TA Guide for

Phases of the Moon

Notes

Description

In this activity, students stand around a bright light bulb in an otherwise dark room, holding a styrofoam ball at arm's length. As they turn around, they watch the changing pattern of light and dark on the styrofoam ball which reproduces the phases of the Moon. Then, using a second ball as the Earth, students explore the geometry of the Sun-Earth-Moon system to predict the rise and set times of different phases of the Moon. The students "accidentally" stumble onto the alignment of the Sun, Earth and Moon during lunar and solar eclipses.

Learning Goals

After this tutorial, together with lecture materials, students should be able to

- use the geometry of the Sun, Earth and Moon to illustrate the phases of the Moon and to predict the Moon's rise and set times
- illustrate the geometry of the Sun, Earth and Moon during lunar and solar eclipses, and explain why there are not eclipses every month

Set-up — 20 minutes

The students will work together in groups of 3. In order to fit enough groups of students, you may need to use 2 light sources (shown at right). Set up one in the center of the lab and, if necessary, one in the center of the reading room (push the tables to the inside around the light. This will stop the students from getting too close to the light and messing up the geometry.) When both lights are needed, both TAs will be "A" TAs that lead the activity to their own groups of students.

The "sunlight" is very bright – try not to look directly at it – so the bulbs are surrounded by shrouds which are supposed to let out just a sheet of light at about eye-level. We also hang a piece of dark paper behind the lightbulb to cut down the reflections off the whiteboard (or the wall in the Reading Room.)

Materials:

- (1 per group) Moon: styrofoam ball marked NEAR and FAR (shown at right), for the near and far sides of the Moon
- (1 per group) Earth: styrofoam ball marked with a North Pole, equator, lines of longitude at 3 hour intervals, compass roses along the equator and a sticker on the equator that marks the location of the observer
- When we hand out all the pages for a tutorial at the beginning, students often rush thru important steps because they think they have to get the last page ASAP. A better strategy for the students is to hand out pages as needed:
    - (1 per group) Intro (page 1) Part 1 (page 2) double-sided

- (1 per group) Part 2 (page 3 only)
- (1 per group) Part 3 (pages 4 and 5) double-sided
- (1 per student) Part 4 (pages 6 and 7) double-sided. The year-long lunar calendar will have to be updated each year.

Either set out the two styrofoam ball and first page (Intro, Part 1) in piles around the light bulb, or get students to pick them up as they form groups.

Part 0: Introduction and Motivation	5 minutes

It's never a bad idea to let the students know why they are doing this, or any other, tutorial. Why should they care? Why should they invest the time and energy? The answer should be more than the marks they'll receive. This tutorial is useful and interesting for a couple of reasons:

- All the students see the Moon occasionally and already know it changes shape. This tutorial will show them why and how the Moon appears the way it does.
- The lunar cycle has a huge influence on our culture, probably much larger than the students realize. The dates of important holidays and celebrations like Ramadan, Hannukah, Lunar New Year and Easter depend critically on the phase of the Moon. If you have any personal experience with these, don't be afraid to share it (briefly!) In order to prepare for these celebrations, one must be able to *predict* when the Moon will be new or full.

Part 1: Phases of the Moon	10 minutes

Part 1 of the tutorial

- forces each student to "play" with the Moon and the sunlight
- reminds them of the definitions of first quarter, waning gibbous, etc.
- gets them to draw a "library" of geometries they can look back at later

One by one, the students hold the styrofoam "Moon" at arms' length in the light and slowly spin around. Remind them that their head is the Earth, so when they look at the styrofoam ball, they're seeing the Moon going through phases. This simple activity has such a huge impact – you'll probably hear *oooh*'s and *aaaah*'s – try to ensure every student actually does a full 360° spin with the Moon.

If a student stands too close to the Sun, the Sun-Earth-Moon geometry gets messed up (there will not be a 90° angle between the Earth-Moon and Moon-Sun at first quarter, for example, which there should be.) If you see an Earth standing too close to the Sun, just get them to back up a couple of steps.

It's important for the students to get an "overhead" view of the Sun, Earth and Moon, so if they're unsure what to draw, ask them to imagine what they would see if they were looking down from the ceiling of the lab.

Lunar and solar eclipses This is also a great opportunity to watch for lunar and solar eclipses: When the student moves the Moon into the shadow of his or her head, take the opportunity to see if they realize they just created a lunar eclipse. Some students will try to "fix" things by crouching down or lifting the Moon higher so that it stays in the sunlight.

Notes

This gives them the important idea of the extra up-and-down dimension you don't see in the textbook, which explains why there is *not* a lunar eclipse every month. Half a turn later, they can cause a solar eclipse (or not) depending on how carefully they align the Moon between their heads and the Sun.

Part 2: Local Time on Earth	5 minutes

hand out Part 2 group-by-group as they finish Part 1

In Part 3 of the tutorial, the students will be asked to predict the rise and set time of different phases of the Moon. To make those predictions, you must be able to determine the *local time* of an observer. That is, the time that observer standing on the rotating Earth reads of his or her watch. We added this short activity just to remind the students how local time is determined.

To keep the goal of the activity clear, the students are asked to hold the Earth ball in the light, with the axis vertical. Not tilted at 23.5°: that extra factor will only cloud the results. And they're asked to imagine they are the sticker on the Earth's equator. Not at some other latitude, again, to keep the results clear.

So, with a student holding the Earth ball straight up and down in the sunlight, their first task is to figure out which way to rotate the ball: to the East or to the West. If they're stuck, ask them to imagine a map of Canada on the globe. Who sees the Sun first, people on the East Coast or people on the West Coast? East, of course. So how do you rotate the Earth so the Sun rises on the East Coast first? By spinning the ball to the East.

The key to determining local time is remembering that it's noon when the Sun is directly overhead. Every other time is simply hours (or rotation) before that moment or afters after that moment, with 1 rotation of the Earth equal to 24 hours (6 hours for each $\frac{1}{4}$-rotation). If, at any moment of Part 2 the students are stuck, get them to go back to noon and then rotate forward or backward from there.

A couple of answers are already in the Tables to give the students an idea of the kind of descriptions of the Sun's location we're looking for. When it comes to the Sun's location at midnight, just tell them to write down something they'll understand later - there's no right answer.

Part 3: Moonrise and Moonset	20 minutes

hand out Part 3 group-by-group as they finish Part 2

In this Part, students combine everything together: the geometry of the Sun, Earth and Moon, the monthly motion of the Moon, the daily rotation of the Earth and the local time for observers.

Each student will have an opportunity to do all three tasks: spinning the Earth and determining local time, orbiting the Moon around the Earth and recording the results. The first few cases might be slower (which is why those are the more straightforward cases, first quarter and full Moon) but the team will get faster and faster.

As each student becomes the Moon, they're asked to make one full orbit around the Earth, keeping the NEAR side of the Moon facing the Earth. The goals is for them to realize the Moon is, indeed, rotating on it's axis, exactly once each orbit. If the student-Moon "shuffles" around the student-Earth, always facing inwards towards the Earth, the student-Moon may not realize the Moon is rotating because they never had to spin the Moon's pencil in their fingerstips. Although the "ballet" is slightly more complicated, ask the student-Moon to always face the same way (the front of the room, for example) as they orbit the Earth. Then they'll have to spin the Moon's pencil in their fingertips to keep the NEAR side towards the Earth.

Notes

If students are confused about what moonrise means, here are some questions you might ask to guide the students to the answer. First, get them to spin the Earth so the Moon is directly overhead (over the sticker.)

TA:	Is the Moon visible in the sky?
Student:	Of course, it is.
TA:	[Rotate the Earth 180° in the student's hand] What about now?
Student:	No, not anymore.
TA:	[Slowly rotate the Earth in the student's hand. But don't just rotate to moonrise and stop – that gives away the moment of discovery.] When does the sticker first see the Moon? That moment is moonrise...

The student must realize the moment of moonrise and moonset occurs when the Moon appears on the observer's horizon, when the line-of-sight between the sticker and the Moon is *tangent* to the Earth. If they're still not getting it, stand behind them and look over their shoulder and model how you look along the edge of the Earth at the Moon. Once they're rotated the Earth to the right orientation, they convert that orientation of the Earth into local time, which they did in Part 2.

You can quickly check they're "getting it" because the day-night line between where the Earth ball is illuminated and where it's in shadow will coincide with the lines of longitude drawn on the ball. If you see the day-night line somewhere else on the ball, they might be too close to the Sun (and messing up the angles) or they might not have grasped how the Moon has to be on the observer's horizon. You might gently rotate the Earth in the student's hand to "snap" orientation onto one of the $\frac{1}{8}$-rotations.

It's also likely there will be some confusion when they get to the waxing crescent Moon which rises at 9:00 a.m. This is first time they've had to observe a phase that doesn't occur on one of the $\frac{1}{4}$-turn (6-hour) orientations. Try rotating the Earth in the student's hand to noon: "What time is this?" ("Noon") Rotate the Earth in the student's hand back $\frac{1}{4}$ of a turn: "Now what time is it?" ("6 a.m.") Finally, rotate forward $\frac{1}{8}$-turn to when the waxing crescent Moon rises: "So here, halfway in between, the time is...?" ("Ahh! 9 a.m.")

And don't be surprised that many students, even after doing it 8 times, won't realize moonset occurs 12 hours after moonrise. In reality, it's not exactly 12 hours because the Moon moves along it's orbit during the day, among other things.

Part 4: Questions — 10 minutes

Of course, you don't want to give away the answers to these questions, so here are a few questions and comments you might use to guide the students. There is a lot of educational value in the students working with their peers to answer these questions, so there's no problem if they work together.

hand out Part 4 group-by-group as they finish Part 3

Some students may find it useful to use the balls and light while working on the questions (especially the eclipses question) so don't put away the apparatus until all the students are finished.

can you see the Moon? This question combines all the skills they've acquired in the tutorial. Since the question asks for phase of the Moon on that day and at that time, the answer will be different for each tutorial section.

Depending on the exact time, both "Yes" and "No" are possible as long as the student includes an acceptable explanation (for example, the Moon is just above the horizon but hidden by buildings.)

The choice "You can never see the Moon during the day" is included because this is recognized as a common misconception in astronomy. By including it, the students who may still believe it are confronted by their peers. If that's what they believed when the came into the tutorial an hour ago, maybe we've managed to change their minds.

visible at 1 a.m. This question gets the students to gather their data from Part 3. It also turns the results "inside out" by asking what phases are visible at a certain time, rather than what times each phase is visible. The time 1 a.m. was chosen so it didn't coincide with any moonrises moon sets.

The waxing gibbous, full, waning gibbous and third quarter Moons are visible at 1 a.m.

evil plan The fact that this question asks about the Moon phases "next month" reinforces the importance of predicting, well in advance, how the Moon will appear. This ties back to Moon's role in the religious celebrations.

They have just figured out what phases are visible at 1 a.m. and what phases are not. It's the not-visible phases (waning crescent, new, first quarter and waxing crescent) they want for the evil plan. Watch out for students who pick the "Moon is visible" phases. If you see that, you might try

> I see you chose the full Moon as a possible date. Is the full Moon in the sky at 1 a.m.? It is? Hmm, it would shine a lot of light on you, wouldn't it...?

lunar eclipses Just in case they didn't recognize the lunar eclipses in Part 1, this question highlights the alignments of the Sun, Earth and Moon. If they're stuck, hand them the styrofoam balls and get them to act it out again. While it's difficult *not* to block the Moon ball with the shadow of your head, in real life, the orbit of the Moon is tilted with respect to Earth's orbit, so the full Moon usually passes above or below the Earth's shadow.

Credits

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