SOLAR SCIENCE

EXPLORING SUNSPOTS, SEASONS, ECLIPSES, AND MORE

Dennis Schatz
Andrew Fraknoi

NSTA press
National Science Teachers Association

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Dedication

To Alan J. Friedman,
good friend, colleague,
and mentor, who inspired
everyone he met to remember
that science is a way of
thinking, not a list of facts.

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Understanding and Tracking the Annual Motion of the Sun and the Seasons

CHAPTER 3

Solar Activity and Space Weather

About the Authors

Dennis Schatz is the author of numerous resources for educators and museum professionals, including *Astro Adventures: An Upper Elementary Curriculum* (Pacific Science Center 2002) and *Astro Adventures II* (Pacific Science Center 2003). He is also the author of 23 science books for children that have all together sold almost 2 million copies worldwide and have been translated into 23 languages. These include *Astronomy Activity Book* (Simon and Schuster 1991) and *Stars and Planets* (SmartLab Toys 2004).

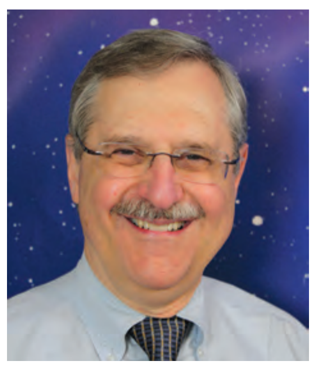
Dennis was a member of the five-person design team that developed the Earth and space sciences disciplinary core ideas for the National Research Council that are found in *A Framework for K–12 Science Education*, which was used to develop the *Next Generation Science Standards*.

For many years, Dennis was the senior vice president for strategic programs at the Pacific Science Center in Seattle, Washington. For four years he served as a program director for science education at the National Science Foundation. At the Pacific Science Center, he codirected Washington State LASER (Leadership and Assistance for Science Education Reform), a program to implement a quality K–12 science program in all 295 school districts in Washington State. He was also principal investigator for Portal to the Public, an initiative to develop programs—both on-site and off—that engage scientists in working with diverse audiences to enhance the public's understanding of current science research.

He has received numerous honors, including several from the National Science Teachers Association (NSTA): the 2009 Faraday Science Communicator Award, the 2005 Distinguished Service to Science Education Award, the 1996 Distinguished Informal Science Education Award, and the 1980 Ohaus Honorary Award for Innovations in Science Teaching.

More information about Dennis Schatz is available at *www.dennisschatz.org.*

Andrew Fraknoi is the author of *Disney's Wonderful World of Space* (an astronomy book for grades 5–7) and is the lead author of several successful introductory astronomy textbooks for nonscience majors (such as *Voyages Through the Universe*, 3rd ed., published in 2004 by Brooks-Cole/Cengage). In the 1980s, he also edited two books of science and science fiction for Bantam. He is editor and coauthor of *The Universe at Your Fingertips 2.0*, a collection of astronomy activities and teaching resources published by the Astronomical Society of the Pacific that is in use in formal and informal educational institutions around the world.



He is the chair of the astronomy department at Foothill College, Los Altos Hills, California, and appears regularly on local and national radio explaining astronomical developments in everyday language. Fraknoi was the cofounder and coeditor of *Astronomy Education Review*, the online journal and magazine published by the American Astronomical Society. The International Astronomical Union has named Asteroid 4859 Asteroid Fraknoi to recognize his contributions to astronomy education and outreach (but he wants us to mention that it's a very boring asteroid and no threat to the Earth!).

Andrew is the winner of the 2012 Faraday Science Communicator Award from NSTA, as well as the 2007 Andrew Gemant Award from the American Institute of Physics. Also in 2007, he was selected as the California Professor of the Year by the Carnegie Foundation for the Advancement of Teaching. His other awards include the Annenberg Foundation Award for astronomy education from the American Astronomical Society and the Klumpke-Roberts Award for public outreach in astronomy from the Astronomical Society of the Pacific.

For more about Andrew Fraknoi, see *www.foothill.edu/ast/fraknoi.php*.

Introduction

The Sun is not only the easiest astronomical object in the sky to observe, but it has a greater influence on our lives than any other cosmic object. The fundamental elements of how we mark time—the day and year—are based on the Earth's relationship with the Sun. The cycle of our seasons (from winter to summer and back to winter again) has to do with the tilt of the Earth toward or away from the Sun as a year passes.

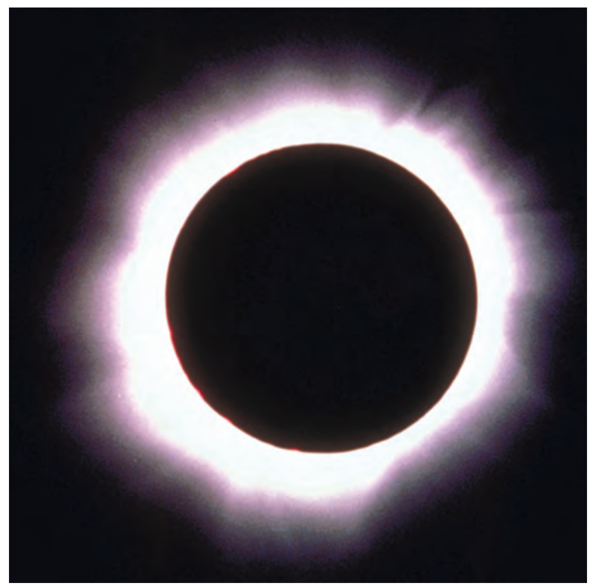
The charged particles streaming from the Sun's surface (the solar wind) cause the spectacular auroras that people travel thousands of miles and brave the cold of northern nights to see (Figure I.1). When these particles overload our planet's storage capacity, they can disrupt our radio transmissions and interrupt electrical power distribution. As our civilization gets more and more interconnected on Earth and in space, the chances of serious problems from a storm on the Sun increase.

The unique relationship between sizes and distances in the Earth–Moon–Sun system also cause spectacular eclipses of the Sun and the Moon. Total solar eclipses that reveal the eerie glow of the Sun's outer atmosphere (the corona) are so beautiful and rare that people travel from all over the world to witness them (Figure I.2).

Both the new and the older science standards suggest that students need to have a good fundamental understanding of the Sun's effect on their daily lives. There's no better way of providing that understanding than through the kinds of eye-opening (indeed, mind-opening) experiences in this volume.

FIGURE I.2

Total solar eclipse showing the Sun's corona, which becomes visible during totality



This book is specifically designed for instructors of grades 5–8 who teach about the Sun and Moon and their cycles as well as eclipses, but some of the materials could easily be adapted for higher grades or (informal) settings outside of school. Throughout, we provide classroom-based activities, background information, and

FIGURE I.1

(*Left*) Aurora (northern lights) above Bear Lake in Alaska experience with the science practices and crosscutting concepts identified in the *Next Generation Science Standards* (*NGSS*). The core of the book is a series of student-centered learning experiences that put the students in the position of being scientists: asking questions; exploring phenomena; and drawing, discussing, and refining conclusions.

Educators who use the experiences and suggested teaching strategies in this book will involve students in the three-dimensional learning process recommended by the *NGSS*, effectively integrating the teaching of the disciplinary core ideas, science practices, and crosscutting concepts related to the Sun and the Moon and their motion in the sky. Sections strategically located throughout the chapters identify especially good places to emphasize the three-dimensional learning that students are experiencing.

In addition, we provide a variety of resources that connect the content to best practices in mathematics and literacy, including the use of age-appropriate web pages and real-time data from observatories and satellites, such as the Solar Dynamics Observatory (Figure I.3).

Although the first edition of this book is timed to allow teachers to prepare for the Great American Eclipse of 2017, which will be visible throughout the United States, the book is not tied to that event and will be useful for teaching about the Sun and its effects on our culture and our understanding of nature in any year.

FIGURE I.3

A digital rendering of the Solar Dynamics Observatory satellite

How This Book Is Organized

The book contains four chapters, each of which deals with disciplinary core ideas in the *NGSS*:

1. **Understanding and Tracking the Daily Motion of the Sun:** What does the Sun do in the sky each day, and how does that relate to our notions of time and direction?
2. **Understanding and Tracking the Annual Motion of the Sun and the Seasons:** How does the Sun's motion and position in the sky vary throughout the year, and how does that relate to our ideas of a calendar and the seasons?
3. **Solar Activity and Space Weather:** What phenomena do we observe on the surface and in the atmosphere of the Sun, and how do these influence what we observe and how we live our lives on Earth?

4. **The Sun, the Moon, and the Earth Together: Phases, Eclipses, and More:** How do the relationships among the Earth, the Moon, and the Sun produce solar and lunar eclipses?

Each chapter identifies the specific performance expectations, disciplinary core ideas, science practices, and crosscutting concepts in the *NGSS* that are addressed in the activities. Also listed are connections that the experiences make with the math and literacy standards in the *Common Core State Standards* (*CCSS*).

Learning experiences in each chapter move students from initially engaging with the disciplinary core ideas, science practices, and crosscutting concepts to having a deeper understanding of each of them. These experiences follow the successful 5E Instructional Model developed by Biological Sciences Curriculum Study (BSCS; see the more detailed explanation of the 5E Model, p. xviii), dividing the experiences into the following five categories:

Engage experiences hook the students into wanting to learn more about the topic and reveal their preconceptions about the subject.

Explore experiences allow students to build from their preconceptions by making observations (e.g., by viewing the Sun through special glasses [Figure I.4, p. xvi]), and using the scientific practices to generate questions and consider new ideas based on their observations.

Explain experiences allow the teacher, via continued student discussion and activities, to help students develop a deeper and improved understanding of the core disciplinary ideas, scientific practices, and crosscutting concepts.

Elaborate experiences provide opportunities for students to apply their new level of understanding to related questions or topics.

Evaluate experiences allow students (and teachers) to gauge how well they understand the concepts covered in the chapter.

Each learning experience in the book provides all you need to organize, prepare, and implement it, offering the following information:

1. Overall concept: A general description of the experience.
2. Objectives: What students will learn or produce by completing the experience.
3. Materials: Everything you need to have before you begin.
4. Advance preparation: Important steps that need to be completed before you are ready to have the students do the experience.
5. Procedure: Step-by-step directions for your students and you, plus answers to the questions we suggest asking. Also included are alternative approaches to deal with different classroom structures (e.g., a self-contained classroom vs. multiple sections throughout the day).

Finally, each chapter ends with suggestions for activities to connect to math and literacy concepts and other resources that allow for further exploration of the concepts by students and teachers.

We do not expect that every teacher will use every experience in each chapter. The goal is to provide you with a wealth of activities so that you can choose the ones that best fit your students' developmental level, your class structure, and your time limitations. At a minimum, we think it is important you include at least one each of the *engage*, *explore*, and *explain* experiences.

As students will learn using these experiences, what they discover about the Sun's motion across the sky, the phases of the Moon, and other astronomical phenomena will be different for people at different locations on the Earth. Given that this is a publication primarily for use in the Northern Hemisphere, some of the experiences will need modification to be effective at latitudes outside mid-Northern Hemisphere locations (i.e., outside the continental United States and southern Canada).

FIGURE I.4

Students learn about safe viewing of the Sun.

Use of an Astronomy Lab Notebook

If you already use notebooks or journals in your class, you can skip this explanation of their value, although it is important to understand the difference between notebooks and journals in general and why we refer specifically to using astronomy lab notebooks.

Journals are typically dominated by personal reflections on what the student is currently thinking and how the student is reacting to what is happening in his or her daily life—somewhat akin to a memoir. Science notebooks hold more structured, objective descriptions of science experiments and observations being made by students, plus conclusions reached based on the data collected. While a science notebook also allows for occasional reflection regarding students' initial understanding of a concept and how their thinking changes after analyzing the collected data and discussion with other students and the teacher, it always comes back to making sense of observations and data (see Figure I.5 for an example of Galileo Galilei's use of a notebook).

There are numerous reasons why having students keep astronomy lab notebooks is valuable:

- Students have a single place to document what they have done over an extended period of time and across a number of science experiences. This makes it easy to recover details that students may have forgotten.
- Students can reflect on how their understanding of a concept has changed from the beginning of a unit of study to the end. This type of reflection—especially written reflection—is key to deeper learning (an idea well confirmed by research on how people learn).

FIGURE I.5

Drawings of the Moon from Galileo's astronomy lab notebook

- Teachers can see—and assess, if necessary—what students have done step by step and how well the students understand the concepts being studied.
- It creates an entry point for discussion between student and teacher or among students, which can lead to deeper understanding of the concept being studied.
- Keeping the journal enhances students' writing skills, which support all areas of study by them.
- The process of keeping a contemporaneous lab notebook mirrors what scientists do in their daily lives to document and reflect on their area of research.

Although there is no one way to use notebooks, here are a few criteria that we think are important for creating an astronomy lab notebook:

1. Whatever you use as your notebook (e.g., commercial spiral notebook or composition book; student-created notebooks from 8 ½ × 11 paper), it is important to let the student personalize the notebook including his or her name on the cover along with artwork of an astronomical nature. This can consist of drawings made by the student or astronomical images printed from the internet or cut out of magazines.
2. Several pages at the beginning should be reserved for a table of contents, which is completed as students add material to the notebook.
3. The pages should be numbered so material can be easily referenced in conversations with the teacher and other students.
4. Each experience in our book suggests the minimum material that should be included in the notebooks to document what students are doing. Sometimes this calls for writing directly in the notebook, and other times it involves attaching observations or a worksheet into the notebook. You may wish to have students add more detail than we suggest regarding the procedures they follow or to reflect more on predictions and conclusions.

If you are new to the use of science notebooks, here are some of our favorite resources related to their use:

- *Science Notebooks in Middle School* (from the Full Option Science System program at the Lawrence Hall of Science): *http://goo.gl/glnddU*
- Science Notebooks (Washington State LASER [the website was formerly kept by the North Cascades and Olympic Science Partnership]): *www.wastatelaser.org/Science-Notebooks/home*
- Fulwiler, B. R. 2007. *Writing in science: How to scaffold instruction to support learning*. Portsmouth, NH: Heinemann. *www.heinemann.com/products/E01070.aspx*. (Read a free sample chapter at *www.heinemann.com/shared/onlineresources/e01070/chapter2.pdf*.)

Use of the 5E Instructional Model

The use of a learning cycle method to teaching science goes back to at least the 1960s and is based on a constructivist learning approach that emerged from what research tells us about how people learn (e.g., Bransford, Brown, and Cocking 1999). There are a number of learning cycles used by different curricula, but we have settled on the 5E Instructional Model developed by the BSCS because it is one of the most studied and widely used approaches (see *http://bscs.org/bscs-5e-instructional-model* for more background).

If you already use a learning cycle in your classroom, you can skip the rest of this section. If not, here are the key attributes to keep in mind during each step of the 5E Model:

ENGAGE

- **What it is time to do:** Hook the students' interest and curiosity to learn more, determine the students' current understanding and preconceptions, and raise questions the students want answered.
- **What it is not time to do:** Provide definitions, conclusions, or the right answer; lecture to students; or explain concepts.

EXPLORE

- **What it is time to do:** Provide opportunities to conduct and record observations, have students work together in research teams to compare results and discuss their data, have students suggest conclusions based on the data, ask probing questions of students that encourage them to reflect on their thinking and redirect their investigations if needed, make sure that everyone (including the teacher) is a good listener, and help all students be actively engaged in collecting and discussing data.
- **What it is not time to do:** Allow students to stop considering other conclusions once a single solution is offered, give students answers or provide detailed explanations of how to work through a problem, tell students they are wrong, or give information or facts that solve the problem immediately.

EXPLAIN

- **What it is time to do:** Encourage students to explain concepts and definitions in their own words, based on justification using data; explain concepts relying on experiments or observations; and build from students' previous experiences and preconceptions.
- **What it is not time to do:** Accept or propose explanations without justification or discourage or stifle students' explanations.

ELABORATE

- **What it is time to do:** Expect students to apply the concepts, skills, and vocabulary they have learned to new situations; make additional observations and collect data; and use previous learning to ask questions, design new experiments or observations, and propose appropriate solutions.
- **What it is not time to do:** Provide students with detailed solutions to new problems, provide answers before thorough discussion, or ignore previous data and evidence related to the concept.

EVALUATE

- **What it is time to do:** Have students demonstrate and assess their own learning regarding the concepts while the teacher assesses student progress.
- **What it is not time to do:** Introduce new concepts or subjects or test for isolated vocabulary and facts.

Teachers across the country have found the 5Es a useful and effective way to proceed through their science lessons. At first, individuals not used to the rhythm or pace of the 5Es might get impatient with them, but research shows that allowing students to learn through their own investigations makes for far deeper and longer-lasting learning than just lecturing to them or showing a video.

Use of Think-Pair-Share

The think-pair-share learning strategy is also encouraged throughout the book and is closely aligned with the 5Es. Like the 5Es, the think-pair-share sequence is based on many years of research regarding how people learn. It provides a mechanism for individual students to personally reflect (think) on a question or topic, typically in writing, before having a discussion with a partner or small group of students (pair). The sharing allows students to further reflect on their own and others' thinking about a subject, often leading to refined and improved understanding. Different groups may initially come up with different ideas or solutions about the problem at hand. When all the groups have a chance to discuss their thinking in front of the entire class (share), a wider range of ideas come to the fore. Guided by a skillful (and not too intrusive) teacher, the class can list, discuss, and evaluate the various ideas the groups have come up with and deepen everyone's understanding.

Personalizing the Use of This Book for Your Class

Although this book and its student handouts can be used effectively on its own, it may also be supplemented by a textbook, by student research in a library or on the internet, and by audiovisual materials that help reinforce or develop concepts that are hard to visualize. We have listed some of our favorite outside resources throughout the book.

We understand that different classes and groups have different schedules. Some teachers reading this book will have a class for most of each day and can apportion their time in such a way that experiments can be carried out throughout the day. Other teachers will have each class for only one period and—if experiments need to be continued at another time on the same day—may need to pool the work of several classes to obtain the data needed to continue. We have tried to take into account both kinds of classes in the instructions, but we also appreciate that no one knows a class better than its teacher, and thus you may want to modify our suggestions to fit your particular circumstances.

We also know (from our past experience leading professional development workshops for teachers) that the readers of this book will likely find ways to improve, expand, and personalize the experiences we suggest for their students. If you come up with great new ways of treating the subjects we cover or simply find a clever modification of our suggestions, we would love to hear from you. You can reach us by e-mail at *dschatz@pacsci.org* (Dennis) and *fraknoi@fhda.edu* (Andrew).

Both of us were trained as astronomers and have spent our professional careers explaining the wonders of the sky and the greater universe to students, teachers, museum educators, and museum visitors. Nothing gives us greater pleasure than when someone looks up and says, "Oh, I get it! For the first time, I get how that works." May you have many such experiences with your students as you use this book.

—Dennis Schatz and Andrew Fraknoi

Special Note of Acknowledgment

Student activities, like the experiences in this book, are often put forward by a number of authors independently. One version is often influenced by other adaptations that educators try and then report on in write-ups, conference sessions, and web pages.

We gratefully acknowledge inspiration for sections of a number of these experiences from the talented staff of the following institutions: the Stanford Solar Center; the NASA Science Missions Directorate Heliophysics Forum; the Exploratorium science museum in San Francisco; the University of California, Berkeley, Space Sciences Lab Center for Science Education; Hands On Optics; the Astronomical Society of the Pacific; the Pacific Science Center; David Huestis at Skyscrapers, Inc.; NASA's Goddard Space Flight Center; the Chabot Space and Science Center; the National Oceanic and Atmospheric Administration, NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA), and others. We are particularly grateful to Deborah Scherrer of the Stanford Solar Center for many useful suggestions.

Finally, many thanks go to Paul Allan, coauthor of *Astro-Adventures II* (Pacific Science Center 2003), who developed and refined many of the activities that are the basis of a number of experiences in this book.

A Website for This Book

A special set of web pages to go with this book has been established at the National Science Teachers Association (NSTA) website. You can find it at *www.nsta.org/solarscience*.

The page includes the following:

- PDF versions of student forms, material templates, and handouts for the book
- An updated list of links from the book (so that you don't have to retype URLs)
- News and resources about upcoming eclipses and other topics related to the book
- New ideas and reader suggestions for the experiences in the book

REFERENCE

Bransford, J. D., A. L. Brown, and R. R. Cocking, eds. 1999. *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academies Press.

Flares on the Sun

4

The Sun, the Moon, and the Earth Together

PHASES, ECLIPSES, AND MORE

Chapters 1 and 2 focused on important cycles of time produced by the rotation of the Earth on its axis and the revolution of Earth in its orbit around the Sun. These determine how we measure two key periods of our lives: the day and the year. This chapter adds a third cycle of importance in astronomy (and human culture): the revolution of the Moon around the Earth. The Moon's cyclical motion is not only connected to our notion of a month, but it also produces the changing phases of the Moon and explains why we have solar and lunar eclipses.

FIGURE 4.1

An image of the Moon taken with the NASA Galileo spacecraft

Note the lighter rays coming from the Tycho crater at the bottom of the Moon's disk.

4

Learning Goals of the Chapter

After doing these activities, students will understand the following:

1. As the Moon orbits the Earth, its position relative to the Sun changes and produces the different lunar phases we see.
2. The lunar phases have a predictable pattern over about a month's time, going from new Moon to waxing crescent, to first quarter, to waxing gibbous, to full Moon, to waning gibbous, to third quarter, to waning crescent, and back to new Moon.
3. Solar eclipses can only occur when the Moon is in its new moon phase.
4. Lunar eclipses can only occur when the Moon is in its full Moon phase.
5. Because the orbit of the Moon is tilted with respect to the orbit of the Earth, lunar and solar eclipses do not occur each month as one might expect but instead occur in pairs of solar and lunar eclipses around every six months.
6. While people on half of the Earth can see a total lunar eclipse, only people in a narrow path on the Earth can see a total solar eclipse.
7. Because the Moon takes the same amount of time to rotate as it takes to revolve around the Earth, we on Earth only see one side of the Moon.

Overview of Student Experiences

Teacher note: For maximum effectiveness, the first three experiences in this chapter should be done significantly in advance of when you do the experiences that follow. This will allow students to have 10 to 30 days to observe the Moon on their own before doing the later experiences in this chapter. This might mean interrupting another science unit with the first three activities, but we assure you that the effectiveness of keeping a Moon observation journal far outweighs the short-term challenge of starting this chapter before finishing another science topic.

Alternatively, you can begin your unit with the first three experiences and then move to other chapters of this book, allowing for a 10- to 30-day gap between the time you do the first three experiences in this chapter and when you do the rest.

ENGAGE EXPERIENCES

This chapter starts with what appears to be a simple challenge for the students: putting a series of lunar photographs in order by the shape of the Moon as it would appear if they observed it over a number of weeks. Because the students want to know if their answers are correct, this experience "hooks" them into observing the Moon, which ultimately leads to a deeper understanding of lunar phases, the connection of the lunar phase cycle to our concept of the month, and the cause of solar and lunar eclipses.

- **4.1. Predicting What the Moon Will Look Like:** Students examine six photographs of the Moon and predict the order of the different phases.

- **4.2. What Do We Think We Know?** Students discuss and record their thoughts regarding the following questions: (1) What are the different phases of the Moon, and how do the phases change throughout the month and year? (2) What causes the different phases? (3) What are solar and lunar eclipses, and what causes them?

EXPLORE EXPERIENCE

Students make their own observations of the Moon, which they will need for the *explain* experiences, including the time they see the Moon, the phases they see, the position of the Moon in the sky, and key features on the lunar surface (e.g., craters, maria).

- **4.3. Observing the Moon:** Students begin making basic observations of the Moon when it is out during the school day, followed by observations in the evening sky from their homes. They use the data collected over a number of days to conclude how the Moon's phases and its position in the sky change over time.

EXPLAIN EXPERIENCES

Building from their lunar observations, students create a model with their heads (the Earth), a bare lightbulb (the Sun), and a Styrofoam ball (the Moon) to understand what causes the lunar phases and solar and lunar eclipses.

- **4.4. Modeling the Moon:** This activity builds on the modeling activities from Chapters 1 and 2 in which the students' heads are the Earth and a lightbulb in the front of the room is the Sun. Each student receives a model Moon (a small Styrofoam ball attached to a pencil) that they use to explore the sequence of lunar phases they see as the Moon orbits the Earth.
- **4.5. Modeling Eclipses:** After students understand where the Moon has to be in its orbit to see each phase, the modeling process continues as they explore where the Moon has to be to produce solar and lunar eclipses.

ELABORATE EXPERIENCES

Students engage in additional experiences that reinforce and build a deeper understanding of the core ideas and science practices regarding the Moon's motions and phases and the timing of and explanation for eclipses.

- **4.6. How Often Do Eclipses Occur?** The teacher uses hula hoops to model the Moon's orbit around the Earth and the Earth's orbit around the Sun to help students understand why there are typically two solar eclipses and two lunar eclipses each year.
- **4.7. Why Do People Spend $10,000 to See a Total Solar Eclipse?** Students use the Earth–Moon–Sun model to discover that the shadow of the Moon only covers a small portion of the Earth (the student's head), leading to the realization that people who want to see a solar eclipse often need to travel to elsewhere in the world to do so. Students then play with the model to discover that this is not true for a lunar eclipse: The entire half of the Earth facing toward the Moon will see a lunar eclipse.

- **4.8. Does the Moon Rotate?** Many people believe that the Moon does not rotate because we always see the same side of the Moon facing the Earth. Students use a model in which students' heads are the Moon and Earth to determine whether or not the Moon rotates.
- **4.9. What Do Eclipses Look Like From a Space Colony on the Moon?** Students use their Earth–Moon–Sun model to predict what they would see during a solar eclipse if they were astronauts at a Moon base. They then use internet resources to see simulations of this as well as observations made from the International Space Station that show what astronauts there see during solar and lunar eclipses.

EVALUATE EXPERIENCES

These experiences allow both students and teachers to assess how well the students understand the key ideas presented in the chapter.

- **4.10. Lunar Phases Revisited:** Students are given a new set of six photographs of the Moon and are asked to repeat the process of predicting the order in which they would see the shape of the Moon if they observed it over a month's time.
- **4.11. What Causes Lunar Phases and Eclipses?** Students are asked to label a diagram that shows the Earth, Sun, and Moon to indicate where the Moon is in its orbit to produce each phase and to note where the Moon must be in its orbit to produce solar and lunar eclipses.

Recommended Teaching Time for Each Experience

Table 4.1 shows the amount of time needed for each experience.

Connecting With Standards

Table 4.2 (pp. 276–277) shows the standards covered by the experiences in this chapter. Chapter 2 dealt with any phenomena associated with seasons and the seasonal changes related to the apparent motion of the Sun in the sky, so this chapter emphasizes the cyclic patterns of lunar phases and eclipses. Additionally, this table does not give *Common Core State Standards*, but gives general connections to the language arts and mathematics standards.

TABLE 4.1

Recommended teaching time for each experience

Experience	Time
***Engage* experiences**	
4.1. Predicting What the Moon Will Look Like	**45 minutes**
4.2. What Do We Think We Know?	**45 minutes**
***Explore* experiences**	
4.3. Observing the Moon	**45 minutes** for introduction of experience, followed by **10 minutes each day** for follow-up observations; requires students to make observations outside of class time and a number of days with clear weather; summing up of what students learn takes another **45 minutes**
***Explain* experiences**	
4.4. Modeling the Moon	**Two 35-minute** periods
4.5. Modeling Eclipses	**45 minutes**
***Elaborate* experiences**	
4.6. How Often Do Eclipses Occur?	**45 minutes**
4.7. Why Do People Spend $10,000 to See a Total Solar Eclipse?	**45 minutes**
4.8. Does the Moon Rotate?	**45 minutes**
4.9. What Do Eclipses Look Like from a Space Colony on the Moon?	**45 minutes**
***Evaluate* experiences**	
4.10. Lunar Phases Revisited	**45 minutes**
4.11. What Causes Lunar Phases and Eclipses?	**30 minutes**

TABLE 4.2

Chapter 4 *Next Generation Science Standards* and *Common Core State Standards* connections

Performance expectations	• MS-ESS1-1: Develop and use a model of the Earth–Sun–Moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.
Disciplinary core ideas	• MS-ESS1.A: (The Universe and Its Stars) Patterns of the apparent motion of the Sun, the Moon, and stars in the sky can be observed, described, predicted, and explained with models.
Science and engineering practices	• Develop and use a model to describe phenomena (e.g., model of the Earth–Moon–Sun system). • Analyze and interpret data to determine similarities and differences in findings (e.g., daily observations of the lunar phases are compared with observations of others and to the student's own prediction). • Engage in argument from evidence (e.g., discussion of which order of the lunar phases is the most appropriate).
Crosscutting concepts	• Patterns can be used to identify cause-and-effect relationships (e.g., observations of the Moon's phases and modeling of the Earth–Moon–Sun relationship reveals what causes the lunar phases). • Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation (e.g., the pattern of lunar phases is revealed though observations of the Moon). • Systems and system models (e.g. use of Earth–Moon–Sun model to understand the cause of lunar phases and eclipses).

Content Background

THE PHASES OF THE MOON

Earth's natural satellite (which we call the Moon with a capital *M*, to distinguish it from the moons of other planets) is the only object we can see in the sky with just our eyes that changes its appearance on a regular cycle. The differing amounts of light and dark on the face of the Moon are called its phases, and they repeat every 29.5 days with clockwork regularity.

Since the Moon is a world made of cold rock, it produces no light of its own. Moonshine, as the ancient Greeks figured out, is really reflected

Table 4.2 *(continued)*

Connections to the *Common Core State Standards*	• *Writing:* Students write arguments that support claims with logical reasoning and relevant evidence, using accurate, credible sources and demonstrating an understanding of the topic or text. The reasons and evidence are logically organized, including the use of visual displays as appropriate. • *Speaking and listening:* Students engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners, building on others' ideas and expressing their own clearly. Report on a topic or text or present an opinion, sequencing ideas logically and using appropriate facts and relevant, descriptive details (including visual displays as appropriate) to support main ideas or themes. • *Reading:* Students quote accurately from a text when explaining what the text says and when drawing inferences from the text. Students determine the meaning of general academic and domain-specific words and phrases in a text relevant to the student's grade level. • *Mathematics:* Students recognize and use proportional reasoning to solve real-world and mathematical problems. Students summarize numerical data sets in relation to their context, including reporting the number of observations and describing the nature of the attribute under investigation, including how it was measured and its units of measurement.

sunshine. Therefore, to understand the cycle of the Moon's phases, we must look at the relationship—in the course of a month—between the Earth, the Moon, and the Sun.

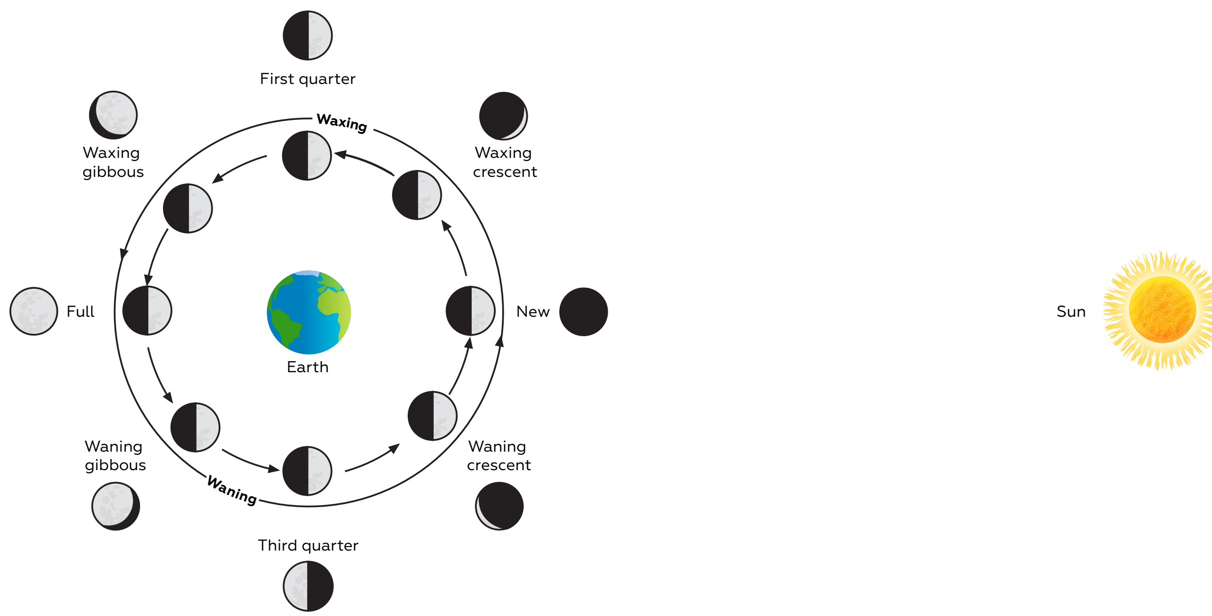
For example, when the Sun is shining on the side of the Moon facing the Earth, we on Earth see the Moon lit up with sunshine—what we call a full Moon. On the other hand, when the Sun is shining only on the side of the Moon facing away from the Earth, we see no reflected sunlight from the Moon—what we call new Moon. Between those two phases, we see some part of the side of the Moon facing us lit up and some part dark. It is this sequence of phases that this chapter helps students to understand (Figure 4.2, p. 278).

THE SURFACE FEATURES OF THE MOON

In a very general way, the surface of the Moon can be divided into two types of terrain, the dark round *maria* and the lighter *highlands* (Figure 4.3, p. 279). The word maria is Latin for "seas," a designation that dates from centuries ago when early Moon observers thought that the shadowy, round regions were quiet, dark oceans. Today we know the maria (pronounced "mar-ee-ah")

FIGURE 4.2

A diagram of the Moon phases showing the full Moon and new Moon



The outer circle of Moon diagrams shows what is visible in the sky from Earth. The inner circle of Moon diagrams shows what would be visible from space, looking down from above the Earth–Moon system.

are where overlapping round impact craters were flooded with darker lava from beneath the Moon's surface. Maria is the plural of mare (pronounced "mah-ray").

The highlands get their name from the fact that they are at a somewhat higher altitude than the maria. It is the contrast of the dark maria with the lighter highlands that has inspired many generations of Moon watchers to imagine that they can see familiar shapes on the side of the Moon facing us, including a man in the Moon, a lady's face, two children, and animals (Figure 4.4).

The Moon is full of *craters*—depressions made when chunks of rock or ice hit the Moon and explode with the energy of impact. Such explosions carve out a round hole in the surface of the Moon roughly 10 to 20 times the size of the object that exploded. Younger craters tend to be brighter, as their impact exposes material that has not yet been covered by the darker Moon dust that blankets so much of our natural satellite. You can see some large, young craters in Figure 4.3, including Tycho and Copernicus (also see the "Lunar Map" on p. 300). On good photographs of the Moon, you

FIGURE 4.3

A photo of the Moon with major features labeled (see p. 300 for a larger version)

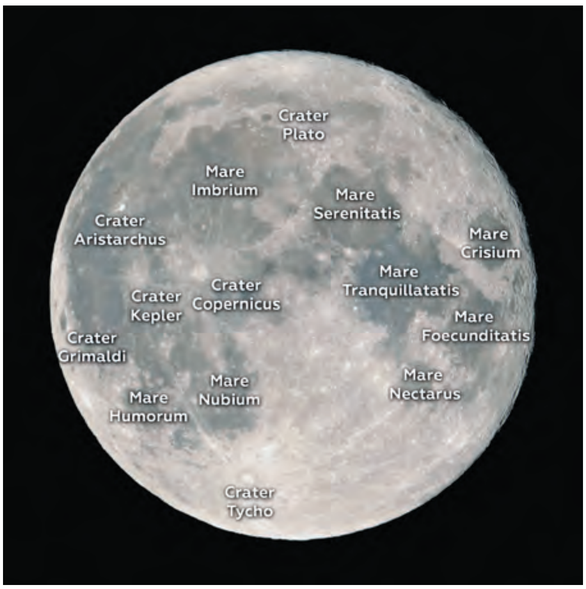


FIGURE 4.4

People imagine they can see various faces and animals, such as a rabbit, in the shapes on the Moon.

can see that the shapes of the dark maria all consist of combinations of big craters that were made long ago when giant chunks of rock were still common in the inner solar system.

Depending on the size and nature of the explosion that forms a crater, good-sized chunks of exploded rock can be thrown sideways away from the site of the explosion. When these pieces fall, approaching the surface and scraping along it before coming to a rest, they leave lighter streaks along their paths. Called *rays*, some of these features on the Moon can extend dozens or even hundreds of miles from the original crater, but they all point back to the original explosion that produced them. Rays from the crater Tycho are easily seen on photos of the Moon that show good detail (Figure 4.5).

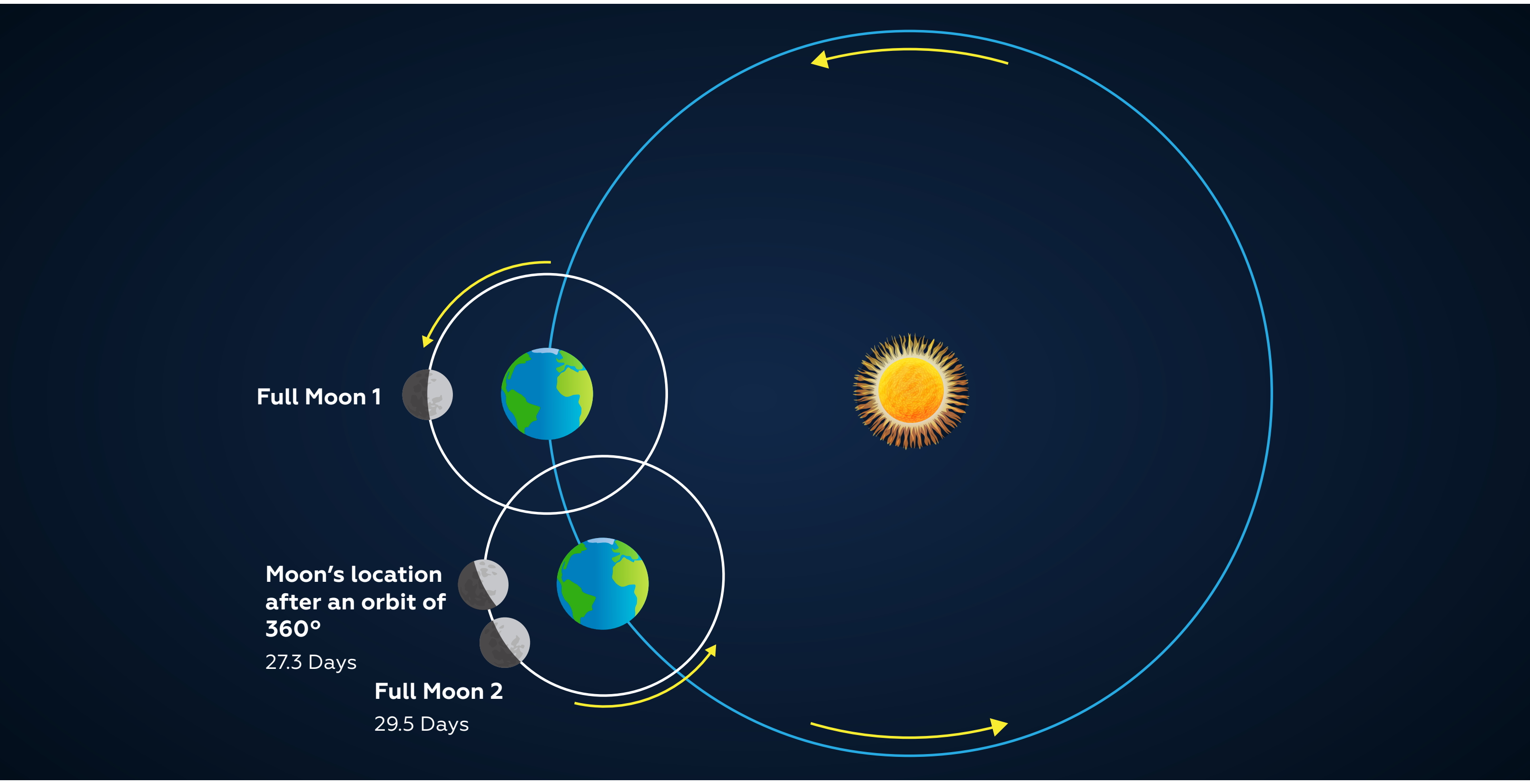
FIGURE 4.5

Rays from a crater on the Moon

On this image of the Moon taken by the Clementine spacecraft, the bright crater Tycho has rays coming out of it in many directions.

FIGURE 4.6

An illustration of the Moon's orbit relative to the Earth and Sun



It takes two extra days for the Moon to go from full Moon to full Moon compared with the time it takes to complete one full orbit (360°) of the Earth because the Earth is also orbiting the Sun. Thus, the Moon has to revolve more than 360° to get back in line with the Earth and Sun, which is required to see a full Moon.

THE MONTH AND THE MOTIONS THAT DEFINE IT

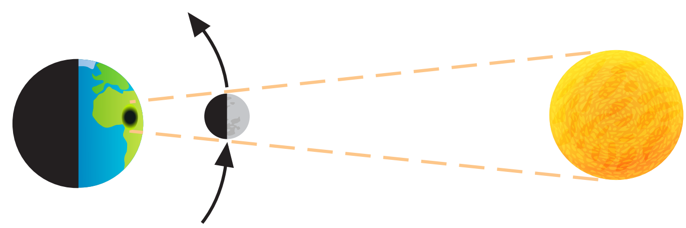
The Moon takes 27.3 days to orbit (revolve around) the Earth—that is, to return to the same place relative to the stars. However, the Earth–Moon system is also revolving around the Sun during that time, which means that the relative position of the three bodies is slowly changing. This is why the phases of the Moon take about 29.5 days to repeat (Figure 4.6). It is this cycle of repeating phases that has given its length to the unit of time we call the month, a term that is based on the word Moon.

The cycle of the Moon's phases over 29.5 (roughly 30) days has been one of the fundamental elements of timekeeping in human history. Since the Moon is easy to see and remember, it is simple to keep track of the cycle. Many cultures in earlier millennia and centuries kept an annual calendar based on the Moon's cycle and not the Earth's yearly trip around the Sun. Since the 29.5-day month does not go evenly into the 365.25-day solar year, adjustments had to be made to the length of each month to get 12 months to fit into 365 days. In our western calendar, we adjust (somewhat awkwardly) by making some months have more days and one month (February) have fewer days than 30.

In other traditions, a calendar based on the lunar cycle dominated, which is why certain holidays (Easter, Hannukah, Ramadan) come on different calendar days in different years.

FIGURE 4.7

A diagram of a solar eclipse (not to scale)



THE MOON'S ROTATION

In addition to revolving around the Earth, the Moon also spins on an axis. It takes the same amount of time to turn as it takes to orbit the Earth. This "synchronous rotation" means that the Moon turns around the Earth at the same time as it turns around itself. Thus, it always keeps roughly the same face toward our planet—which is why there is a near side and a far side to the Moon.

Such synchronous rotation is not confined to our Moon. Jupiter's four giant moons, Io, Europa, Ganymede, and Callisto, also show this connection between their time for orbiting and spinning, as does Pluto's large moon Charon. When a planet and a moon can exchange rotational energy (through some process like the ocean tides that the Moon pulls on Earth), their tendency is to make rotational motions equal to or small ratios of one another. (Long ago, after it formed, the Moon was molten, and the differences in the Earth's pull on its front and back side deformed it into a shape that was not entirely spherical. This asymmetrical shape of the Moon allows the Earth's gravity to pull on the Moon in a way that slowly changes its motion).

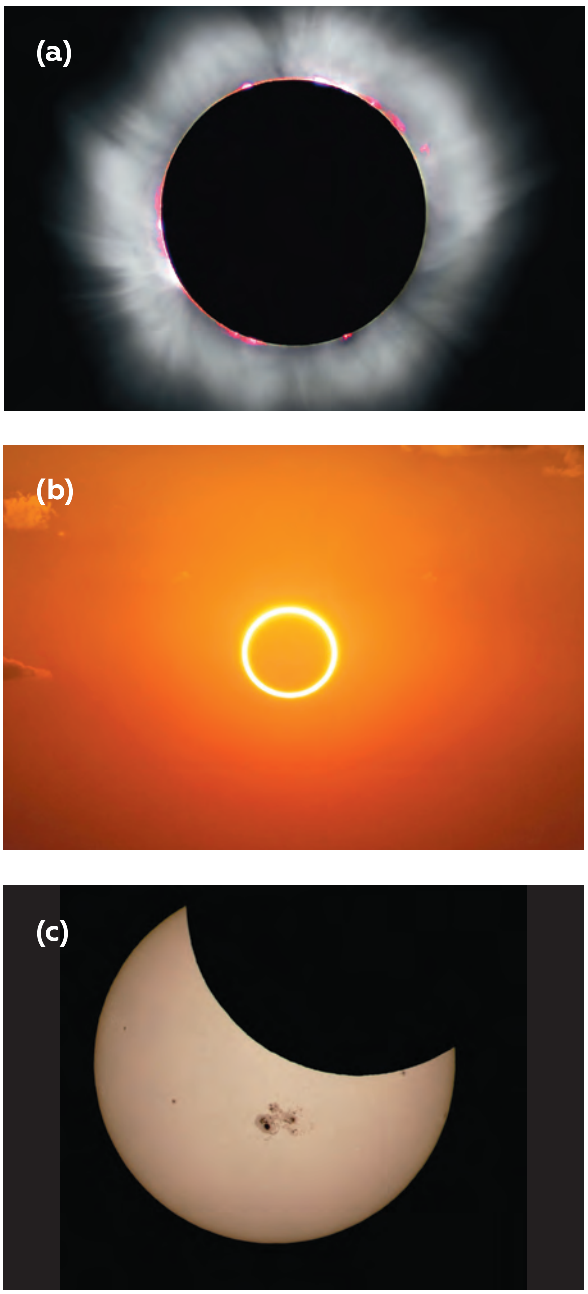
UNDERSTANDING SOLAR ECLIPSES

A solar eclipse happens when the Sun, Moon, and Earth are lined up, and the Moon covers some or all of the Sun as seen from Earth. The Moon must be in its new Moon phase for a solar eclipse to be possible (Figure 4.7).

It is a remarkable coincidence that, in our present epoch, the Sun as seen from Earth and the Moon as seen from Earth happen to be the same angular size in the sky. Therefore, the disk of the Moon can exactly cover up the disk of the Sun in what is called a *total solar eclipse* (Figure 4.8a, p. 282). Eclipses of the Sun are not always total, however. If the Moon is a bit farther away from us in its not-entirely circular orbit, then it doesn't quite manage to cover up the outermost ring of the Sun, leading to an *annular eclipse* (Figure 4.8b). And if the Moon is not lined up precisely with the Sun, we get only a piece of the Sun covered up in what is called a *partial eclipse* (Figure 4.8c).

FIGURE 4.8

Photographs of a (a) total, (b) annular, and (c) partial solar eclipse



During a total eclipse of the Sun, the Moon's darkest shadow makes a spot on the Earth's surface, roughly 60–160 mi. wide, that moves across the Earth as the Moon and Earth move relative to each other, producing what is called the *path of totality*. If you are standing in that path, you will see the Moon slowly cover the entire Sun until the faint outer atmosphere of the Sun (the corona) appears like a ring of faint light around the dark disk of the Moon (see the corona around the edge of the Sun in Figure 4.8a). Because the Sun is completely covered for a few minutes during the total solar eclipse, the sky goes dark and, if it is not cloudy, the stars come out. Animals become confused by what is happening. For example, birds become quiet and begin to roost as if night were coming. This experience of darkness in the midst of day is quite beautiful and awe-inspiring. People pay thousands of dollars to go to remote parts of our planet just to stand in the Moon's shadow and witness such a thing. But the total phase is brief—in less than five minutes (usually much less), the Moon starts to uncover the Sun and totality is over (Figure 4.9).

UNDERSTANDING LUNAR ECLIPSES

A lunar eclipse, on the other hand, happens when the Sun, Earth, and Moon are lined up, and the Earth casts its shadow on the full Moon. Lunar eclipses can only occur during the full Moon phase of the Moon (Figure 4.10). The Earth's shadow on the Moon is much bigger than the smaller Moon's shadow on the Earth. Thus, the Earth's shadow can cover the entire surface of the Moon during a total lunar eclipse, and we can see the entire face of the Moon go slowly dark (Figure 4.11).

As the Earth's shadow moves across the bright full Moon, everyone on the side of the Earth facing the Moon can see the eclipse. Thus, many more people get to witness a total eclipse of the Moon than a total eclipse of the Sun. No one travels great distances to see a lunar eclipse; people can stay where they are and nature will bring a lunar eclipse their way soon enough.

If the three bodies are not entirely lined up, it's possible to have a partial eclipse of the Moon, in which only part of the full Moon is covered. As with solar eclipses, the partial lunar eclipse is not quite as spectacular as the total one, but it's still interesting for students to try to see.

During a total lunar eclipse, the Moon does not go completely dark but turns a reddish-brown color. This is the result of sunlight refracting (bending) onto the Moon in the Earth's thick atmosphere. Much like we see at sunset, the red color from the Sun gets through the Earth's atmosphere

FIGURE 4.9

The path of the August 2017 total eclipse of the Sun

FIGURE 4.10

A diagram of a lunar eclipse (not to scale)

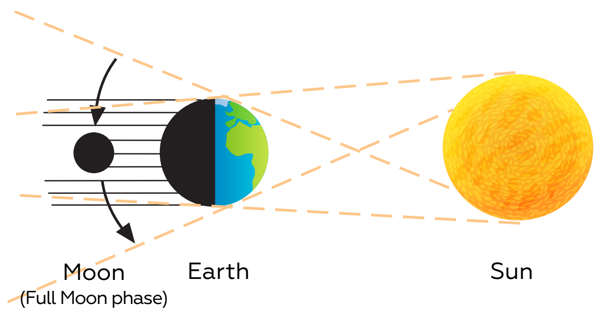
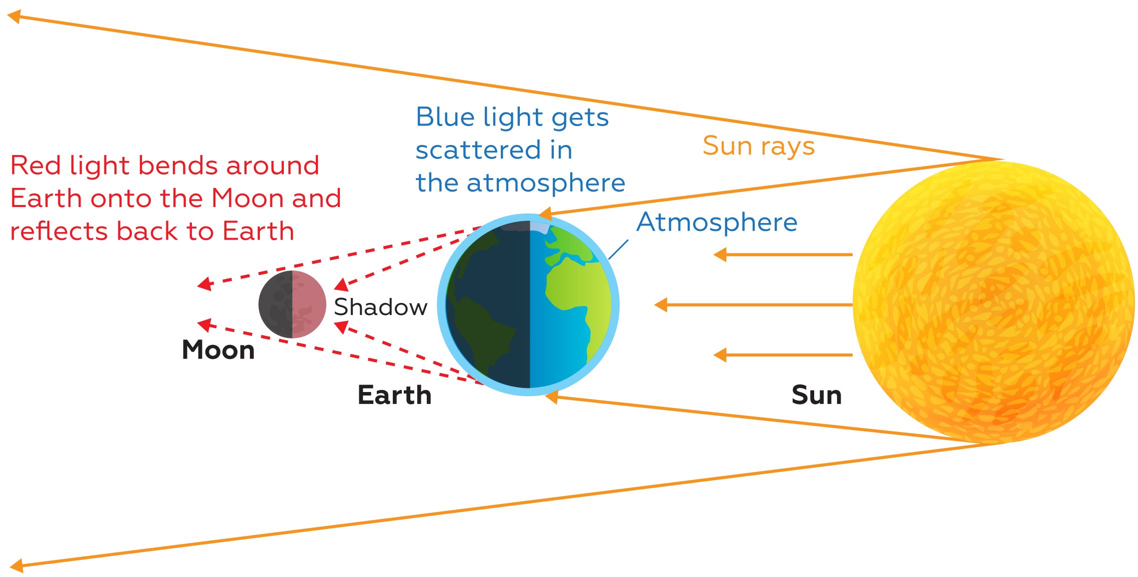


FIGURE 4.11

Stages in a total lunar eclipse

FIGURE 4.12

A diagram showing how light diffracts during a total lunar eclipse



A total lunar eclipse occurs when the Moon enters the Earth's shadow. If the Earth did not have an atmosphere, the Moon would go completely black, but Earth's atmosphere acts like a lens to bend the sunlight into the Earth's shadow. The atmosphere also scatters the shorter wavelengths of light (blue and green) more and the longer wavelengths (orange and red) less. This means mostly orange and red light get through to continue toward the Moon. When the orange and red light reaches the Moon, these colors are reflected back to the Earth, so we see the Moon not as being completely dark but as having a reddish hue. (Image not to scale.)

while the other colors are scattered (Figure 4.12). The exact color of the Moon depends on how polluted our atmosphere is with small particles of dust, dirt, or ash. Lunar eclipses are always more colorful after large volcanic eruptions, for example.

WHY ECLIPSES DON'T HAPPEN EVERY MONTH

Since there is a full Moon and new Moon every month, students often wonder why we don't have a lunar and solar eclipse every month. The key to why eclipses don't happen every month is that the plane of the Moon's orbit is not exactly aligned with the plane of the Earth's orbit around the Sun. The Sun appears to travel along what is called the *ecliptic*, and the Moon's orbit is inclined about 5° relative to this (Figure 4.13). Therefore, in most months, we see the Moon a little bit above or below the position where we see the Sun in the sky. Only twice a year, when the two orbits intersect, can the Sun, Moon, and Earth line up in such a way as to make an eclipse possible. During these roughly twice yearly "eclipse seasons," we typically have a pair of eclipses, one during the full Moon and the other during the new Moon, followed by another pair of solar and lunar eclipses about six months later.

For a list of upcoming solar and lunar eclipses, see Tables 4.3 and 4.4 on pages 286 and 287 or visit *www.nsta.org/solarscience*.

SAFE ECLIPSE VIEWING

Important warning: Viewing all or part of the Sun without proper protection is dangerous—except for the few minutes during the total phase of an eclipse when one can look at the Sun with unprotected eyes and binoculars!

The Sun's visible (and invisible) rays can cause serious damage to the sensitive tissues of the eye, often without one being immediately aware of it! Normally, our common sense protects us from looking directly at the Sun for more than a second. But during an eclipse, astronomical enthusiasm can overwhelm common sense, and people can wind up staring at the Sun for too long. Make sure you have something with you to protect your eyes before the eclipse becomes total or if you are only seeing the partial eclipse.

The few minutes of total eclipse (when the Sun is completely covered) ARE safe, but any time that even a small piece of the bright Sun shows, your eyes are in danger. See Experience 3.3, "Safe Solar Viewing," for detailed instructions on how to use binoculars to project an image of the Sun that the whole class can look at together. Experience 3.10 (pp. 250–256) describes some other safe ways to look at the Sun.

FIGURE 4.13

The paths of the Sun and the Moon in the sky

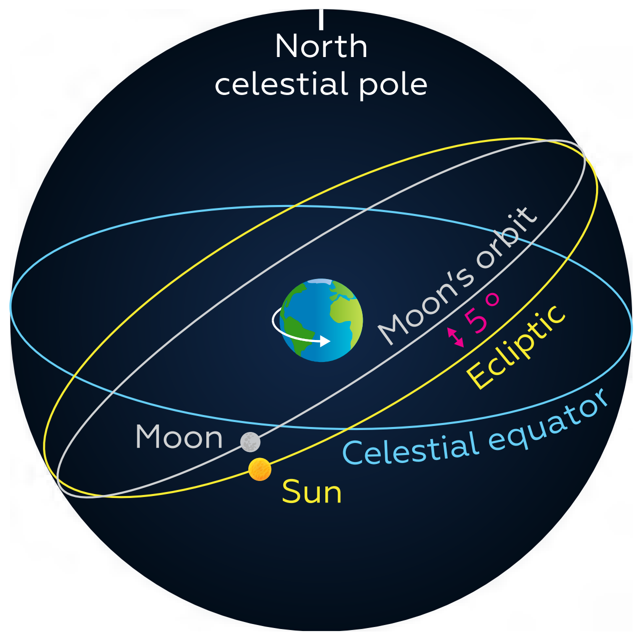


TABLE 4.3

Future total and annular solar eclipses

Date	Type of eclipse	Location on Earth ●
Sep. 1, 2016	Annular	South Atlantic Ocean, central Africa, Madagascar, Indian Ocean
Feb. 26, 2017	Annular	Southwest Africa, southern tip of South America
Aug. 21, 2017	Total	United States (Oregon to South Carolina) and oceans on either side
July 2, 2019	Total	Southwest South America, Pacific Ocean
Dec. 26, 2019	Annular	Saudi Arabia, southern India, Malaysia
June 21, 2020	Annular	(very short) central Africa, Pakistan, India, China
Dec. 14, 2020	Total	Chile, Argentina, and oceans on either side
June 10, 2021	Annular	Northern Canada, Greenland
Dec. 4, 2021	Total	Only in Antarctica
April 20, 2023	Total ○	Mostly Indian Ocean and Pacific Ocean, plus Indonesia
Oct. 14, 2023	Annular	Oregon, Nevada, Utah, New Mexico, Texas, Central America, Colombia, Brazil
April 8, 2024	Total	Northern Mexico, United States (Texas to Maine), southeastern Canada, oceans on either side
Oct. 2, 2024	Annular	Southern Chile, southern Argentina, oceans on either side
Feb. 17, 2026	Annular	Antarctica only
Aug. 12, 2026	Total	Greenland, Iceland, Spain
Feb. 6, 2027	Annular	South Pacific, Argentina, Chile, Uruguay, southern Atlantic Ocean
Aug. 2, 2027	Total	Spain, Morocco, Egypt, Saudi Arabia, Yemen, Arabian Sea
Jan. 26, 2028	Annular	Ecuador, Peru, Brazil, northern Atlantic Ocean, Portugal, Spain
July 22, 2028	Total	Indian Ocean, Australia, New Zealand, southern Pacific Ocean

● Remember that a total or annular eclipse is only visible on a narrow track. The same eclipse will be partial over a much larger area, but partial eclipses are not as spectacular as total ones.

○ This is a so-called hybrid eclipse, which is total in some places and annular in others

TABLE 4.4

Future total lunar eclipses

Note: Because partial and penumbral lunar eclipses are not that spectacular, we list only the eclipses that become total (when the Moon is completely within the Earth's dark shadow).

Date	Type of eclipse	Location on Earth
Jan. 31, 2018	Total	Asia, Australia, western North America
July 27, 2018	Total	South America, Asia, Africa, Australia, Indian Ocean
Jan. 21, 2019	Total	North America, South America, western Africa, western Europe
May 26, 2021	Total	Eastern Asia, Australia, Pacific Ocean, western North America, western South America
May 16, 2022	Total	North America, South America, Europe, Africa
Nov. 8, 2022	Total	Asia, Australia, Pacific Ocean, North America, South America
March 14, 2025	Total	Pacific Ocean, North America, South America, Atlantic Ocean, western Europe, western Africa
Sep. 7, 2025	Total	Europe, Africa, Asia, Australia, Indian Ocean
March 3, 2026	Total	Eastern Asia, Australia, Pacific Ocean, North America, Central America
June 26, 2029	Total	Eastern North America, South America, Atlantic Ocean, western Europe, western Africa
Dec. 20, 2029	Total	Eastern North America, Eastern South America, Atlantic Ocean, Europe, Africa, Asia

4.1

ENGAGE

EXPERIENCE 4.1

Predicting What the Moon Will Look Like

Overall Concept

Students examine and predict the order of six photographs of the Moon that show different phases. Their predictions are then compared to the actual observations students make over the next 10 to 30 days as part of *explore* Experience 4.3, "Observing the Moon."

Objectives

Students will

1. use photos of the Moon to predict the sequence of the Moon's phases based on their prior knowledge,
2. recognize that the Moon's overall appearance changes on a regular cycle,
3. question how and why the Moon's appearance changes, and
4. identify a number of features on the Moon's surface.

Teacher note: Many students—and teachers—think of the Moon as having eight phases (see, for example, Figure 4.14, p. 297). There is not a specific number of phases, since the Moon goes through a continuous change in phase as it slowly shows more of its lit side after its new phase until we see the full Moon. It then shows less and less of its lit side until it gets back to new phase after 29.5 days. The selection of only six photos for this experience rather than eight is to reinforce the idea that there are not eight specific lunar phases. The photos are also oriented in a random pattern to encourage students to look at the features on the Moon to determine "which way is up" when viewing each image. This provides a reason for the students to learn about craters, maria, and rays. For your reference only at this time, the correct order of the images is in Figure 4.15 (p. 299).

MATERIALS

One per group:

- "Six Lunar Photographs, Set 1" (p. 291)
- Blank sheet of paper
- Scissors
- Tape or glue

One per student:

- Astronomy lab notebook

Advance Preparation

Make a copy of the "Six Lunar Photographs, Set 1" handout for each group.

Procedure

1. Tell the students that a teacher colleague of yours (identify by name if desired) had a set of lunar photographs sent to him or her by an amateur astronomer friend. Unfortunately, your colleague dropped the photos on the floor and no longer knows the order or orientation of the photographs. The friend asked for help from you and your class to get them in the correct order. You have made copies of the photos so the students can help with this challenge.
2. Distribute copies of the "Six Lunar Photographs, Set 1" handout, scissors, tape or glue, and a blank sheet of paper to each work group. It is important to use a photocopy machine that will preserve the detail in the photos. The students' goal is to place the photographs on the sheet of paper in the order in which they think they would see the shape of the Moon if they made observations for several weeks. Allow 10 to 15 minutes for discussion and decision making in each group.
3. Once each group is satisfied with the order, students should tape or glue the photos to the blank sheet of paper. Have them number the pictures from 1 to 6 in the order each would be seen. Be sure they indicate which way is up. They should also put their names on the paper to show who made the prediction.
4. When all of the groups have completed their photo sequences, have them move around the room to see the predictions of other groups. Ask the work groups, one by one, to explain their reasoning for choosing the sequence they came up with. These reasons should not yet be judged for appropriateness since the students are only presenting their best guess.
5. Use this discussion as a transition to Experience 4.3, "Observing the Moon," by pointing out that the best way to know the correct order is to observe the Moon over a number of days. The students' predictions should be posted on a wall of the room for ongoing reference during Experience 4.3. Alternatively, one

member of each work group can keep the team's photo sheet in his or her astronomy lab notebook for later reference.

Teacher note: Students will want to be immediately be told the "right" answer for the order of the Moon photographs. It is important not to share the right answer at this point but to use Experience 4.3 as a way for students to discover the correct order for themselves.

6. The discussion in step 4 is also an effective transition to the next *engage* experience, whichlets students think about and express what they already know about lunar phases and eclipses.

Six Lunar Photographs, Set 1

Source:
Fred Espenak,
www.astropixels.com

EXPERIENCE 4.2

What Do We Think We Know?

Overall Concept

Just as in prior chapters, this "What Do We Think We Know?" experience allows students to reflect on what they already know about a topic covered in this chapter. This gives you an understanding of what knowledge they already have and if they have any preconceptions that need to be dealt with.

Objectives

Students will

1. reflect on and write in their astronomy lab notebooks what they think they know about lunar phases and solar and lunar eclipses; and
2. share their ideas with other students.

Advance Preparation

Identify space where the list of student preconceptions can be located for the length of time the class is researching lunar phases and eclipses.

Procedure

1. Tell students that now that they have explored the lunar images in Experience 4.1, "Predicting How the Moon Will Look," and have a prediction for what they will see when they observe the Moon, you would like to understand what they already know about the Moon's phases and related phenomena.
2. Have them label the top of a page in their astronomy lab notebook with "What I Think I Know." Right below that, have them write the

MATERIALS

For the class:

- Space on a whiteboard, blackboard, or piece of poster paper where student preconceptions can be recorded and kept visible for the duration of the time researching lunar phases and eclipses

One per student:

- Astronomy lab notebook

first question you want them to consider and discuss: "What are the different phases of the Moon, and how do the phases change throughout the month and year?" Explain, if necessary, that "phases" are the shape that the Moon appears to have when we look at it in the sky. At the top of the following page, have them write the next question: "What causes the different phases?" On the third page, ask them to write the final prompt: "What are solar and lunar eclipses, and what causes them?"

3. Use the think-pair-share process described in the book's Introduction (p. xix) to have students (1) individually write answers to the questions in their notebooks; (2) discuss their answers with other students in small groups and add more detail to their notebooks as desired; and finally, (3) report out in their groups and write a list of what they, as a whole class, think they know in a location in the classroom where the information can be kept for future reference.

4. Finish up the experience by thanking the students for sharing what they think they know and emphasizing that keeping the answers up will help the class see what new things they learn during the study of the Moon's phases and its relationship to lunar and solar eclipses.

5. As you do the experiences in this chapter, you should periodically refer back to what students said in this experience to see how their thinking has changed.

4.3

EXPLORE

EXPERIENCE 4.3

Observing the Moon

Overall Concept

A major outcome of Experience 4.1, "Predicting How the Moon Will Look," is that students want to know who has the right sequence for the phases of the Moon, so they are motivated to go outside to observe the Moon, which is the focus of this experience. To completely identify the appropriate sequence—and orientation—of the photos, the students need to be able to identify a number of features on the lunar surface, so this activity also allows for a study of lunar craters and maria. (Just a reminder that the word maria means "seas" in Latin and is plural; the singular is mare.)

Objectives

Students will

1. make a daily record of their Moon observations;
2. identify features (e.g., craters, maria) that they see on the lunar surface; and
3. use their observations to develop an understanding of the sequence of lunar phases and the location of a select number of lunar features.

Advance Preparation

Experience 4.1, "Predicting How the Moon Will Look," provides an excellent introduction to this experience, so we suggest you

MATERIALS

For the class:

- A large poster or projection of the "Lunar Map" (p. 300)
- A large poster of the "Lunar Observing Record Chart" (p. 301)

One per group:

- "Six Lunar Photographs, Set 1" (from Experience 4.1, p. 291)
- Predictions of the order of the lunar phases from Experience 4.1, if you did that experience

One per student:

- "Lunar Map" (p. 300)

begin this experience at its conclusion. This experience is ideally started a few days before the Moon is at first quarter. The Moon will be in the western sky in the afternoon and evening, which will allow you to take students outside near the end of the school day to make the first observation together. Some students may not realize that the Moon is often visible in the daytime as well as at night, so you may want to have the students think about the different times of the day they have seen the Moon. This first daytime observation allows you to review with the students what each lunar observation consists of and gets them into the routine of making daily observations either when the entire class can observe together or on their own. With your assistance, students will then be able to use their skills to make nighttime observations in the coming weeks when the Moon is not visible in the daytime sky.

You may also find it useful to provide the students with a chart (see Table 4.5) that tells them when the Moon will be above the horizon for some of the key phases.

If you have multiple classes or cannot take students out near the end of the day to make the observations, you can ask them to do their first Moon observation as homework on the way home or shortly after they get home.

You can easily find when the Moon is near first quarter by looking on a calendar or searching the internet for "phases of the Moon." You can start the experience at any time, but certain phases work better for

TABLE 4.5

Rising and setting times of the Moon during key phases

Moon phase		Approximate rise time	Approximate set time
New Moon		Sunrise	Sunset
First quarter		Noon	Midnight
Full Moon		Sunset	Sunrise
Third quarter		Midnight	Noon

MATERIALS *(continued)*

- "Lunar Observing Record Chart" (p. 301); you may provide two charts per student if you want them to make observations over a longer period of time
- Pencil
- Clipboard or other firm writing surface
- Astronomy lab notebook
- (*Optional*) Binoculars—some schools may have extra binoculars to lend to students overnight on a rotating basis

making observations during times when students are outside or awake. You should also check the weather reports to help identify a day around first quarter when it is likely to be clear in the afternoon.

We highly recommend that you do this experience yourself a month or two in advance of doing it with the class so that you will be prepared for some of the challenges that students will encounter—primarily bad weather, trying to observe from a location where buildings or trees block the view of the Moon, or looking at the wrong time of day.

Procedure

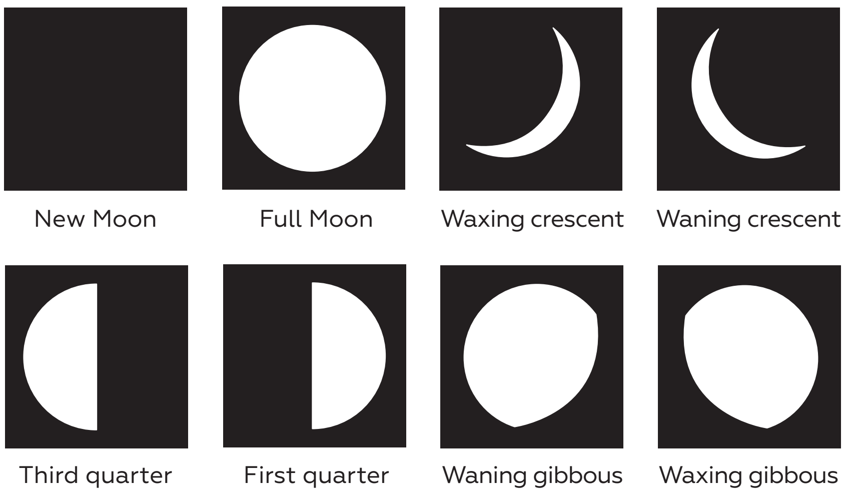
1. Distribute the "Lunar Map" handouts and have students use the maps to identify some key features they should look for when out observing the Moon. These features should be large or noticeable for another reason (e.g., different in coloring), so students can see them with no equipment except their eyes. Ask the students to find the features on the photographs they sequenced in Experience 4.1. This is also a good time to provide more information about craters, maria, rays, and what caused them. See the Content Background section on the surface features of the Moon (pp. 277–279) for more information about these features.

2. Distribute copies of the "Lunar Observing Record Chart." Tell the students they will now have an opportunity to observe the Moon themselves to determine the correct order for the lunar photographs. They will also be able to explore some of the ideas they raised in Experience 4.2, "What Do We Think We Know?" (if you did that experience). This is also a good time to introduce the astronomical vocabulary regarding what we call each phase of the Moon (Figure 4.14).

   Teacher note: Ideally, the students will make observations over an entire month. If time constraints or the weather do not allow the students to observe the Moon for that long, they should be able to begin determining the pattern of the phases after about 10 observations. Observations are not required every day, so some days without observations should be fine. When the weather becomes a problem (clouds for more than two or three days in a row), students can use internet resources to complete their observation charts.

FIGURE 4.14

Names of the phases of the Moon



Websites for finding the current lunar phase include the following:

- Calculator Cat: *www.calculatorcat.com/moon_phases/phasenow.php*
- Calendars Through the Ages: *www.webexhibits.org/calendars/moon.html*
- Moonpage.com: *www.moonpage.com*

3. Explain how the "Lunar Observing Record Chart" is used. This is best done by going outside with the class to locate and make the first observation of the Moon together. Bring a pair of binoculars with you if you have one so that students can get a better look at some of the surface features, which are often difficult to see in the daytime. Record the date, the time of the observation, the Moon's location in the sky, and its shape. Add small drawings that show the shape and location of lunar features that can be identified from the lunar map.

   Teacher note: When the Moon is in a crescent or quarter phase, it can often be difficult to be sure which feature is being seen. Tell the students to make their best guess and then follow the feature during the coming days as they make observations.

The key features will become obvious as the Moon approaches full Moon.

4. Have students go out every clear day or night to repeat their observations. Encourage them to use binoculars if they have access to a pair to help identify various lunar surface features. After the first observation, make a class activity of predicting what phase the Moon will be in before the next observation.

   Teacher note: In some urban areas, parents may not be comfortable with students going outside at night to find the Moon. You may want to send a sheet about this experience home with students and get a sense of how parents feel and whether they would be comfortable going out with their students to help. If not, then students could use internet resources to fill in the phases for days when the Moon is only visible at night. Also, binoculars may not be available to students at home. If the school has binoculars in quantity, you might want to arrange for a loan program, or you may want to make the identification of features at home a less important part of this experience.

   It is helpful to summarize daily observations on a classroom copy of the "Lunar Observing Record Chart" that can be posted on a wall. An alternative to this is to have one student draw a picture each day on construction paper of the class's observations for the previous day. These could be posted daily in consecutive order to allow the students to see the pattern of the phases emerge throughout the activity. After a number of days, students should be encouraged to compare their daily observations to the predictions they made in Experience 4.1. Some students will want to start making changes to their predictions. Tell them that they will have plenty of opportunity to compare their observations to their predictions, but for now they need to leave their predictions unaltered.

5. After observing the Moon for 10 to 30 days (which are required to see the pattern for the lunar phase cycle), it is time to summarize what the students learned from their observations. Use the think-pair-share process to have students write and discuss what their observations revealed about the phases of the Moon. The following are key ideas that should emerge, assuming you are observing from typical Northern latitudes in the continental United States:

a. The phases started with a crescent Moon that had sunlight on the right side (assuming you started a few days before first quarter).

b. More and more of the Moon facing the Earth became lit by the Sun over the next week or two until it was all in sunlight (full Moon).

c. After the full Moon, less and less of the Moon facing the Earth was lit by the Sun, and the lit part was on the left side.

d. If students observed for a full month, then they should be able to conclude that the time to go from a given phase back to that phase is approximately a month (actually, it's 29.5 days).

e. Although the amount of light on the Moon's surface facing toward the Earth changes throughout the month, the features on the Moon appear to stay in the same location on the side of the Moon we can see.

This is a good time to talk about the relationship between the lunar phase cycle and why we divide the year into months. You might also discuss that many cultures had calendars based on the lunar cycle rather than the cycle of the Earth's orbit around the Sun.

6. Conclude the experience by giving each group another copy of the "Six Lunar Photographs, Set 1" handout and asking them to redo the ordering process. This new order should be attached to the original paper just below their initial predictions. Once they have done this, you can confirm the appropriate order for the photographs (see Figure 4.15) and also review the different phases the Moon goes through. Finally, you can reinforce that the Moon takes 29.5 days to go through a full set of phases.

7. If you need to assess individual student understanding of lunar phases, this is an appropriate time do the first *evaluate* experience (Experience 4.10, "Lunar Phases Revisited").

FIGURE 4.15

Correct order for the lunar photographs in set 1

Waxing crescent

First quarter

Waxing gibbous

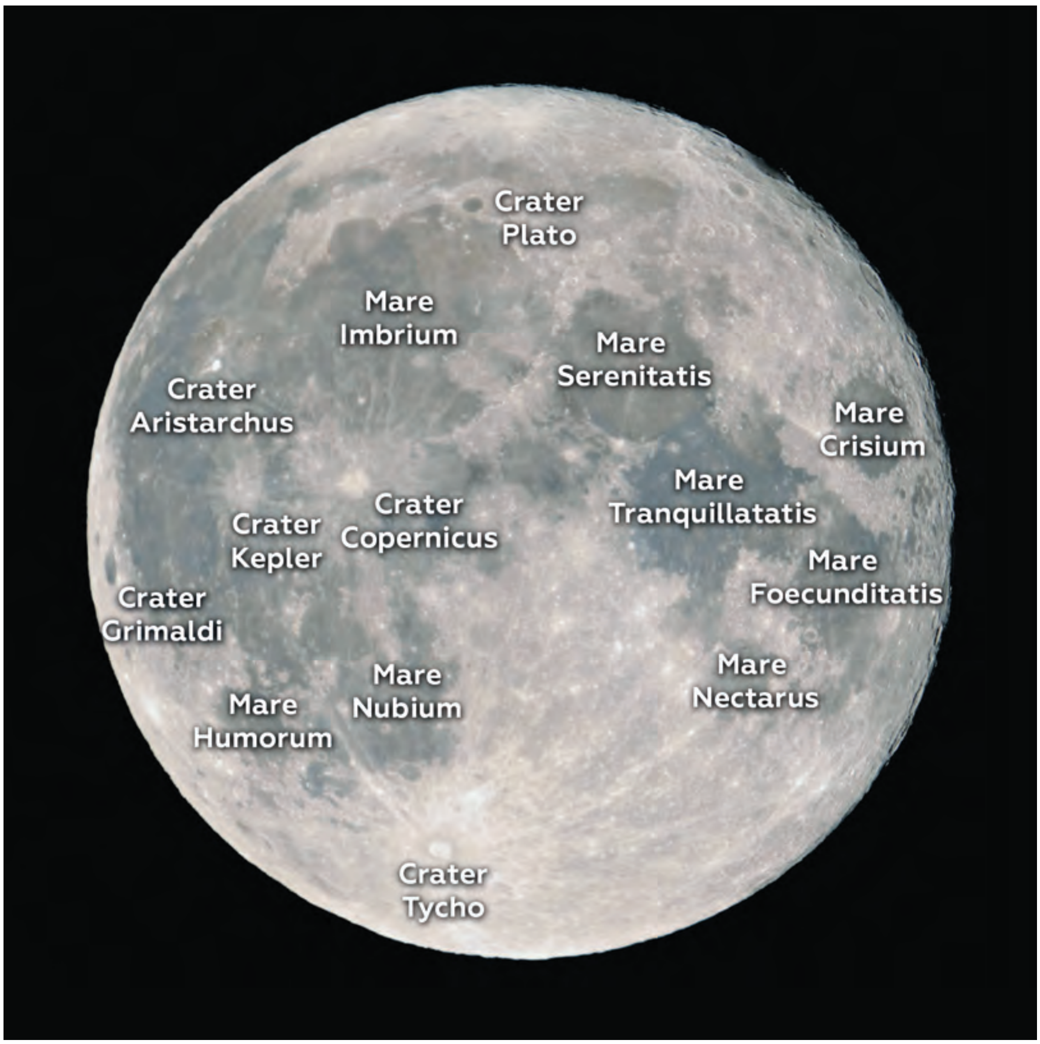
Full Moon

Waning gibbous

Waning crescent

Source: Fred Espenak, *www.astropixels.com*

Lunar Map



Source:
Fred Espenak,
www.astropixels.com

Lunar Observing Record Chart

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:
Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:	Date______ Time______ Location:

Three-Dimensional Learning Exposed

Three-dimensional learning (the integration of the disciplinary core ideas, science practices, and crosscutting concepts from the *Next Generation Science Standards*) is best demonstrated in this chapter when combining Experience 4.1, "Predicting How the Moon Will Look," Experience 4.3, "Observing the Moon," and Experience 4.4 "Modeling the Moon."

Not only do students develop an understanding of the "cyclic patterns of lunar phases [and] eclipses," as written in the middle school performance expectation MS-ESS1-1, but they engage in the following key science practices:

- Analyze and interpret data during their efforts to predict the order of the lunar phases and then when they make the regular observations of the Moon in the sky.
- Use a model of the Earth–Moon–Sun system (lightbulb, Styrofoam balls, and their heads) to describe the relationship between the Earth, Moon, and Sun—thus developing an understanding of what causes the Moon's phases and both lunar and solar eclipses.
- Engage in argument from evidence as they compare their predictions for the order of the lunar photographs and during their daily observations of the Moon.

These experiences also allow the teacher to identify crosscutting concepts embedded in the learning. The key crosscutting concepts include the following:

- Patterns observed in the experiences can identify cause-and-effect relationships, as seen in how the relative position of the Earth, Moon, and Sun are the cause of the Moon's phases.

- Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation, as demonstrated by observations of the Moon and Sun leading to an understanding of when solar and lunar eclipses occur, allowing astronomers to predict when future eclipses will be visible.
- System models provide an opportunity for understanding and testing ideas, as provided in the model of the Earth-Moon-Sun system created using the student's head, Styrofoam ball, and lightbulb.

As mentioned in Chapter 1, we suggest you take time during the experiences to emphasize the value of the science practices and crosscutting concepts in all areas of science.

EXPERIENCE 4.4

Modeling the Moon

Overall Concept

Now that students understand the order of the lunar phases and the length of the cycle, the typical question they bring up is, "What causes the phases?" This experience allows students to understand the cause by building on the modeling activity from Chapter 1 in which the students' heads were the Earth and a lightbulb at the front of the room was the Sun. The Moon is now added to the model—in the form of a small Styrofoam ball attached to a pencil. This allows the students to explore the relationships among the Earth, Moon, and Sun to understand what causes lunar phases.

Objectives

Students will

1. be able to identify the order of the Moon's phases from one full Moon to the next; and
2. demonstrate how the Moon's position around the Earth (relative to the Sun) creates the phases.

Advance Preparation

Be sure there is plenty of space for students to stand with a hand stretched out and to spin around as they work through this experience. Check that the lamp or lightbulb for the model Sun works properly and can be placed high in the front of the room for everyone to see it. The room you use

MATERIALS

For the class:

- Lightbulb on a stand or clamp (or a lamp with its shade removed); a 60 W bulb is best for this experience
- Extension cord
- A room that can be made completely dark

One per student:

- Smoothfoam or Styrofoam ball or light-colored sphere for each student (as a model Moon)

  Teacher note: Smoothfoam balls have a denser, smoother surface that works better for this activity, but they are often harder to find than Styrofoam balls. Either will work. Places on the web that sell Smoothfoam or Styrofoam balls include Michaels (*www.michaels.com*) or Smoothfoam.com (*www.smoothfoam.com/category/balls.html*). Staples and other similar companies also carry them online.

- Pencil
- "Moon Phase Activity Sheet" (p. 310)
- Astronomy lab notebook

for this experience needs to be completely dark, which often means you have to switch rooms or spend time putting up black plastic sheets, dark tablecloths, or poster boards to cover light leaks in your classroom.

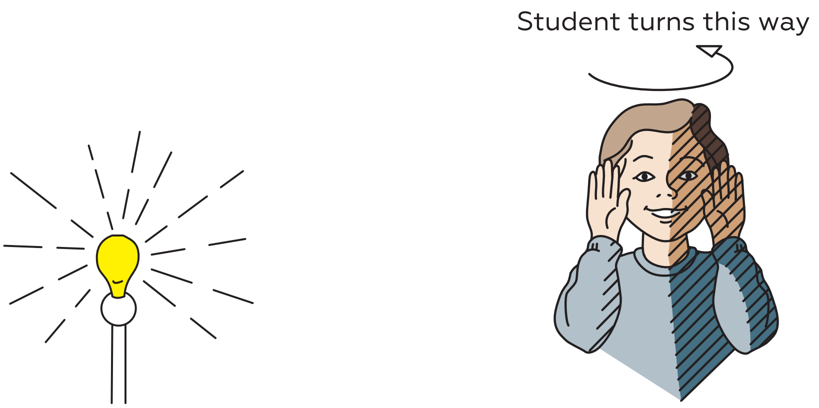
Procedure

1. Review the results of Experience 4.3, "Observing the Moon," which showed that the Moon goes through a sequence of phases. Work with the students to review the order of the phases from one full Moon to the next. Discuss some of the students' predictions about what causes the lunar phases, if this was explored in earlier discussions.
2. Tell the students that since we cannot go to outer space to observe the Moon orbiting Earth and the change in phase, we will use a model to learn what causes the Moon phases. Make the room completely dark and place the lamp at the front. Remind students of safety near the hot lightbulb and electrical cord. Have students stand facing the lamp. Make sure they are spread out enough that light from the lamp reaches each student. If you did Experience 1.5, you can remind students that this activity will be an extension of their model Sun–Earth system. The lamp still represents the Sun and their heads still represent Earth, with their noses being the students' hometown.
3. Review what they learned from the model of the Earth and Sun developed in Chapter 1. Ask students to stand so it is noon in their hometown (noses-at-noon). If disagreement occurs as to what position this would be, have students discuss until it is agreed that noon is when their nose is pointed toward the model Sun. Next, ask them to stand so it is midnight at their noses. They should turn so that they face away from the Sun.
4. Students should recall which way Earth rotates on its axis from the experiences in Chapter 1. If students did not do those experiences or do not remember them, you will need to review a few things. Determine which way north, south, east, and west are for their model Earths (their heads). If their hometown (nose) is in the Northern Hemisphere, north is the top of their heads, south is their chins, east is to their left, and west is to their right. From prior knowledge and their Moon observations, they should know

that the Sun rises in the east. Have the students place their open hands on the sides of their heads, acting as horizon blinders. Have them determine which way Earth rotates so that the Sun rises over their left (eastern) hand. After some trial and error, they will be able to determine that the Earth rotates from right to left in their model, with their right shoulder moving forward (Figure 4.16).

FIGURE 4.16

Diagram showing how the students should stand in the model



5. Ask students to stand so it is sunrise and then so it is sunset. Practice the ideas of sunrise, noon, midnight, and sunset until you feel that the students have a good understanding of these relative positions. This is a good review of what they learned in Chapter 1, and it gives them some practice with the model before introducing the Moon.
6. Distribute one "Moon ball" to each student. Have them stick a pencil into the ball to make it easier to hold and observe the phases of the Moon in the model. If there is already a hole in the ball from previous use, tell them to use that one and not make a new one. Have students hold the model Moon at arm's length. Allow time for students to explore how the Sun's light reflects off the model as they place their Moons in different positions around the Earth. This is a good time to tell students that the Moon orbits the Earth in a counterclockwise direction when

looking down on the Earth and Moon from above the North Pole. As they explore the different lunar phases, remind them to always have the Moon move in the correct direction.

One question that usually comes up and must be addressed is how high the model Moon should be held. If it is held at head height, there will be an eclipse (instead of a full Moon) during each orbit of the Moon around the student's head. Help the students develop the idea that they did not observe a lunar eclipse during Experience 4.3, and generally people make a big deal about eclipses. Therefore, they probably do not occur every month. Students should then conclude that they have to hold the Moon balls up high so the balls are exposed to the Sun's light throughout their orbit around Earth. The topic of eclipses is covered in Experience 4.5, "Modeling Eclipses," and in Experience 4.6, "How Often Do Eclipses Occur?" In Experience 4.6, they will learn that the Moon's orbit is not aligned with the Earth's orbit around the Sun (or relative to the circle that the Sun appears to make among the constellations in the course of a year, which is how we on Earth perceive our motion around the Sun). As a result, the Moon is usually either above or below the Sun in the sky. But if you plan to do Experience 4.6, you may not want to give away the answer while you help them with the current activity.

7. Help students find a few of the phases of the Moon with which they are already familiar, such as a full Moon, a new Moon, and the first and third quarters. A new Moon occurs when the Earth, Moon, and Sun are aligned, and the Moon is between Earth and the Sun. A full Moon occurs when the three bodies are aligned, and the Earth is between the Moon and the Sun (Figure 4.17, p. 308).

Teacher note: Students will have many questions as they explore. Try not to answer directly. Encourage them to explore their questions using the model before providing an answer.

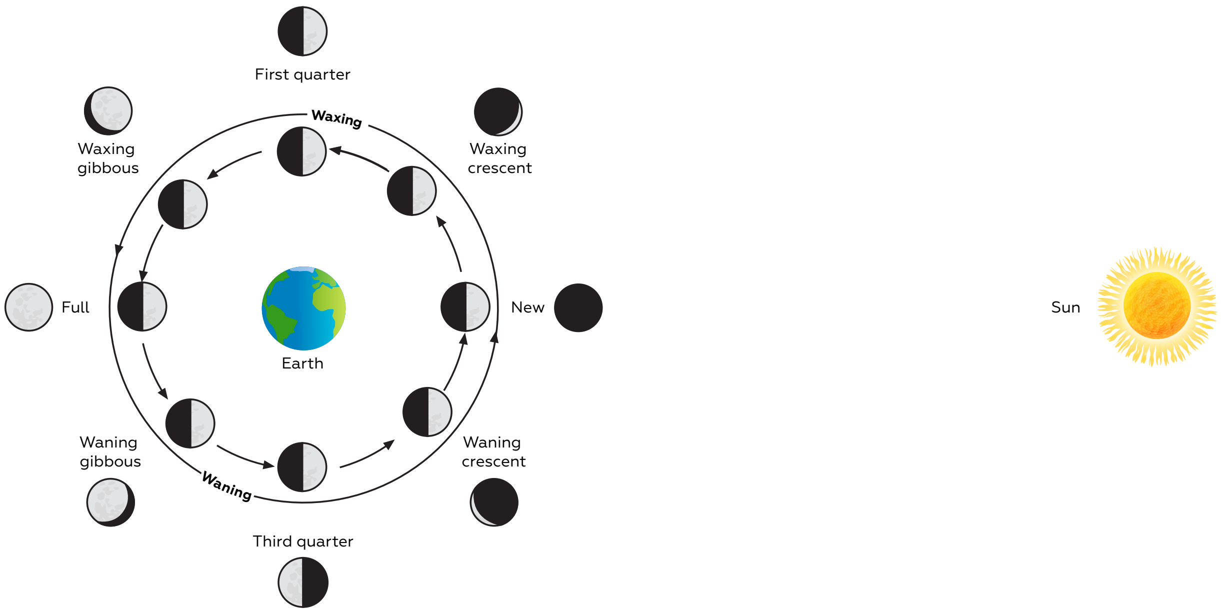
There is a common misconception that Earth's shadow causes the phases, and some of your students may try to involve the shadow of their heads in the modeling. If students are trying to produce the different phases by hiding parts of the Moon with shadows of their heads, you will need to address this. Students should also come to recognize, possibly with some assistance, that they cannot generate the shape of the different phases by using the shadow of Earth.

8. After students explore finding the phases, choose one lunar phase and ask the students to determine what position in the Moon's orbit they must place their Moon to achieve that particular phase. Full Moon is a good phase to start with. Encourage students to compare their positions and discuss differences. Ask a student who has the correct position to explain why it is correct. By walking around the classroom, you can check for understanding by seeing if all the students are holding their Moons in the same position.

9. Have students model other phases, for example, first quarter, third quarter, and new Moon. Use the terminology introduced in Experience 4.3 when requesting a particular phase, such as waning gibbous and third quarter.

FIGURE 4.17

A diagram of the Moon phases in relation to the Sun and Earth



The inner sequence shows the Moon's relative position to the Earth and the Sun as viewed from outer space, above the solar system. Students are asked to produce a portion of this diagram on the "Moon Phase Activity Sheet." The outer sequence shows the Moon as seen from Earth. For example, you would see the waning crescent (lower right) as a small slice of the Moon illuminated on the left side. A waxing crescent, upper right, would have the right side of the Moon illuminated.

10. Allow time for students to experiment with the movement of the Moon—always moving it in a counterclockwise direction around the Earth. They can observe their own model as well as other students' models. This activity is very powerful and can answer many questions that the students generate about the motion of the Moon and its appearance in the sky.

    Teacher note: Students may find it helpful to change the model slightly to answer certain questions. If one student holds the Moon ball and another student is Earth, they can more easily see Earth spinning on its axis while the Moon is barely moving in its orbit. How much of a circle does the Moon travel each 24 hours? (*About 1/29th or 1/30th of a circle.*) So everyone on Earth basically sees the same phase on the same night.

11. Now have students work together in small groups as they each complete the "Moon Phases Activity Sheet." The goal is for them to produce a diagram similar to the one in Figure 4.17. These drawings should be kept in their astronomy lab notebooks.

12. After completing the diagrams, ask students to write down in their astronomy lab notebook the causes of the changing Moon phases. (*The movement of the Moon around Earth and the relative positions of the Sun, Earth, and Moon cause the phases. The spinning Earth—the student's head—makes the Moon rise and set each day, but this does not affect the phase of the Moon.*) Encourage them to use diagrams in their explanations.

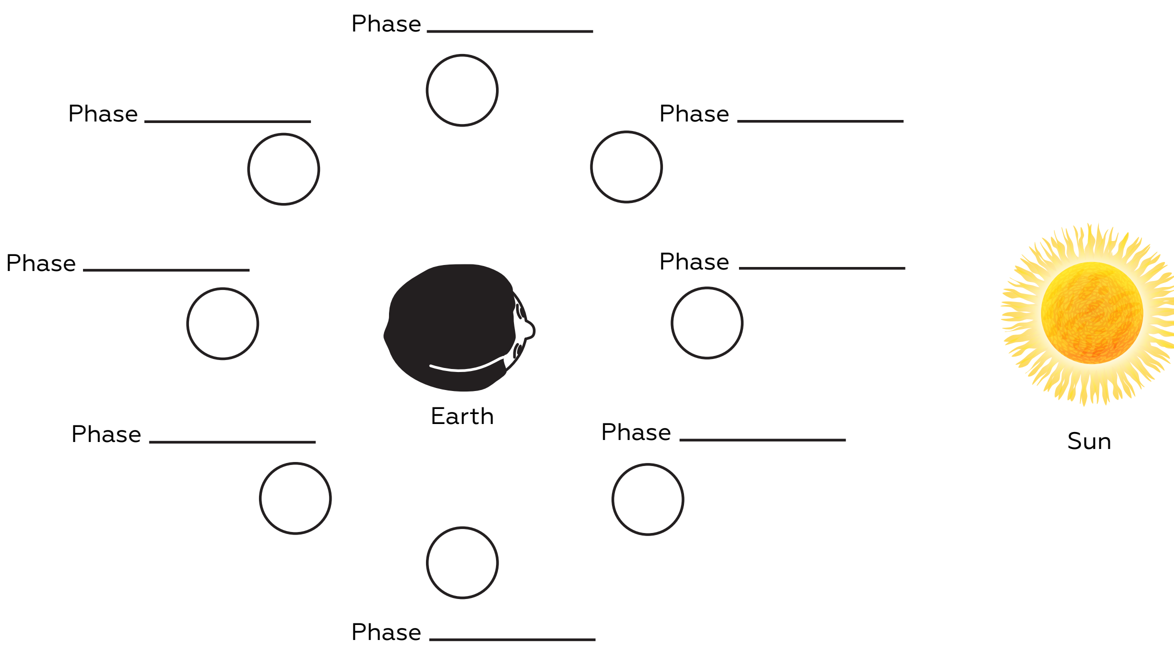
13. Check student diagrams and explanations for the causes of phases. Ask students if they are sure that their observations and the model support their diagrams and statements. If discrepancies arise, have students go back to the model to further clarify the concepts.

    Teacher note: If you have not already used the first *evaluate* experience (Experience 4.10, "Lunar Phases Revisited"), now is a good time to do Experience 4.10 to assess student understanding of lunar phases.

Moon Phase Activity Sheet

This diagram represents a view you would see looking down from above at your head when you are modeling the Moon orbiting Earth. Darken the areas on each Moon that are not illuminated by the Sun. Then label each Moon phase as you would see it when your nose (on Earth) is pointed directly at it.

Be sure to use the Moon phase terms: new Moon, full Moon, first quarter, third quarter, waxing crescent, waning crescent, waxing gibbous, and waning gibbous.



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