or less the same thing, but what students on one side of the room see is different from what students on the opposite side of the room see | Ask class: We’re all looking at the same Moon. Why are we all seeing something different?  
  - How much of the Moon does the Sun light up?  
    - HALF  
    *Emphasize this key point #1 by writing it on the board.*  
  - How much of the lit up part of the Moon do we see?  
    - It depends on where in the room we are sitting.  
    - What perspective do we care about?  
      - Earth’s.  
      - Our Moon might look different on Jupiter, but what we care about is what Earth sees  
      *Emphasize this key point #2 by writing it on the board.* |
Let everyone participate in the model now. Everyone pretends to be the Earth.
- To preserve the equipment, warn students: Styrofoam balls are fragile; try not to drop them; do not bang them together, spear them with toothpicks, tap them on things, etc

<table>
<thead>
<tr>
<th>Give everyone a foam ball on a toothpick to hold to represent the Moon.</th>
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<tbody>
<tr>
<td>- Let’s look carefully at how the Moon’s appearance changes</td>
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<tr>
<td>- Face the Sun (lamp)</td>
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<tr>
<td>- Hold the Moon in your left hand, at a 45 degree angle away from your body</td>
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<tr>
<td>- What does the Moon look like? Which side is lit up?</td>
</tr>
<tr>
<td>- Now hold the Moon in your right hand, at a 45 degree angle on the other side of the Sun.</td>
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<tr>
<td>- What does the Moon look like now? Which side is lit up?</td>
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<th>Now try modeling a whole Moon cycle</th>
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<tr>
<td>- Start with Moon between Earth and the Sun. What does it look like?</td>
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<tr>
<td>- New Moon; the Moon is dark</td>
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<tr>
<td>- Revolve counterclockwise if viewed from above north pole, so bring Moon to your left</td>
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<tr>
<td>- It now looks like a sliver</td>
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<tr>
<th>Notice how the changing position of the Moon changes how much of the lit side is facing Earth.</th>
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<tr>
<td><em>Emphasize this key point #3 by writing it on the board.</em></td>
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<tr>
<th>We won’t try to model going around the Sun, but remember that it takes a much longer time for the Earth to go around the Sun than for the Moon to go around the Earth once.</th>
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<tr>
<th>Now, hand out “Activity Sheet, Day 1” and have students try to answer the questions.</th>
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<tr>
<td>- Students can work in pairs so that they can discuss their answers with someone</td>
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<tr>
<td>- Make sure students know how to hold their papers, so the orientation of the diagram matches with where the lamp is in the room</td>
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<tr>
<td>- If students are having trouble finding the right positions, help walk them through the process of moving the Moon around until what they see change matches the Moon image; then help them figure out which position on the overhead diagram matches the location of the ball they found</td>
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*WorldWide Telescope is a free program developed by Microsoft Research. These materials were developed at Harvard University by the WWT Ambassadors Program (wwtambassadors.org) with support from the National Science Foundation (Award Number IIS-1254535).*
Post-Activity Discussion (this material can also be used to introduce eclipses on Day 3 if out of time on Day 2).

- Did anyone have trouble making this gibbous Moon?
  - Make sure everyone is clear on the difference between holding the Moon on the left or the right, and making sure the lit side of the Moon matches up with what’s in the diagram
- Did anyone have trouble making the full Moon?
  - In our experience, usually 1-2 groups will say they had trouble because their heads’ shadows made it impossible to create a full Moon. (If no one volunteers this problem, offer it as a problem that you had.)
    - Ask students to offer a solution. How can you ever get a full Moon if your head is in the way?
      - Usually, someone says, “I held it up a little higher.”
      - Show students how you can hold it up at a steep angle and get a full Moon
  - Ask students:
    - Does the Moon ever go up this high in its orbit, do you think?
      - NO.
    - Can anyone think what’s wrong with our model? The only way we can get a full Moon is to put it at an awkwardly steep angle, which doesn’t really happen. How can we resolve this?
      - Think about the true scale of the model. Remember that the real Moon is much farther away than typical model Moons. We have to hold the Moon 15 feet away. At this distance, the angle we have to hold it at to make the Earth not block the Sun’s light is very small: only 5 degrees or less

Summarize
- The Sun lights up half the Moon
- The amount of the lit-up part that faces the Earth determines what phase we see
- Earth doesn’t usually block the Sun’s light from reaching the Moon because the Moon orbits at a slight tilted angle (5 degrees). Because the Moon is so far away, that small tilt makes it high (or low) enough that the Earth doesn’t block the light.
- Terminology:
  - When the lit side is growing → waxing
  - When the lit side is shrinking → waning

Day 3

Introduction/Review
- Review the causes of the Moon’s phases (see 3 key points in summary from Day 2).
  - It helps to introduce a specific example of a Moon in orbit and ask students to predict what phase has been drawn. For example, draw this scenario on the board:
Tell students this is an “overhead” or “space based” view (looking down from above North Pole) and ask someone to shade the half of the Moon and Earth that are dark.

- If students have trouble, it helps to line up a ruler with all the arrowheads and step it toward the moon until it cuts across half the moon.

Ask another student to divide Moon into a half that is facing the sketched person, and a half that’s facing away from the sketched person.

- If students have trouble, it helps to line up a ruler along the person’s “horizon” and step it toward the moon until it cuts across half the moon.

Ask students to imagine what kind of Moon the person standing in Northern Hemisphere would see. This works well as a think-pair-share activity where everyone has time to think of his/her answer, then they talk to a partner and discuss their answers and report back to the class.

- (They should see a crescent moon – mostly dark, with just a sliver of light, lit up on the left)

Next, draw two more people on either side of the first person, so they’re still on the side of the Earth that is facing the Moon, but as far apart (East-West wise) as possible. Ask them if they think those people should see the same phase or different phases from the first person. This is also a good think-pair-share exercise.

- Most students will say they should be different, and you can point out that the PICTURE makes it look like people on the far sides of the Earth should see different phases. (A person to the right would see almost a new moon; a person to the left would see almost a half moon).

- Ask students if they’ve ever had a calendar that tells them what day of the month will be a full moon, new moon, etc? Ask them if they think someone living across the country has a different calendar with full moons on different dates? NO. Everyone sees a full moon on the same day. In real life, everyone sees the same phases. Something is wrong with the PICTURE. What?

- Remind students of the exercise showing the true scale separation between the Earth and Moon. Usually someone will remember that the PICTURE on the
board is not to scale. If the real life moon were really that close, people on far sides of the Earth really would see different phases, and the phase would change over the course of a day/night. That’s NOT what we see because our Moon is really much farther away than shown in the picture. When the Moon is far away, everyone sees the same phase.

- Discuss misconception of phases being caused by Earth’s shadow.
  - Ask students – where is the Earth’s shadow in this particular scenario? (It’s on the side of the Earth opposite the sunlight.)
  - Can that shadow fall on the Moon when the Moon is in this position? NO. The dark part of the Moon that we can’t see is just the nighttime side of the Moon and has nothing to do with Earth’s shadow.

- Optional extension discussion on Moon rise/set times:
  - Ask students if the person in the picture is experiencing night time or day time. (Many people have a very strong association of the Moon being a night time object, despite the fact that they themselves have seen the Moon during the day). The knee-jerk reaction to this question is that it must be night time if the person is facing the Moon.
  - Point out that the person is on the side of the Earth facing the Sun, so it is daytime for them. Early morning is the best time to see a waning crescent moon. It is NOT POSSIBLE to see a waning crescent moon in the evening. (Many children’s books/comics depict a waning crescent moon in the window as a child is being put to bed. Point out that if those books take place in the Northern hemisphere, such a scenario is impossible!)

- Optional - discuss these misconceptions:
  - Clouds cause the phases of the Moon?
    - No, the Moon phases follow a predictable pattern/cycle that repeats every 29 days.
    - Clouds are NOT repeatable, predictable.
  - The Moon has its own light?
    - No. Rocks don’t make their own light, unless they’re as hot as coals in a grill. The Moon is not hot.

Eclipses
- Transition: We said the Earth doesn’t usually cause a shadow on the Moon, but it sometimes does. What is this called?
  - A lunar eclipse. How does a lunar eclipse happen?
    - The Moon, Earth, Sun need to be lined up exactly.
      - Lunar Eclipse -> something is covering the Moon -> Earth blocks light from the Moon.
  - What about a solar eclipse?
    - Solar Eclipse -> Something is covering the Sun.
    - What can block the Sun’s light from reaching Earth? The Moon.
    - Solar Eclipse -> Something is covering the Sun -> Moon blocks the Sun’s light.
Demonstration
- Go back to the lamp/Styrofoam ball model. Use a hula-hoop now, to represent the tilted orbit of the Moon.

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<td>Ask students to imagine a huge, flat sheet of paper filling the room that goes between your head (Earth) and the light bulb (Sun). This is called a “plane.” Show them the hula-hoop orbit. Can they imagine two places where the path of the Moon along the hula-hoop would cross the plane we just described?</td>
<td>It might be beneficial to have a helper hold up some sheets of paper along the plane between the “Earth” and the “Sun”.</td>
</tr>
<tr>
<td>Now think about this: Where does the Earth have to be in its orbit to make it possible for the Earth to cast a shadow on the Moon?</td>
<td>It helps to start walking around the Sun with the hula-hoop’s position fixed, with your hands marking the points where the orbit crosses the plane, and have students yell “stop” when you’re at a position where a lunar eclipse should occur. (This sounds confusing, but it is effective. When your hands are lined up with full Moon/new Moon positions, they understand that eclipses can occur.)</td>
</tr>
<tr>
<td>Ask: Are there any other locations where eclipses could occur?</td>
<td>Instructor should continue to orbit the Sun. Students should identify the location directly across from your original stopping point six months later. Show the students that if the Earth is at these locations, when the Moon comes around to full Moon position, Earth does block its light; when it’s at new Moon position, it can block the Sun.</td>
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WTT Tour
- Run “Eclipses Tour” WWT tour. (See Day 1 instructions on running Moon Phases tour).

Hand out and complete Activity Sheet 3

Summarize
- Solar eclipse $\rightarrow$ something (Moon) blocks the Sun
- Lunar eclipse $\rightarrow$ something (Earth) blocks the Moon

Discussion
- Why are solar eclipses visible in only a small part of the world?
  - Hold up Moon in solar eclipse position. How much of my face is in shadow?
    - Only a small part is in shadow, say my cheek. If my eyes can still see the Sun, there is no solar eclipse from that location; only the people on my cheek see a solar eclipse.

End Lesson

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