INSTRUCTOR'S MANUAL

21st Century Astronomy

FIFTH EDITION

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BEN SUGERMAN

Goucher College

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PART I:

Instructor's Manual

CHAPTER 1

Thinking Like an Astronomer

INSTRUCTOR'S NOTES

Chapter 1 is an introduction to the measures and methods of astronomy. Major topics include

- our cosmic address; that is, the hierarchy of structures from solar systems to superclusters
- an intuitive scale of the universe
- relevant and relative distance scales, including the light-year and light-travel time
- the scientific method and relevant vocabulary; that is, distinguishing *theory* from *idea*
- reading graphs and using trends or patterns to understand data

Greetings, fellow professors! Whether you are using this textbook to teach a one semester or a yearlong astronomy course, to teach nonscience majors for general education credit, or to teach prospective physics and astronomy majors, you have an auspicious and audacious task ahead of you: to teach the whole universe, from the unimaginably small to the incomprehensibly large. As Dr. Mike Seeds of Franklin & Marshall College explains, "The Universe is very big, but it is described by a small set of rules and . . . we have found a way to figure out the rules—a method called science." It is my hope that I can share in these "Instructor's Notes" some successes and failures, tips and traps, in teaching this material to a diverse audience.

At the beginning of every course, I provide to students an anonymous survey in which I ask them to rate their comfort and previous experiences with math and science, and a majority usually report that they consider themselves to be bad at math and afraid of science. Over nearly two decades of interacting with introductory astronomy students, I have found that they report a few common themes. First, they think that physics and astronomy are only about doing math problems, and second, much of their discomfort comes from previous experiences in which they were assumed already to be well versed in the vocabulary of science. Much as I do in my first lessons, this chapter aims to ease students into the astronomy curriculum by addressing both of those issues.

Astronomy deals with numbers that span the gamut from the subatomic to the whole universe. I may be quite comfortable discussing wavelengths in nanometers, particle densities in atoms per cubic centimeters, masses in 10^{30} kilograms, and distances in gigaparsecs, but I find it useful to conduct exercises with Figures 1.1 and 1.3 or show a version of the "Powers of Ten" montages to provide students with some visual context for the ranges of size, mass, speed, and time that are discussed in this course. Much of the quantitative problem solving in this course can be achieved through proportional reasoning (that is, how does brightness change if distance triples?), so in addition to asking questions about scientific notation and unit conversion, I introduce some basic ideas of how area or volume changes with size.

For many of my students, this is the last formal science course they will ever take, so one of my learning outcomes is that they learn the process of science, gain scientific literacy, and understand the difference between science and pseudoscience. The seeds of these outcomes are sown in this first chapter through discussion of the scientific method and of the various logical fallacies presented in the Exploration section. Although science is ideally independent of culture or creed, it has often collided with religious or other strongly held beliefs. Therefore, because science is a human activity carried out by individuals who may hold nonscientific beliefs, I emphasize that we must construct safeguards within our work to counteract any personal bias that might taint their results. Thus, science is all about searching for objective truths that lead to conclusions that are repeatedly found to be unfalsifiable.

DISCUSSION POINTS

- Have students look at the sketches shown in Figures 1.1 and 1.3. Ask them if they are familiar with any of the shapes and structures shown. Where have they encountered them before?
- Have students think about the times given in Figure 1.3. Discuss the distances and times between our planet and nearby stars, and relate that to the likelihood that we will communicate with extraterrestrials in our lifetime

(remind students that we have only been broadcasting and listening for 60 to 70 years).

- Astronomers need to keep collecting data from the objects in the universe to find unexpected trends and to test new and old hypotheses. Discuss how this process has analogies in students' own experiences. Have they ever had to collect data to learn something or to explore the unknown? One possible exercise is to have students compare their course grades with the amount of time they spend using a professor's office hours as a gentle but realistic way to compare their actual and desired performance.
- Why do scientists adhere to the principle known as Occam's razor? Is that principle an objective truth? Discuss examples of applications of Occam's razor and examples of objective truths.
- Ask students if they are familiar with any scientific equations. Discuss differences and similarities between a well-known scientific equation and a world-renowned work of art.
- Discuss how the reclassification of Pluto as a dwarf planet rather than as a major planet makes sense in light of current scientific evidence and our understanding of the Solar System. Why did the case of Pluto create so much emotional turmoil among astronomers and the public? Is the final result of the voting at the meeting of the International Astronomical Union (IAU) in Prague representative of the majority of the astronomical community? It may be useful to have students investigate the biological reclassification of the duck-billed platypus as a parallel example that did not stir such emotional responses.

NEBRASKA SIMULATIONS

Developed at the University of Nebraska–Lincoln, these Interactive Simulations enable students to manipulate variables and work toward understanding physical concepts presented in Chapter 1. All simulations are available on the free Student Site (digital.wwnorton.com/Astro5), and offline versions can be found on the USB drive.

Look-Back Time Simulator

The Look-Back Time Simulator shows the finite speed of light and how the great distances to most astronomical objects cause us to observe things as they were in the past. This simulation is very useful when developing both the scale of the universe and an intuitive understanding that distant objects allow us to look back in time.
Text reference: Section 1.1

END-OF-CHAPTER SOLUTIONS

Check Your Understanding

1. Radius of Earth–light-minute–distance from Earth to Sun–light-hour–radius of Solar System–light-year. Use Figure 1.3
2. (b) Theories must be testable, and a theory is valid up until a test fails.
3. (c) Patterns and order are indicative of a physical process at play.

Reading Astronomy News

1. Enceladus is 310 miles across, according to the article. The moon's diameter is about 2160 miles, or roughly seven times bigger. According to Google Maps, the distance from Chicago to St. Louis is about 260 miles, or about 50 miles less than the size of Enceladus. The distance from Santa Cruz to Los Angeles is about 290 miles, or about 20 miles less than this moon's diameter. The ocean is hypothesized to be about 6 miles deep and about the size of Lake Superior (about 160 miles wide, according to Wikipedia).
2. The original discovery of geysers on Enceladus was from an observation (image).
3. Scientists made this new discovery by observing both geysers *and* subtle Doppler shifts in the radio signals from the satellite. They did not directly observe water but concluded the presence of an ocean based on the terrain of the moon, the presence of geysers, and the possible sources of inhomogeneity in the moon's internal structure.
4. Two key parts of the scientific process are that the hypothesis be testable and that tests be repeatable. Implicit in these is the need for multiple and independent tests and confirmations.
5. Life, as we know it, is dependent on the presence of a solvent such as water. Also, the presence of liquid water suggests warm temperatures for life-forms to grow and thrive.

Test Your Understanding

1. f, e, c, b, a, g, d is the correct order from smallest to largest size.
2. (a) See Figure 1.3.
3. (b) Note that one must accumulate facts (a) to consider how they are related, and that science makes predictions based on these relationships (d), but "understanding" is the development of these relationships.

4. (a) The universe is understood to be homogeneous and isotropic on its largest scales.
5. (d) The Sun is the center of our Solar System, just one of the billions of stars in our galaxy, and one of the billions of galaxies in the universe.
6. (a) It is the distance that light travels in one year.
7. (c) Occam's razor suggests that nature relies on the simplest (or most straightforward) processes.
8. (d) Distance units in terms of light speed are very convenient but sometimes odd to think about at first because we seem to be using *time* to refer to distance. This problem shows us two ways of considering the meaning of light distance.
9. (d) A reading of the plot 1.12c shows that at time step 10, the number is about 1000 whereas four orange dots to the left, it is under 100; therefore, it went up by a factor of more than 10 times.
10. (d) As the answer indicates, science relates only to the natural world.
11. (c) Our understanding must be tested and, at any time, a test could show that it is wrong. Note that this is not an issue of being worthless or incomplete, but merely reflects the fact that we are constantly testing our theories and hypotheses.
12. (c) Light travels a light-year in one year, so a star that is 10 light-years away emitted its light 10 years ago for us to see it today.
13. (d) Carbon is made inside stars.
14. (b) Except for hydrogen and helium (and a tiny bit of lithium), all the elements found on Earth were produced in stars. Note that the beryllium produced in the Big Bang was unstable and decayed long before the Earth formed.
15. b, d, a, c, e. The material for the Sun had to come before the Sun could be formed. Gas came first (b), then formed stars to make heavier elements (d), then the stars blew up to spread those elements around (a), then the gas had to collect (c) before it could form the Sun and the planets (e).

Thinking about the Concepts

16. Tau Ceti e, Tau, Ceti Milky Way Galaxy, Local Group, Laniakea Supercluster.
17. The cosmological principle essentially states that every observer in the universe should find that the natural laws governing his or her local region are representative of the natural laws governing the universe as a whole. Consequently, he or she should derive the same natural laws that an observer on Earth derives.
18. 8.5 minutes.
19. Andromeda is about 2.3 million light-years away, so it would take 2.3 million years.
20. Answers will vary. An example is General Relativity superseding Newtonian mechanics, which began at the first step of the Process of Science when Einstein thought about gravity and spacetime.
21. This is a pseudoscientific theory because it is not falsifiable. Although it is possible that we may someday stumble upon irrefutable evidence that aliens visited Earth in the remote past, the absence of evidence today cannot be used to refute the hypothesis. In fact, proponents of the theory will simply argue that we just have not found any evidence yet. Evidence that could support the theory would include finding advanced technology in ancient archaeological sites or buried in old geological layers. The only tests I can think of to refute the hypothesis are: (1) to demonstrate that every piece of technology and archaeological monument could have been reasonably constructed with human knowledge of the time; or (2) to invent a time machine and return to the most likely times for aliens to have visited Earth. Because option 2 is utterly implausible, and because option 1 does not preclude alien visitations, it is impossible to falsify the hypothesis.
22. *Falsifiable* means that something can be tested and shown to be false/incorrect through an experiment or observation. Some examples of nonfalsifiable ideas might include emotional statements (such as "love conquers all"), and opinions (such as "coffee is better than tea"). Students may have a wide variety of these and other ideas, but all sacred cows are usually considered to be nonfalsifiable by the people holding those beliefs. Falsifiable ideas include cause and effect (coffee puts hair on your chest) and logic (if I drink coffee, I will not sleep tonight).
23. A "theory" is generally understood to mean an idea a person has, whether there is any proof, evidence, or way to test it. A "scientific theory" is an explanation for an occurrence in nature; it must be based on observations and data and make testable predictions.
24. A *hypothesis* is an idea that might explain some physical occurrence. A *theory* is a hypothesis that has been rigorously tested.
25. (a) Yes, this is falsifiable. (b) Find a sample of a few hundred children born during different moon phases who come from similar backgrounds and go to similar schools, and follow their progress for a number of years.

26. In 1945, our distance-measuring methods were not correctly calibrated and, as a result, our distance to Andromeda was wrong. As we improved that calibration, we found different and more reliable measurements of its distance. In science, statements of "fact" reflect our current best understanding of the natural universe. A scientific "fact" does not imply that science has determined absolute truth; rather, it is simply a statement that this is the best understanding of nature that our current knowledge and technology supports. Over time, all scientific "facts" evolve as our knowledge base and technology grow.
27. Answers will vary. Depending upon the generality of the horoscopes, students may provide a wide array of answers for this question. For general statements, students might find that several, if not all, of the horoscopes on a given day could describe their experience. For a very specific horoscope, we expect that it should match approximately one-twelfth of the students regardless of their astrological sign. In any event, if astrology accurately reflected some natural truth, we would expect nearly everyone to find one and only one horoscope each day that describes his or her experience, that the horoscope would match the person's astrological sign, and that the daily horoscope would be accurate for each person for the entire week of record keeping. Students should perform this experiment and be honest with themselves about the results.
28. Taken at face value, this is a ridiculous statement, but there are several items to consider critically before we apply a label of "nonreputable." First, was this statement a sound byte taken out of context? Did the scientist simply misspeak when he or she might have been trying to say that we have not yet found extraterrestrial life? If, in fact, the statement can be taken at face value, then the credibility of the scientist might be called into question because he or she has forgotten that absolute truth is not falsifiable (and therefore not scientific) by definition.
29. Some scientific fields rely heavily on math, whereas others hardly use it at all. The use of mathematics is not the hallmark of good science. Rather, it is following the scientific method, which astrology does not employ.
30. Only hydrogen and helium (with perhaps a trace amount of lithium) were created in the Big Bang. Heavier elements such as carbon, oxygen, nitrogen, and iron are manufactured in the interiors of massive stars. At least one generation (and more likely several generations) of stars must die in massive supernova explosions to make heavy elements available to construct planets and the building blocks for life. Therefore, because all the heavy elements in our bodies were originally manufactured in stars, it is fair to claim that we are truly made of stardust.

Applying the Concepts

31. Setup: Remember that to convert to scientific notation, count up all the digits to the right of the first one if the number is greater than 1, or the number of digits between the decimal point and the first nonzero digit if it is less than 1.
    Solve: (a) 7×10^9. (b) 3.46×10^{-3}. (c) 1.238×10^3.
    Review: A good way to check is to use a scientific calculator, where "times 10 to the" is usually the "EE" key.
32. Setup: To convert scientific to standard notation, move the decimal point the number of digits indicated in the exponent, to the right if the number is positive, and left if negative.
    Solve: (a) 534,000,000. (b) 4,100. (c) 0.0000624.
    Review: Again, you can test this by using your calculator.
33. Setup: Distance is given in terms of speed and time by $d = vt$, where v is speed and t is time. If speed is in km/h, then use time in hours, for which we may have to convert. Remember there are 60 minutes in an hour.
    Solve: (a) $d = vt = 35\frac{\text{km}}{\text{h}} \times 1\,\text{h} = 35\,\text{km}$.
    (b) $d = vt = 35\frac{\text{km}}{\text{h}} \times \frac{1}{2}\text{h} = 17.5\,\text{km}$.
    (c) $d = vt = 35\frac{\text{km}}{\text{h}} \times \frac{1}{60}\text{h} = 0.58\,\text{km}$.
    Review: A good sanity check is to make sure the distance traveled is smaller if the time traveled decreases.
34. Setup: We are given the relationship surface area A is proportional to radius r squared or $A \propto r^2$. To work a proportional-reasoning problem, insert the factor by which one variable changes into the formula to see how the result changes.
    Solve: (a) If r doubles, then $r \rightarrow 2r$, or r changes by a factor of 2. Putting this in our formula shows $A \propto 2^2 = 4$, or the area changes by a factor of 4. (b) If r triples, then it changes by a factor of 3, or $A \propto 3^2 = 9$. (c) If r is halved, then $r \rightarrow \frac{1}{2}r$, or r changes by a factor of $\frac{1}{2}$ therefore $A \propto \left(\frac{1}{2}\right)^2 = \frac{1}{4}$. (d) If r is divided by 3, then $A \propto \left(\frac{1}{3}\right)^2 = \frac{1}{9}$.

Review: Note first that the change in area is much larger than the change in radius, which reflects the dependence on size squared. Note also how easy it is to do proportional reasoning rather than using the full surface-area formula ($A = 4\pi r^2$), when all we need to know is how much the result changes.

35. Setup: In this problem, we convert among distance, rate, and time with $d = vt$, or solving for time, $t = d/v$. The problem is straightforward because the units of distance are already the same.

Solve: $t = \frac{d}{v} = \frac{384{,}000 \text{ km}}{800 \text{ km/hr}} = 480 \text{ hr}$. There are 24 hours in a day, so this would take

$480 \text{ hr} \times \frac{\text{day}}{24 \text{ hr}} \times 20$ day, or about two-thirds of a month (a typical month is 30 days).

Review: A typical flight from New York to London takes about 7 hours and covers a distance of about 6,000 km. The moon is 64 times farther away so it would take about $64 \times 7 = 448$ hours to reach the Moon using these estimates. This is about the same amount of time as we found by exactly solving the problem.

36. Setup: In this problem, we will convert between distance, rate, and time with $d = vt$ or, solving for speed, $v = d/t$. The problem is straightforward because the units of distance are already the same.

Solve: $v = \frac{d}{t} = \frac{384{,}000 \text{ km}}{3 \text{ days}} \times \frac{\text{day}}{24 \text{ h}} = 5{,}333 \text{ km/h}$.

This is about $\frac{5{,}333}{800} \approx 6.7$ times faster than a jet plane.

Review: Using the result from problem 35, we have to travel $120/3 \approx 6.7$ times faster than a jet plane, which agrees with our solution.

37. Setup: We are given the problem in relative units, so we don't need to use our speed equation or use the actual speed of light. Instead, we will use ratios.

Solve: (a) If light takes 8 minutes to reach Earth, then it takes $8 \times 2 = 16$ minutes to go twice as far. Neptune is 30 times farther than the Sun, so light takes $8 \times 30 = 240$ minutes, or $240/60 = 4$ hours. (b) This means that sharing two sentences will take half a day, so it would take a few days just to say hello and talk about the weather.

Review: If you watch *2001: A Space Odyssey*, you will note that the televised interview between Earth and David Bowman had to be conducted over many hours and then edited for time delays. This was factually correct. Because Pluto is much farther than Jupiter, it stands to reason that it would take light and communication a lot longer still!

38. Setup: Light travels at 3×10^5 m/s.

To find the travel time, use $d = vt$ or $t = \frac{d}{v}$.

Solve: $t = \frac{d}{v} = \frac{56 \times 10^6 \text{ km}}{3 \times 10^5 \text{ km/s}} = 187\text{s}$.

Likewise using 400×10^6 km, $t = 1330$ s.

Review: Light takes about 8.3 min to travel from the sun to Earth, or about 500 sec. Our numbers are consistent with this duration.

39. Setup: We are given the relationship surface area $A \propto r^2$. To work a proportional-reasoning problem, insert the factor by which one variable changes into the formula to see how the result changes.

Solve: If the Moon's radius is one-fourth that of Earth, then its surface area is $A \propto \left(\frac{1}{4}\right)^2 = \frac{1}{16}$ the area of Earth.

Review: We saw this same behavior in problem 34.

40. Setup: Note that 3.6×10^4 km is 3.6×10^7 m. We will use the equation $d = vt$, where the distance is $2 \cdot 3.6 \times 10^7$ m and light travels at $v = c = 3 \times 10^8$ m/s.

Solve: $t = \frac{d}{c} = \frac{2 \cdot 3.6 \times 10^7 \text{ m}}{3 \times 10^8 \text{ m/s}} = 0.24$ sec or about $\frac{1}{4}$ a second.

Review: If we are receiving information by Internet satellite on a regular basis, we almost never notice a lag so the time has to be short, on the order of what we found (much less than 1 second).

41. Setup: Let the horizontal axis be time and vertical be population. If we choose to plot a graph in linear space, then a constant population will be a horizontal line, whereas an exponential growth will look similar to Figure 1.7, and a crash will be almost vertical.

Solve: Answers will vary. Here is one example in which the baseline population is "1" unit.

Review: Note how the growth starts out very slowly, jumps up very rapidly, and takes a nosedive down. This is what the text described.

42. Setup: We need our assumptions of speed. Assume a car goes 70 miles per hour if we include filling up with gas, eating, and restroom breaks. On foot, a person walks about 2 miles per hour with these same stops. We also need to relate distance, rate, and time with the formula distance equals rate times time, or $d = vt$.

Solve: Solving for time, $t = d/v$, so by car, $t = 2{,}444 \text{ miles}/70 \text{ mph} = 34.9$ hours. Because there are 24 hours in a day, the car takes $34.9/24 = 1.45$ days.

Note these assume you travel around the clock, which we do not usually do!

Review: If you drive "almost" non-stop, you can go from NY to LA in 3 days. This is consistent with our value, because that assumed no stops at all. There are 30 days in a month, so this is 51/30 = 1.70 foot-months. There are 12 months in a year, so this would take 1.70/12 = 0.14 foot-years.

43. Setup: For water to freeze, it has to cool down to 0°C; then the liquid has to become solid.

Solve: (a) This theory makes no sense to me because hot water will have to cool down much more (and therefore take much more time) than cold water once in the freezer. (b) Yes, this is easily testable. Simply try it in your dorm or room fridge (they all have little ice cube areas at the top). (c) I tried it, and it took about five times longer for the hot water to freeze, confirming my hypothesis.

Review: Going back to our original physical reasoning, we see that this theory could be easily refuted without experimentation. Sometimes it is not as straightforward, and the experiments must be performed.

44. Setup: On the surface, it seems that the two pizzas cost the same number of dollars per inch; but remember that each pizza is a circle so we eat the volume, not the diameter.

Solve: If both pizzas have the same thickness, then we only need to worry about area $A = \pi r^2$; so this means area goes as size squared. That is, the 18-inch pizza is four times larger than the 9-inch one. But the 18-inch pizza costs only twice as much, so it is more economical to buy the larger one.

Review: Often, larger items cost less per unit than smaller ones because almost the same amount of labor went into making them, and labor is generally the highest part of the cost. This is why you should always check the unit price when buying things.

45. Setup: For part (a), use the formula given. For part (b), we need to relate distance, speed, and time by $d = vt$, where we will solve for time. We use the formula again for part (c), where we must remember there are 24 hours in one day.

$C = 2\pi r = 2\pi \times 1.5 \times 10^8$ km $= 9.4 \times 10^8$ km. Now,

solve: $v = d/t = \dfrac{9.4 \times 10^8 \text{ km}}{8{,}766 \text{ hr}} = 1.075 \times 10^5 \text{ km/hr}$,

or 107,500 km/hr. (c) Because $d = vt$, and there are 24 hours in one day, the Earth moves about 258,000 km per day.

Review: It is amazing that we are hurtling around the Sun at more than 100,000 km/hr and do not even realize it! Why? Because everything else (planets, the Sun, stars) is so far away that we have no reference point to observe this breakneck speed.

Using the Web

46. Pluto is about the size of the United States. So is the Moon. Venus is a little smaller than Earth, and Sirius B is a little larger. Many stars are larger than the Sun-Earth distance, including Enif, Deneb, R Doradus, Pistol Star, Antares, etc. Voyager 1 is about 0.002 light-year or about ¾ of a light-day away. The Cat's Eye nebula, Gomez's Hamburger, the width of the Hourglass Nebula, and the height of the Blinking Nebula are about the size of the distance to the nearest star. The Milky Way is about 10^{21} meters across, and the Solar System is about 10^{14} meters (Sun to Sedna), so the Milky Way is about 10 million times larger; if a student only measures the Neptune or the Kuiper Belt, the Milky Way is about 100 million times larger. The Local Group is about 100 times larger than the Milky Way. The observable universe is about 10,000 times larger than the Local Group.

47. (a) Answers will vary. You should discuss whether the video was effective for showing the size and scale of the universe. I found this video useful but it starts a little large because I still have to think about my size in terms of the mountains. (b) Answers will vary. You should discuss whether the video was effective for understanding the size and scale of the universe. I found this video quite useful for understanding the extreme variations in scale between the atomic and entirety of the visible cosmos.

48. Answers will vary. A response will include where the image was taken, how it was made, what it shows, where that object is located, whether the explanation given makes sense to you, and whether you feel this website is useful to those who are interested in astronomy.

49. Answers will vary. You should present an article about space or astronomy, and note whether the news site or paper has a separate science section. You should also note whether this is a press release, interview, or report on a recent article. Report on how widespread the coverage is, including whether other papers picked up the news nationally and internationally, and in blogs. Comment on whether you think the story was interesting enough to cover.

50. Answers will vary. Report your reading of a science or astronomy blog. Present who the blogger is and his or her background, the topic of interest, whether it is controversial, what kinds of feedback or reader comments are present, and whether the post was interesting or engaging enough for you to read further posts on this blog. Be warned: many blogs sound authoritative but are not written by experts. So be sure to verify the credentials of the author.

Exploration

1. This is an example of *post hoc ergo propter hoc*, in which we assume that the chain mail caused the car accident.
2. This is a slippery slope, because I am assuming that my performance on the first event must influence the next.
3. This is a biased sample, or small-number statistics, because I assume that my small circle of friends represents everyone.
4. This is an appeal to belief in which I argue that because most people believe it, it must be true.
5. By attacking the professor rather than the theory, I am committing an *ad hominem* fallacy.
6. This is an example of begging the question (a bit of a syllogism, too) in which the proof of my assertion comes from another of my own assertions.

CHAPTER 2

Patterns in the Sky—Motions of the Earth and Moon

INSTRUCTOR'S NOTES

Chapter 2 covers the causes and effects of the (apparent) motions of the stars, Sun, and Moon in our sky. Major topics include

- the celestial sphere
- the daily and yearly paths and motions of stars in our sky
- Earth's axial tilt as the cause of the seasons
- Moon phases
- solar and lunar eclipses

Many students come into our classes believing that Earth's shadows cause Moon phases and that summer happens because Earth is closer to the Sun. There is a video from the late 1980s called "A Private Universe" that shows school children trying to learn the real causes of the seasons and the phases of the Moon. After a full lesson, most of the students have incorporated these original misconceptions into the actual reasons to make new, but still incorrect, explanations. The video then goes to Harvard University and asks graduating seniors and faculty the same questions, and only a physics professor answers both correctly. The point is not to humiliate any of them but to highlight that: (1) it is very hard to unravel a misconception and replace it with a correct model; and (2) a very large number of people carry around incorrect explanations of the regular rhythms of our world.

Two of my own measures for the success of my introductory astronomy course are, first, whether students can correctly explain the causes for the daily and annual changes that occur around them, and second, whether they can use the processes of scientific thought to assess critically the likelihood of their own reasoning or model to explain a phenomenon. With that in mind, I spend about 2 weeks on this chapter because I find it so critical in addressing these two goals. In particular, I like to start by asking students to give me their explanations for these two phenomena, so that I can also focus on guiding them to examine why initially incorrect reasoning is flawed. I often tell my students that understanding why the *wrong* explanations are wrong is an important (if not *the most* important) part of the process of science.

There is, of course, much more in this chapter than just the causes of the Moon phases and the seasons. During these lessons, many of my students discover that they never consciously noticed that days are longer or that the Sun is higher in the sky during summer than winter; that stars move across our sky on angled paths rather than going from due east to the zenith to due west; or that the Moon can be visible during the day. To flush all this out, I spend the first full class having them just learn to describe the positions of objects in the sky. The next class is devoted to how objects at different positions in the sky move across it. We then spend one class on the paths the Sun takes through the sky at different times of year. The next class is spent unraveling all the wrong reasons commonly assumed as causing the seasons. I spend two classes on Moon phases—first on the causes and then on relating phase, position in the sky, and time of day. This slower pace allows students the time to ensure that they can explain to one another both why the right models are correct *and* why the wrong models are incorrect. Plus, out of everything that students will learn in the whole course that can be of practical use for the rest of their lives, I find the contents of this chapter are most relevant. I cover later chapters at a faster pace (roughly one class period once we are done with laws of physics) because by then, students have gained experience thinking "scientifically."

As one final piece of advice, I encourage students to take full advantage of the animations and simulations in this chapter. They are excellent examples of supplementary material to help students master these confusing but critical concepts outside of class.

DISCUSSION POINTS

- During winter in the Northern Hemisphere, Earth is closer to the Sun than at any other time of the year. Have students explain why the changing Earth–Sun distance has no bearing on Earth's seasons.

- Use Figure 2.20 to show why Earth's shadow does not cause the phases of the Moon. Use the same figure to explain why we can sometimes see the Moon during the day.
- Apply the dependence of the perspective on the sky shown in Figure 2.7 to the location of the classroom. Engage students coming from other countries or states to discuss the perspective on the sky from their birthplaces. Make them realize that these perspectives are similar for places with similar latitudes even though they may be very far apart because the perspective does not change with longitude. What are the consequences of similar perspectives of the sky on the perception of the seasons in different places? What are the differences in regions with different latitudes? Discuss how it all depends on the altitude of the Sun.
- To stress the cultural aspect of astronomy over the course of human history, ask students to think about why the constellations have the names they do. How did Egyptian cultures view the sky compared to Greek and Roman cultures?
- To help students become more comfortable with the mathematical ideas involved in astronomy, investigate Working It Out 2.1 with them. The geometric and algebraic practice will be beneficial. Have them convert Earth's radius to miles, and compare that to other lengths such as the distance between London and New York City or between New York City and Los Angeles.
- To familiarize students with the night sky, discuss how to identify Polaris (the North Star) from the position of the classroom. Many students are surprised when they realize that Polaris is not that bright in comparison to other stars—its position is its most important attribute. Utilize the fact that the altitude of Polaris is equal to the latitude of the classroom. Have students identify a way to locate the South Celestial Pole using a celestial globe or map.
- Ask students to think about how the alignments of the Sun, Moon, and Earth would change the frequency or nature of solar and lunar eclipses. What if the Moon were twice as far away from Earth? Twice as close? What if the Sun were moved in those different positions, with or without the Moon being moved as well? What if the Moon's orbit were inclined more or less to the ecliptic? How would things change if the Moon moved more slowly in its orbit?

ASTROTOUR ANIMATIONS

The following AstroTour animations are referenced in Chapter 2 and are available from the free Student Site (digital.wwnorton.com/Astro5). These animations are also integrated into assignable Smartwork5 online homework exercises.

Earth Spins and Revolves

This animation shows Earth as it is positioned with respect to the Sun, including motion along its orbit, spin axis tilt, and discussion of the causes for the seasonal variation in climate in terms of latitude and angle of incident sunlight.
Text reference: Sections 2.1

The View from the Poles

This animation shows how Earth's rotation corresponds to the movement of the stars in the sky and the rotation of the stars around Polaris, which is very nearly at the north celestial pole. It also explores the precession of Earth's rotation, including how the movement of the stars will look when Polaris is no longer the North Star.
Text Reference: Section 2.1

The Celestial Sphere and the Ecliptic

This animation shows side-by-side perspectives of: (1) the view of the sky (day and night) from a backyard; and (2) an "outside" view of Earth embedded in a concentric celestial sphere. The point of view moves with Earth as it rotates on its axis. The content of the animation focuses on the ecliptic, showing the motion of the Sun, Moon, and constellations in relation to one another.
Text Reference: Section 2.1

The Moon's Orbit: Eclipses and Phases

This interactive animation explores the Earth-Moon-Sun system, building on the elements of two previous animations ("The Earth Spins and Revolves" and "The Celestial Sphere and the Ecliptic"). It shows a changing point of view from the size scale of Earth's orbit down to the size scale of the Moon's orbit, followed by emphasis on the Moon's orbit to distinguish the concept of an eclipse versus a phase, and shows the relative configurations of Earth, Moon, and Sun.
Text reference: Section 2.3

NEBRASKA SIMULATIONS

Developed at the University of Nebraska–Lincoln, these Interactive Simulations enable students to manipulate variables and work toward understanding physical concepts presented in Chapter 2. All simulations are available on the free Student Site (digital.wwnorton.com/Astro5), and offline versions can be found on the USB drive.

Celestial and Horizon Systems Comparison

This simulation demonstrates how the celestial sphere and horizon diagram are related.
Text reference: Section 2.1

Rotating Sky Explorer

This simulation demonstrates how rotation of the Earth leads to apparent rotation of the sky and how the celestial sphere and horizon are related.
Text reference: Section 2.1

Meridional Altitude Simulator

This simulation shows helpful diagrams for finding the meridional (or maximum) altitude of an object.
Text reference: Section 2.1

Declination Ranges Simulator

This simulation shows how an observer's latitude determines the circumpolar, rise-and-set, and never-rise regions of the sky.
Text reference: Section 2.1

Big Dipper Clock

This simulation shows how stars rotate about the North Star over time. Both daily and seasonal motions are shown.
Text reference: Section 2.1

Big Dipper 3D

This simulation demonstrates how the stars of the Big Dipper, which are at various distances from the Earth, project onto the celestial sphere to give the familiar shape.
Text reference: Section 2.1

Coordinate Systems Comparison

This simulation shows how the rotation of the Earth leads to the apparent rotation of the sky and associated phenomena during the day.
Text reference: Section 2.1

Ecliptic (Zodiac) Simulator

This simulation shows the position of the Sun in the zodiac in different months of the year.
Text reference: Section 2.2

Seasons and Ecliptic Simulator

This simulation uses the geometry of the Earth as it goes around the Sun to demonstrate why seasons occur.
Text reference: Section 2.2

Sun's Rays Simulator

This simulation shows the angles at which the Sun's rays hit different parts of Earth at different times of the year.
Text reference: Section 2.2

Paths of the Sun

This simulation shows how the declination of the Sun varies over the course of a year using a horizon diagram.
Text reference: Section 2.2

Sun Motions Overview

This simulation shows the paths of the Sun on the celestial sphere.
Text reference: Section 2.2

Daylight Hours Explorer

This simulation shows the hours of daylight received during the year for an observer at a given latitude. This is an important factor contributing to the seasons.
Text reference: Section 2.2

Union Seasons Demonstrator

This simulation demonstrates the changing declination of the Sun with a time-lapse movie, which shows how the shadow of a building changes over the course of the year.
Text reference: Section 2.2

Daylight Simulator

This simulation shows daylight and nighttime regions on a flat map of the Earth. Daily and yearly motions of the sunlight pattern can be shown.
Text reference: Section 2.2

Lunar Phase Vocabulary

This simulation shows the appearance of the Moon at each of the named phases.
Text reference: Section 2.3

Basketball Phases Simulator

This simulation shows an illuminated basketball that can be viewed from multiple directions, providing an analogy to the Moon phases.
Text reference: Section 2.3

Three views simulator

this simulation shows how the phase of the Moon depends on the viewing geometry by allowing the Moon to be viewed from the Earth, the Sun, and an arbitrary point in space.
Text reference: Section 2.3

Lunar Phases Simulator

This simulation demonstrates the correspondence between the Moon's position in its orbit and its position in an observer's sky at different times of day.
Text reference: Section 2.3

Moon Phases And The Horizon Diagram

This simulation correlates the phases of the Moon with its positions in the sky.
Text reference: Section 2.3

Moon Phases with Bisectors

This simulation demonstrates a method for determining Moon phases using planes that bisect the Earth and Moon.
Text reference: Section 2.3

Phase Positions Demonstrator

This simulation demonstrates how planet and moon phases depend on orbital geometry. Users can drag two bodies around to see how the observed appearances change.
Text reference: Section 2.3

Lunar Phase Quizzer

This simulation shows the standard orbital view of the moon but with the option to hide the moon's phase, the moon's position, or the sun's direction.
Text reference: Section 2.3

Synodic Lag

This simulation demonstrates the difference between a sidereal and synodic (solar) day, which arises from the Earth's revolution around the sun.
Text reference: Section 2.4

Moon Inclinations

This simulation demonstrates how the inclination of the moon's orbit precludes eclipses most of the time, leading to distinct eclipse seasons.
Text reference: Section 2.5

Eclipse Shadow Simulator

This simulation shows the shadows cast by the Moon and Earth due to the Sun and how they can produce the visual effect of an eclipse.
Text reference: Section 2.5

Eclipse Table

This image consists of a table of solar and lunar eclipses, showing the banding that represents eclipse seasons that occur about twice a year.
Text reference: Section 2.5

Obliquity Simulator

This simulation shows how obliquity, or tilt of the planet's axis, is defined.
Text reference: Section 2.5

ASTRONOMY IN ACTION VIDEOS

These videos are a mixture of live demos and mini lectures, enabling students to prepare for class or review what they have learned. All videos are available on the free Student Site (digital.wwnorton.com/Astro5) and offline versions can be found on the USB drive. Assignable assessment questions can be found in Smartwork5 and the Coursepack.

The Celestial Sphere

This video presents the vocabulary of the celestial sphere. The instruction includes how to use an orange and basketball to visualize many of the important features of the celestial sphere.
Text reference: Section 2.1

The Cause of the Earth's Seasons

This video explains the causes for the seasons. Dr. Palen uses a bundle of spaghetti noodles (uncooked, of course) to show the difference between direct and indirect sunlight.
Text reference: Section 2.2

The Earth-Moon-Sun System

Three students act out the relevant motions of the Earth-Sun-Moon system in space.
Text reference: Section 2.2

The Phases of the Moon

Dr. Palen uses an orange and lightbulb to demonstrate the phases of the Moon. Students can easily reproduce this in their rooms (or your lab) using a desk lamp and any round object.
Text reference: Section 2.3

END-OF-CHAPTER SOLUTIONS

Check Your Understanding

1. (b) The Earth rotates about the north and south poles, and the celestial poles are just an extension of this axis on the sky.
2. (d) If we are at the North Pole, Polaris is overhead or at 90° latitude, so it follows that its altitude in our sky and our latitude are the same.
3. (d) The higher the tilt, the more severe the seasons.
4. Full. See Figure 2.20.
5. The holidays would still wander because these calendars are based on a 29.5-day lunar cycle, but the wandering would be much slower than it actually is.
6. (b) If the Moon were farther away, its angular size would be smaller, and it could no longer cover the Sun to make a total eclipse. However, Earth's shadow would still cover the Moon, so lunar eclipses would happen—(c) says they would not.

Reading Astronomy News

1. Solar eclipses travel over only a small swatch of the Earth when they occur; it is fairly rare for them to pass any given location, so the fact that this eclipse is the first total eclipse to hit the continental United States in about 30 years is very exciting.
2. As seen from Hopkinsville, the total eclipse will last 2 minutes, 40 seconds. This is the region of Earth where the eclipse lasts the longest because of the very particular geometry needed to produce a total solar eclipse; anywhere north or south of this region will see much shorter durations of totality.
3. There will be a lunar eclipse either 2 weeks before or after.
4. Answers will vary.
5. For all practical purposes, 0.1 seconds is not a significant enough change to be important *except* for those who care about making the claim of *longest* duration. More important factors will be weather that day, travel, and lodging.

Test Your Understanding

1. (c) Constellations are groupings of stars that appear close together on the sky and generally form a familiar pattern. However, in reality the stars are far from one another.
2. (c) Use Figure 2.2.
3. (b) The rotation of the Earth on its axis brings the Sun into and out of our sky, causing day and night.
4. (b) Currently Polaris is located very close to the north celestial pole, meaning it does not appear to the naked eye to move as the sky rotates.
5. (a) Refer to Figure 2.16, which shows how the Sun's path compares to our orbital plane and the celestial equator.
6. (e) Seasons happen because both (b) days are longer in the summer and (c) light is more direct in the summer.
7. (d) On an equinox, the ecliptic crosses the celestial equator, the Sun rises due east, and one has exactly 12 hours of daylight.
8. (b) The Moon is in a "tidal lock" with the Earth so it spins at the same rate as it orbits.
9. (d) Using Figure 2.20, the Moon must be in the third quarter phase.
10. (a) A lunar eclipse happens when the Earth's shadow falls on the Moon.
11. (b) Different definitions of calendar parts lead to different calendars.

12. (d) The stars that we see at night depend on all of the options listed.
13. (c) The Tropic of Cancer is the northern tropic, and so in summer, the Sun is above the Tropic of Cancer, whereas it is daylight around the clock in the Arctic (northern) Circle.
14. (b) If you read carefully, all other answers are incorrect.
15. (a) "On the meridian" means the highest the Moon will be in the sky. If the Moon is in the first quarter phase and at this position, then using Figure 2.20, it is sunset, or on the western horizon.

Thinking about the Concepts

16. Magellan could not use the North Star (Polaris) for navigation because he was in the Southern Hemisphere, thus Polaris was never above the horizon. Rather, he might have discovered that the Southern Cross constellation points approximately south.
17. Because the north celestial pole is an extension of the North Pole on Earth, if you are standing on the North Pole, you will see the north celestial pole right overhead, that is, at your zenith.
18. If Gemini is high in the night sky in the winter, then it is high in the daytime sky in the summer, which we cannot see. Thus, during the night it is behind the Earth. This is why we cannot see Gemini in the summer.
19. If I am flying in a jetliner, (a) I can tell that I am moving by watching stationary objects go past me. (b) backwards.
20. Our first question as an expert witness is whether the full Moon casts very pronounced shadows or illuminates things quite brightly and, in this reader's opinion, that only happens if one is in an area that is otherwise *extremely* dark, which does not really happen in cities. That being said, the next question is whether the full Moon can cast a long shadow at midnight. To cast a long shadow, the object (Sun or Moon) must be very low in the sky, but at midnight the Moon will be at the meridian. For most observers, this is relatively high in the sky, which negates the defendant's claim. However, if one were living around the Arctic Circle, then this argument might have some credibility because the Moon would never rise to be very high in the sky.
21. The observation is "seasons happen." In Take 1, the hypothesis is that "seasons are due to distance from the Sun." The prediction is that "both hemispheres will be hot at the same time." The test is that "the seasons are opposite." Because this is a failure, we return to a new hypothesis in Take 2. Here, the hypothesis is that "one hemisphere is closer to the Sun than the other because of our tilted axis." The prediction is that "the closer hemisphere will be hotter." The test is that "the difference in distance is too small to account for such temperature differences." Our hypothesis failed, so on to a new hypothesis in Take 3. Here, we propose that "the tilt of our axis changes the distribution of energy on the surface." The prediction is that "more energy will hit the Earth in summer," which we test and confirm. With a confirmed test, we make a new prediction: "summer days are longer." This is true, and we make another prediction, and so on.
22. The average temperatures on Earth lag a bit behind the formal change in seasons because it takes time for the Earth to heat up or cool down. Thus, although the winter starts officially in December, it takes 1 to 2 months for the Earth to cool down, making the coldest months January and February.
23. (a) The Earth takes 24 hours to complete one rotation (about its axis) with respect to the Sun. (b) The Earth takes 26,000 years to complete one "wobble."
24. The full Moon crosses the meridian around midnight, and the first quarter Moon rises (i.e., on the eastern horizon) around noon. To answer these, use a figure such as Figure 2.20.
25. (a) Over the course of one orbit, the Earth will stay in a fixed position in the observer's sky, because the same side of the Moon always faces the Earth. (b) The phases of the Earth as viewed from the Moon will be the opposite of those of the Moon as viewed on Earth, that is, if on Earth we see a full Moon, then on the Moon we would see a new Earth.
26. We would see a solar eclipse from the Moon. See Figure 2.29.
27. A total eclipse of the Sun casts a very small shadow on Earth and thus can only be seen from very narrow strips of the Earth, whereas the partial shadow covers a much larger area and can thus be seen by many more observers.
28. To see an eclipse at each full or new Moon requires that the Moon's orbit be in the same plane as the Earth's orbit around the Sun. Because this is not the case, we see eclipses only on those occasions when the two planes line up, about twice a year.
29. If the Earth's tilt axis was close to 90°, the seasons would be very long and very severe.
30. A cyclic change in the tilt would vary the height of the sun in the sky, thereby changing the seasonal temperatures from their current pattern.

Applying the Concepts

31. Setup: We know that it takes 24 hours for the Earth to make one revolution, so using $d = vt$ we can find the circumference of the Earth. To find the diameter, we will use $C = 2\pi r$, where r is the radius and the diameter is twice that value.
Solve: If the speed v = 1,674 km/h at the equator, then the total distance travelled in 24 hours is $1{,}674\,\frac{\text{km}}{\text{h}} \times 24\text{ h} = 40{,}176\text{ km}$. The Earth's radius is then $r = \frac{C}{2\pi} = \frac{40{,}176\text{ km}}{2 \times 3.14} = 6{,}397\text{ km}$, so the diameter is twice that, or 12,790 km.
Review: I can think of two ways to check this answer. First, look in Appendix 2 of the book. Second, it is about 3,000 miles from New York City to Los Angeles, and there are three time zones, which means there are about 1,000 miles or 1,600 kilometers per time zone. There are 24 time zones so the circumference of the Earth is about 24,000 miles or 38,000 kilometers. This is close to what we found so it is a reasonable sanity check.
32. Setup: For this problem, use Figure 2.6 (which shows observers on Earth at typical North American latitudes), Figure 2.7 (showing how stars move across our celestial sphere), and Figure 2.16b (which shows how the Sun moves in our sky compared to the celestial equator).
Solve: (a) Answers will vary with latitude but should look like Figure 2.6. (b) Combining Figures 2.7 and 2.16b, one finds the maximum and minimum altitude of the Sun at noon on the solstices will be 23.5° above or below the celestial equator, and the celestial equator appears L degrees below the zenith or $90° - L$ degrees above the horizon, where L is your latitude. Thus, the Sun reaches $(90° - L) \pm 23.5°$ on the solstices.
Review: If a student has access to a plastic celestial sphere with a movable Sun inside, using this tool is the best way to review the motion of the Sun in our sky and the relative positions of the zenith, celestial equator, and north celestial pole. It is worth investing in at least one of these for every introductory class.
33. Setup: For this problem, use Figures 2.6 and 2.7, which show in graphics and time-lapse photography how stars move around the north celestial pole.
Solve: If Polaris is D degrees from the zenith, then your latitude is $L = 90° - D$. So in this problem, Polaris is 40° from the zenith, therefore I am at latitude 50° which is in the southernmost part of Canada.
Review: If a student has access to a plastic celestial sphere, using this tool is the best way to review the answer. It is worth investing in at least one of these for every introductory class.
34. Setup: For this problem, use Figure 2.7, which shows how the stars move across our celestial sphere.
Solve: If I am living in the United States (the Northern Hemisphere), then as shown in Figure 2.7, I can see a star in the southern part of the celestial sphere if it is more than L degrees from the southern celestial pole. So if I want to see a star 65° from the celestial equator, that means it is within $90° - 65° = 25°$ of the south celestial pole. To see it in the Northern Hemisphere, I need to be at this latitude or below. The only states that reach this low latitude are Florida and Hawaii.
Review: If a student has access to a plastic celestial sphere, using this tool is the best way to review the answer. It is worth investing in at least one of these for every introductory class.
35. Setup: For this problem, use Figure 2.14 and note that panel (b) corresponds to the summer solstice in the Southern Hemisphere.
Solve: As the Earth rotates, an observer on the South Pole will not move with respect to the Sun. In other words, the Sun will stay at the same height in the sky all day long. Using the same argument as in problem 32, the maximum height the Sun will reach in your sky is $(90° - L) + 23.5°$, or 23.5° above the horizon. This is the height of the Sun (a) at noon and (b) at midnight.
Review: One can also visualize this by combining Figures 2.7 and 2.16b, which shows the Sun 23.5° above the celestial equator and, hence, your horizon.
36. Setup: For this problem, use Figures 2.15 (how the Sun illuminates Earth at different times of year) and Figure 2.17 (how the Sun changes its height in our sky over different times of year).
Solve: If the tilt of the Earth changed to D degrees, then the maximum height of the Sun above the celestial equator would also be D degrees. Because the tropics are D degrees above our equator, and the (Ant)Arctic circles are D degrees below the poles, we see that for this problem the tropics would be at latitudes ±10° and the circles at ±80°.
Review: Imagine the Earth had no tilt; then where would the tropics and circles be? Now tilt the Earth by a tiny amount, and answer the question. One can easily derive the logic used in the solution in this way to verify that it is correct.
37. Setup: For this problem, use Figure 2.16, which shows how the Sun's path compares to our orbital plane and the celestial equator.
Solve: On the equinox, the highest the Sun in your sky will be L degrees below the zenith or $90° - L$ degrees

above the horizon, where L is your latitude. So the highest the Sun will be on the summer solstice will be $(90° - L) + 23.5°$, and if the Moon can be up to 5° above that, then in Philadelphia the Moon can be as high as $(90° - 40°) + 23.5° + 5° = 78.5°$ above the horizon.
Review: This figure shows this situation as described.

38. Setup: For this problem, use Figure 2.14a (how the Sun illuminates the Earth when it is summer in North America).
Solve: According to this figure, (a) if we travel to latitudes of 66.5° or higher and (b) make this trip as close to the summer solstice as possible, then the Sun will never set.
Review: Knowing that it is winter in Australia when it is summer in New York City, or that in the (Ant)Arctic circles it can be daylight or night for 24 hours straight, we see that this is correct.

39. Setup: Follow the worked example in Working It Out 2.1 but replace 185 meters with 157.5 meters. Or, in the final answer, divide out 185 and multiply by 157.5 to remove one unit and replace the other.
Solve: Following the first method, we use $\frac{1}{50} \times C = 5{,}000 \text{ stadia} \times 157.5 \text{ meters/stadion}$ to find $C = 50 \times 787.5 \text{ km} = 39{,}375 \text{ km}$. The modern value is 40,075 km, so this is only 1.7% off.
Review: Check with the second method. Using 180 meters per stadion, the example found a circumference of 46,250 km, and $46{,}250 \times \frac{157.5}{185} = 39{,}375$, as expected.

40. Setup: (a) We need to know how much time it takes for the vernal equinox to move from one constellation to another. Let us assume all constellations are equally distant from the next, then how much time is spent in each constellation for a total circuit of 26,000 years (the period of the Earth's wobble)? (b) Use Figure 2.18b.
Solve: (a) There are 12 constellations, and if they are distributed roughly uniformly around in the zodiac (Figure 2.13), it takes roughly $\frac{26{,}000 \text{ yr}}{12} \approx 2{,}200 \text{ yr}$ for the equinox to move from one constellation to the next. As extra credit, one might ask how long it will take to move from Pisces to Aquarius, because the student must figure out whether the equinox is moving from Pisces *toward* or *away from* Aquarius. The section "Earth's Axis Wobbles" tells us that 2,000 years ago, the Sun was in Cancer on the first day of summer, whereas today it is in Taurus. Looking back at Figure 2.18b, we see that this is a change in the direction of Pisces toward Aquarius; therefore, the equinox need only move by one constellation or 2,200 years. (b) We find that Stonehenge was built when the equinox was exiting Taurus and entering Aries, or two constellations behind where we are now.
Review: (a) Note that the question asked how long the equinox spends in a constellation, not how much time it takes to move between the two. If we assume that they are all about the same size and equally spaced apart, then the two questions are really the same! (b) Given that we determined it takes about 2,000 years to move one constellation, we need only move two constellations back.

41. Setup: Looking at Figure 2.18b, Vega is around 13000 to 14000 CE. The question is, how long will it take to move from Polaris (today) to Vega? We have all we need, as long as we remember that today is 2000 CE.
Solve: $13{,}500 - 2{,}000 = 11{,}500$ yrs.
Review: We could also estimate this from Figure 2.20b as an angle. It looks like the angle between Polaris and Vega (as measured from the center of the image) is almost 180°. That means it will take about half of the total period, or $\frac{1}{2} \times 26{,}000 = 13{,}000$ years, which is close to what we found.

42. Setup: To solve this problem, remember there are 360° in a circle, and it takes about 29 days for the Moon to complete one orbit around the Earth, that is, to make one complete path through the fixed stars on the sky. We must find out how long it takes to move 1°.
Solve: If the Moon moves 360° in 29 days, then it takes $\frac{29 \text{ days}}{360°} = 0.08$ days to move 1°, and $0.08 \text{ day} \times \frac{24 \text{ hr}}{\text{day}} \approx 1.9 \text{ hr}$. We want the Moon to move half a degree, which will take half as long or about 1 hour, roughly.
Review: There are 720 half-degrees in one revolution, so $720 \times 1 \text{ hr} = 720 \text{ hr} \times \frac{\text{day}}{24 \text{ hr}} \times 30$ days, which is about 1 lunar month. Check!

43. Setup: The problem gives us the formula that $\text{apparent size} \propto \frac{\text{diameter}}{\text{distance}}$, so compare the ratio of the values for the Sun and Moon.
Solve: For the Sun, the ratio is $\frac{696{,}000}{1.469 \times 10^8} = 4.73 \times 10^{-3}$ and for the Moon, $\frac{1{,}737}{3.780 \times 10^5} = 4.59 \times 10^{-3}$, so we see that the two are indeed about the same size.

Review: If we did not find that the two were roughly the same size, then the Moon would not seem to almost perfectly cover the face of the Sun during a solar eclipse!

44. Setup: Using the small-angle formula from the previous problem, we know that the size $\theta = \frac{\text{size}}{\text{distance}}$. In the case of our problem, the Earth-Moon distance is the same and so the ratio between the angular size θ_{Moon} of the Moon as seen on Earth, and θ_{Earth} of the Earth as seen on the Moon, will be the ratio $\frac{\theta_{\text{Earth}}}{\theta_{\text{Moon}}} = \frac{R_{\text{Earth}}}{R_{\text{Moon}}}$, where R indicates the actual (or physical) diameter of each object.
    Solve: Given the values in the text, $\frac{\theta_{\text{Earth}}}{\theta_{\text{Moon}}} = \frac{6371\text{ km}}{1737\text{ km}} = 3.67$, so the Earth appears 3.67 times larger to the observer on the Moon.
    Review: Try setting out a tennis and basketball some distance apart, and then observe each object from the other's location. It will become clear that the change in angular size varies with the size of each object.
45. Setup: Refer to Figure 2.31, which shows why eclipses only happen at certain times of year.
    Solve: If the inclination of the Moon's orbit drops, then there is a longer period of time during which the Moon can pass through the Earth's shadow. Hence, the lunar eclipse seasons would become longer. The solar eclipse still requires a very accurate alignment of the Sun-Earth-Moon system, so this season would probably not change.
    Review: You can try this for yourself by going into a dark room with a single lightbulb and holding a tennis ball at arm's length. The bulb represents the Sun, your head is the Earth, and the ball is the Moon. By turning around, you can cause solar and lunar eclipses.

Using the Web

46. I am writing this in summer, and the days are becoming shorter and nights longer as I approach autumn. The shortest day occurs on December 21 and the longest on June 21. Everything is opposite for the Southern Hemisphere.
47. The answers will vary on the day of the year and time chosen. For mid-September around 3 pm, it is daytime, regardless of hemisphere. However, if one goes to the other side of the Earth, it is night. It is night directly on the North Pole, and day on the South Pole. Twelve hours earlier or later, it is night where we are located and day in the Southern Hemisphere, night at the North Pole but day on the South Pole.
48. Answers will vary depending on the time of year. As one example, if the Moon is currently a waning gibbous, it will rise at 8 pm and set at 10:30 am. Over the next 4 weeks, it will become a third quarter, then waning crescent, then new, then waxing crescent, then first quarter, then waning gibbous, then full, and become waning gibbous again. A first quarter Moon rises around noon. One can observe waxing crescent through waxing gibbous during the day.
49. Answers will vary with the initial phase of the Moon. The reported phases will follow one-quarter of the full phase pattern, that is, if one starts at new Moon, then it becomes more illuminated over 7 days until it is a first quarter Moon. The Moon will change its distance from the Sun, or the stars seen behind it, every day.
50. Answers will vary according to the date in question. For example, as of October 2015, the next lunar eclipse is a penumbral (partial) eclipse on March 23, 2016, and will be just visible from the western seaboard of the United States. The next solar eclipse will be a total eclipse 2 weeks earlier on March 9, 2016. It will be visible from Sumatra, Borneo, and Sulawesi. Solar eclipses can only be seen from a tiny fraction of the Earth because the Moon's shadow is very small and it only strikes a tiny portion of the Earth.

Exploration

1. At startup, the time is noon, because the Sun is going to be at the meridian (i.e., the highest in our sky that it will reach).
2. The Moon is also at the meridian because it is located at the same position in the sky.
3. The Moon is new, as shown on the top right panel. Also, none of the illuminated face is toward us.
4. I would see a "full" Earth, that is, fully illuminated.
5. The Moon orbits counterclockwise.
6. The right side of the Moon is illuminated first.
7. If the horns of the crescent Moon point right, it must be a waning Moon.
8. At midnight, the first quarter Moon is setting.
9. The full Moon crosses the meridian at midnight.
10. At noon, the third quarter Moon is on the western horizon.
11. At 6 P.M., the full Moon is rising.