INSTRUCTOR'S MANUAL

Understanding Our Universe

SECOND EDITION

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Stacy Palen, Laura Kay, Brad Smith, and George Blumenthal

Ben Sugerman

GOUCHER COLLEGE

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CHAPTER 1

Thinking Like an Astronomer

INSTRUCTOR 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.
- Relevant and relative distance scales, including the light-year.
- The scientific method and relevant vocabulary; that is, distinguishing *theory* from *idea*.
- Reading graphs.
- Unit conversion and scientific notation.

This course is generally taken by nonscience students to fulfill a general education requirement. At the beginning of the 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 that they are afraid of science. Over nearly two decades of interacting with introductory astronomy students, I've 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 1.2 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 (Working It Out 1.1), 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 some of my learning outcomes are that they learn the process of science, gain scientific literacy, and understand the difference between science and pseudoscience. The seeds of this are sown in this first chapter through discussion of the scientific method and of the various logical fallacies presented in the Exploration. While 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 Figure 1.1. 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 1.2. 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 60–70 years).
- Astronomers need to keep collecting data from 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 to 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 response.

TEACHING READING ASTRONOMY NEWS

Note to Instructors

If you would prefer to save the article in the textbook about Pluto for use later in your course, the following alternate article may be of use. This story will provide a platform for further discussion of the scientific method and pseudoscience.

Alternate News Story

"Many Gather to Ponder End of Maya Days; Ancient Calendar Ends in 2012. Does Calamity Await? Or a Rebirth?" Louis Sahagun, *Los Angeles Times*, November 3, 2008. Available at http://articles.latimes.com/2008/nov/03/local/me-mayan3.

Evaluating the News

1. Is the 2012 prediction based on a theory, an observation, a hypothesis, a physical law, a physical principle, or none of these? Explain.
2. There are two competing ideas about what will happen on December 21, 2012. The first says the world will end. The second says nothing will happen. Which choice does the principle of Occam's razor support? Why?
3. How does the 2012 apocalypse claim presented in the story fit with the scientific method? Go back to Figure 1.7 and give examples of how it does and does not fit with each step of the scientific method.
4. What will happen to this "theory" on December 21, 2012?
5. What is the likely motivation for progenitors of "2012-ology"? How does this bias their ability to look at this prediction scientifically?
6. What hypothesis is offered for the immense popularity of apocalypse claims? Is this hypothesis scientific? Explain.

TEACHING EXPLORATION

Note to Instructors

The Exploration activity for this chapter discusses logical fallacies. The following are additional examples of logical fallacies that can be used in conjunction with the discussion provided in the chapter. The following logical fallacies come from product, service, and political advertisements.

Goal

- For students to use logic to evaluate claims critically

Required Materials

- Computer with Internet access

Pre-/Post-Assessment Question

Suppose someone were to say to you, "Most pedestrian accidents occur at crosswalks. Therefore, people would be safer crossing the street in the middle of the road." This statement would be an example of what kind of logical fallacy?

a. biased sample
b. appeal to belief
c. *post hoc ergo propter hoc*
d. slippery slope

Answer: (a).

Preactivity Introduction

There is a plethora of videos on YouTube that give examples of logical fallacies. "The Fallacy Project: Examples of Fallacies from Advertising, Politics, and Popular Culture" is one such video, and it makes an excellent introduction to common logical fallacies. You can view this video at http://www.youtube.com/watch?v=fXLTQi7vVsI.

Exploration: More Logical Fallacies

The following videos are real-world examples that can be shown to your students in order to generate discussion about the types of logical fallacies presented in this chapter's Exploration.

- Lyndon B. Johnson's famous "Daisy" political advertisement against Barry Goldwater is an excellent example of a ridiculous slippery slope (vote for Johnson or there will be atomic war). You can view this video at http://www.youtube.com/watch?v=63h_v6uf0Ao.

- An *ad hominem* political advertisement for Robert Barber, running for comptroller general in Charleston, South Carolina. You can view this video at http://www.youtube.com/watch?v=PAPi_my4uIg.
- An advertisement for Miss Cleo, a purported psychic medium, appeals to people's beliefs in psychic powers. You can view this video at http://www.youtube.com/watch?v=pWyHiV3l3MA.

Postactivity Debriefing

Recognizing and understanding logical fallacies are crucial parts of scientific thinking. Along with scientific literacy, these skills rank among the most important outcomes of science courses for nonscience majors. Enforce this by having students write a brief reflection (5 minutes or less) on one or both of the following writing prompts:

1. "Why is it important to be able to spot a logical fallacy?"
2. "Think of an example of a logical fallacy you have encountered outside of class. What type of fallacy is it?"

END-OF-CHAPTER SOLUTIONS

Evaluating the News

1. When Pluto was first discovered, astronomers called it a "planet" because it orbited the Sun. But as more information was obtained, we realized that it did not share many common characteristics with the other planets (that is, its size, mass, and the shape of its orbit). We didn't classify Ceres as a planet, even though it has a mass similar to Pluto's, as we knew early on that it was really just a large asteroid. However, as we discovered more Pluto-sized objects, we had to decide whether to keep increasing and changing the number of planets or accept that these really belonged to a different group of objects. Pluto didn't change, but our understanding of it did, and we realized that our initial categorization of Pluto as a planet had to be reevaluated.
2. Science is not a belief system but a process of skepticism and testing that leads us to constantly reevaluate what we know (or think we know) as new discoveries are made and predictions are investigated. When we find that long-held ideas are wrong, it may be difficult to let them go or it may take a long time to accept change, but science follows data, not faith. Dr. Brown was referring to this when he discussed "strong emotions" (that is, we all grew up knowing Pluto was a planet and naturally wanted to keep it that way).
3. We constantly reclassify things, but they generally receive little public attention. Two examples from biology are the duck-billed platypus and the colugo, both of which are sufficiently strange that they didn't fit into common biological classifications (kingdom, phylum, class, and so forth) and eventually needed new classifications of their own.
4. Suppose we call all Pluto-like things a planet. Many astronomers are constantly searching the skies for new objects orbiting the Sun, so while today there might be 12 "planets," each year we will probably add one or two more. In a few years there might be 20 planets, or 200, or more! The list will just keep growing. If nothing else, this is very impractical, especially considering that small, cold, dead, Moon-sized objects will dominate the list. As you will learn in later chapters, these will not teach us much about the formation of our Solar System compared to what we learn from Jupiter- and Earth-like planets.
5. The scientific method makes a prediction, tests it, and evaluates the prediction based on the results. Consider Ceres: It was predicted to be a planet until astronomers discovered that it was just one example of a huge sea of similar objects. The test failed because no other planet is part of a belt of similar objects. Thus, Ceres was demoted. Essentially the same thing happened with Pluto, except the test involved mass.

Summary Self-Test

1. **Earth–Sun–Solar System–Milky Way Galaxy–Local Group–Virgo Supercluster–universe**. Use Figures 1.1 and 1.2.
2. **(c)** Our explanation and understanding of the universe would not be very useful if things only applied here on Earth.
3. **(b)** Other than hydrogen and helium, all the elements in the universe were made in stars.
4. **Falsify**. The scientific method involves skepticism and testing, and you can only test something that could be proved wrong.
5. **(a)** Speed is the change in distance over a time interval. Here, distance is growing smaller in time, meaning the car is approaching. We don't know if the car is speeding up or slowing down unless we know the shape of the line.

6. **Radius of Earth–light-minute–distance from Earth to Sun–light-hour–radius of Solar System–light-year**. Use Figure 1.2
7. **Its age**. Figure 1.2 shows that "the age of the observable universe is about three times the age of the Earth."
8. **b-d-a-c-e**. You have to make the material to form the Sun before you can make the Sun. You have to make gas first (b), then make stars to make heavier elements (d), then the stars blow up to spread those elements around (a), and then the gas has to collect (c), all before you can form the Sun and planets (e).
9. $1.60934 \times 10^3 \rightarrow 1{,}609.34$ and $9.154 \times 10^{-3} \rightarrow 0.009154$.
10. $86{,}400 \rightarrow 8.64 \times 10^4$ and $0.0123 \rightarrow 1.23 \times 10^{-2}$.

Questions and Problems

Multiple Choice and True/False

11. **False**: You can test a theory, but you can't prove it is true because another piece of evidence could come along and prove it wrong. All you can do is disprove something.
12. **True**: We build our understanding by watching and explaining patterns.
13. **False**: A theory is "a carefully constructed proposition . . . of how the world works." It is never a guess.
14. **False**: Scientists never stop testing a theory, as it is just our best explanation at the time. A better one can always come along!
15. **True**: Astronomers use a variety of scientific instruments that are used in many different fields beyond astronomy.
16. **(c)** A galaxy is full of stars, and our Solar System only has one star (the Sun).
17. **(d)** The Sun is the center of our Solar System, just one of the billions of stars in our galaxy, which is one of the billions of galaxies in the universe.
18. **(a)** It is the distance that light travels in 1 year.
19. **(d)** The Big Bang made mostly hydrogen and helium and a very small amount of lithium and beryllium.
20. **(c)** Science provides an explanation for natural phenomena, however as we learn more, sometimes these explanations fail to explain all our observations adequately or they are proved to be false. Our understanding of the universe changes as we learn more. An example is how we first observed the Sun moving around Earth and had believed Earth to be the center of the universe. Then we understood that Earth moves around the Sun but believed the Sun to be the center of the universe. Now we know that there is no center to the universe. Each model was correct at the time, given the data we had available. But our model today is the most complete.
21. **(c)** This is a just a restatement.
22. **(a)** The universe is understood to be homogeneous and isotropic on its largest scales.
23. **(c)** There are 1,000 billionths in one millionth.
24. **(b)** The curve is changing slope, becoming horizontal (which would be a car at rest). Thus the car is slowing down. But the distance is increasing with time, so the car is moving away also.
25. **(a)** We generally place *time* on the horizontal axis, meaning *stock value* would be on the vertical one, in this case.

Conceptual Questions

26. Tau Ceti e, Tau Ceti, Milky Way Galaxy, Local Group, Virgo Supercluster. See Figure 1.1.
27. Answers will look like Figure 1.1. Differences in scale compare city vs. state vs. country.
28. Answers will vary. For example, the distance from the Sun to Neptune is equivalent to the time needed to fly from New York City to London.
29. About $8\frac{1}{2}$ minutes. This is the amount of time it takes for light that leaves the Sun to reach us.
30. 2.5 million years. This is the amount of time it takes for light that leaves Andromeda to reach us.
31. Only hydrogen and helium (with perhaps a trace amount of lithium and beryllium) 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.
32. *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 religious beliefs (such as Jesus is Messiah), political views (such as less government is better), and emotional statements (such as love conquers all). 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).

33. A *theory* is generally understood to mean an idea a person has, whether or not there is any proof, evidence, or way to test it. A *scientific theory* is an explanation for an occurrence in nature that must be based on observations and data and must make testable predictions.
34. A *hypothesis* is an idea that might explain some physical occurrence. A *theory* is a hypothesis that has been rigorously tested.
35. This suggests to me that one of the fields has an incorrect theory, basis, or understanding, and the two fields need to be carefully considered to reconcile this discrepancy.
36. (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.
37. In 1945, our distance-measuring methods were not correctly calibrated, and as a result, our calculation of the 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.
38. 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 1 of 12 of the students regardless of his or her 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 horoscope would match the person's astrological sign; and 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.
39. The cosmological principle essentially states that the universe will look the same to every observer inside it.
40. Answers will vary.

Problems

41. **Setup**: As a rough estimate, 1 meter is 1 yard or, as there are 3 feet in 1 yard, 1 foot is about 0.33 meter.
Solve: Example: Someone who is 5' 6" is 5.5 feet, or $5.5 \times \frac{0.33\text{ m}}{\text{ft}} \approx 1.8\text{ m}$.
Review: The height of an average person is 5 to 6 feet, or about 1.5 to 2 meters.
42. **Setup**: Let's choose Smallville and Metropolis, separated by 60 miles, and Clark and Lois's houses, separated by about 10 blocks. Then we will convert between distance, rate, and time with distance = rate times time, or $d = vt$.
Solve: If I travel 60 miles per hour, then the distance from Smallville to Metropolis is 60 miles, or 1 hour. I walk a block in about 2 minutes, so as there are 10 blocks from Clark Street to Lois Street, it will take about 20 minutes to walk. Or if I call the time to walk a block a "timeblock," then it takes me 10 timeblocks.
Review: One timeblock is 2 minutes, so 10 timeblocks are 20 minutes, which I originally found.
43. **Setup**: We need our assumptions of speed. Let's say a car goes 50 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 miles/50 mph = 48.9 hours, and by foot, it will take 25 times longer, or 1,222 hours. Because there are 24 hours in a day, the car takes 48.9/24 = 2.04 days, while by foot it takes 50.9 days. Note these values assume you travel around the clock, which we don't usually do!
Review: In car-hours, it would take 48.9 hours, or 48.9 car-hours. This is close to 48 hours, or 2 car-days. By foot, it would take 1,222 foot-hours, or 51 foot-days. 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.
44. **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. Pluto is 40 times farther from the Sun, so light takes $8 \times 40 = 320$ minutes, or $320/60 = 5.33$ 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!

45. **Setup**: First we need the numeric values, then we need to count the digits. Figure 1.2 gives 100,000 years for the galaxy, 2.5 million years for the Milky Way to Andromeda, and 13.8 billion years to cross half the universe.

Solve: There are five zeroes in 100,000, so it would take 10^5 years for light to cross the galaxy. There are six zeroes in a million (1,000,000), so it would take 2.5×10^6 years for light to reach the Andromeda Galaxy from here. Similarly, it will take 1.38×10^{10} years to cross half the galaxy.

Review: If you compare these to Working It Out 1.1, you will see that we followed the right procedure.

46. **Setup**: We need to know the size of the galaxy in light-years (100,000 from Figure 1.2) and the number of miles in a light-year (5.9 trillion miles).

Solve: Convert 10^5 light-years $\times \dfrac{5.9 \times 10^{12}\text{ miles}}{\text{light-year}} =$ 5.9×10^{17} miles.

Review: This is 590 quadrillion miles. Honestly, that is too big for me to imagine!

47. **Setup**: This is all about unit conversion, so let's make sure we know our conversion factors. There are 60 seconds in a minute and 60 minutes in an hour. The distance to the Moon is about 1.25 light-seconds, to the Sun is 8.3 light-minutes, and 8.3 light-hours to Neptune, using Figure 1.2.

Solve: If 10 millimeters (mm) equals 1 light-minute and there are 60 seconds in a minute, then using ratios, we can find how many millimeters are in a light-second: 1 light-second $\dfrac{10\text{ mm}}{60} = \dfrac{1}{6}$ mm. There are 60 minutes in an hour, so 1 light-hour = 10 mm × 60 = 600 mm, or 0.6 meter. The Moon is 1.25 light-seconds away, or $1.25 \times \dfrac{1}{6}\text{ mm} = 0.288$ mm away. Neptune is 8.3 light-hours from Earth, or $8.3 \times 0.6 =$ 4.98 meters away.

Review: The Moon would be about the width of a hair away, while Neptune would be about 15 feet away. It just shows how close the Moon is and how much empty space there is in our Solar System.

48. **Setup**: In this problem, we will convert between 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: $t = \dfrac{384{,}000\text{ km}}{800\text{ km/h}} = 480$ h. There are 24 hours in a day, so this would take $480\text{ h} \times \dfrac{\text{day}}{24\text{ h}} = 20$ days, 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 kilometers (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.

49. **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: $v = \dfrac{d}{t} = \dfrac{384{,}000\text{ km}}{3\text{ days}} \times \dfrac{\text{day}}{24\text{ h}} =$ 5,333 km/h. This is about $\dfrac{5{,}333}{800} \approx 6.7$ times faster than a jet plane.

Review: Using the result from problem 48, we have to travel $120/3 \approx 6.7$ times faster than a jet plane, which agrees with our solution.

50. **Setup**: Come up with an estimate for how many galaxies are in the Local Group and how many stars are in our galaxy. The book says there are several hundred billion stars in our galaxy, and our Local Group is dominated by the Milky Way.

Solve: There are two main galaxies, each containing some 300 billion to 500 billion stars, so the total is about 600 billion to 1 trillion stars.

Review: Carl Sagan would always say there are "billions and billions of stars," so we seem to be on the right path.

Exploration

1. This is an example of *post hoc ergo propter hoc*, where we assume that the chain mail caused the car accident.

2. This is a slippery slope, as I am assuming that my performance on the first event must influence the next.
3. This is a biased sample, or small-number statistics, as I assume that my small circle of friends represents everyone.
4. This is an appeal to belief, where 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) where the proof of my assertion comes from another of my own assertions.

CHAPTER 2

Patterns in the Sky—Motions of Earth and the Moon

INSTRUCTOR NOTES

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

- The celestial sphere.
- The paths and motion 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 critical processes of scientific thought to critically assess the likelihood of their own reasoning or model. 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 their 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 a full class having them learn to describe the positions of objects in the sky. The next class is devoted to the motions of objects in the sky. 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 for each of Chapters 5–13) because by then, students have gained experience thinking "scientifically."

As one final piece of advice, encourage your 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 2.15 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 2.8 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.
- Focus on the equations in Working It Out 2.1 where the rotation speed of Earth is computed. Ask the students to convert it to miles per hour. How does it compare with the speed of commercial air jets? How long would it take to travel from London to New York if we could just lift ourselves from Earth's attraction and let it rotate below us before coming back down?
- Manipulate the equations to find out the speed at which the Moon revolves around Earth and the speed at which Earth revolves around the Sun. Discuss how it is possible that even though those velocities are very high, we do not feel them at all.
- Figure 2.12 shows the brightest stars around the north ecliptic pole. The current celestial north pole is marked, and it lies very close to the North Pole star, Polaris. To familiarize the students with the night sky, discuss how to identify Polaris from the location of your classroom. What is the relationship between the altitude of Polaris and one's latitude on Earth? Have them identify for themselves the star or asterism that can play a similar role for finding the celestial south pole.
- Figures 2.16 through 2.18 provide spectacular pictures and pedagogical graphics of eclipses. To test that students have mastered the understanding of eclipses, discuss a limiting case: What would happen if Earth's rotation rate and the Moon's revolution rate were perfectly synchronized? What about if the apparent size of the Moon were double that of the Sun? Half that of the Sun?

ASTROTOUR ANIMATIONS

The following AstroTour animation is referenced in Chapter 2 and is available from the free Student Site (**wwnpag.es/uou2**). The animation is also integrated into assignable SmartWork online homework exercises (**wwnorton.com/smartwork**).

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 and 2.2

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: Sections 2.3 and 2.4

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 (**wwnpag.es/uou2**), and off-line versions can be found on the Instructor's Resource Disk.

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

Motions of the Sun Simulator

This simulation shows the paths of the Sun on the celestial sphere.

- Text reference: Section 2.1

Lunar Phase 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 2.2

Celestial and Horizons Systems Comparison

This simulation demonstrates how the celestial sphere and horizon diagram are related.

- Not referenced in the text, but useful for Section 2.1

Meridional Altitude Simulator

This simulation shows helpful diagrams for finding the meridional altitude of an object.

- Not referenced in the text, but useful for Section 2.1

Path of the Sun Demonstrator

This simulation shows how the declination of the Sun varies over the course of a year using a horizon diagram.

- Not referenced in the text, but useful for 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.

- Not referenced in the text, but useful for Section 2.2

Zodiac Simulator

This simulation shows the position of the Sun in the zodiac in different months of the year.

- Not referenced in the text, but useful for Section 2.2

Moon Phases and the Horizon Diagram

This simulation correlates the phases of the Moon with its positions in the sky.

- Not referenced in the text, but useful for Section 2.3

Eclipse Shadow Demonstrator

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.

- Not referenced in the text, but useful for Section 2.4

TEACHING READING ASTRONOMY NEWS

Note to Instructors

If you spend time showing the difference between astronomy and astrology, this alternate article may help start a discussion while reinforcing the students' understanding of the scientific method and Earth's seasonal motion and precession.

The Evaluating the News questions that follow the article try to help students discover for themselves the distinction between astronomy and astrology (science and pseudoscience) while still maintaining respect for people's beliefs.

Alternate News Story

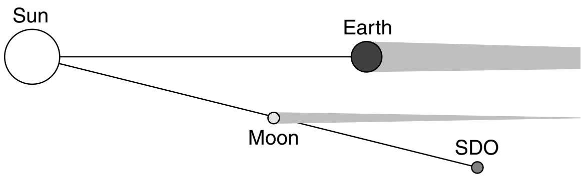
"New Zodiac Signs 2011: Can One Guy Just Change the Zodiac Like That?" Mark Sappenfield, *Christian Science Monitor*, January 14, 2011. Available at http://www.csmonitor.com/Science/2011/0114/New-zodiac-signs-2011-Can-one-guy-just-change-the-zodiac-like-that.

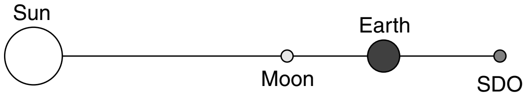
Evaluating the News

1. What makes a constellation a *zodiac constellation*? How many are there? Has this number changed over time?
2. Why are the astronomical dates of the zodiac constellations no longer the same as the ones in the newspaper horoscopes? What caused this change?
3. How is astrology different from astronomy? If you met an astrologer and an astronomer at a party and asked them about what they did at their jobs, what do you think each would say?
4. Does astrology, which is based on the movements of the Sun, Moon, and planets through the zodiac constellations, follow the scientific method? You may want to refer back to Figure 1.7 of Chapter 1 to answer this question. Come up with several specific attributes of astrology and decide whether these are compatible or incompatible with the scientific method.
5. The news presented in this article severely shook the astrological community. Were astronomers similarly affected? Explain.

END-OF-CHAPTER SOLUTIONS

Evaluating the News

1. In Figure 2.20, the eclipses are partial solar.
2. 

3. 

4. If we could draw in three dimensions, then the Moon, Earth, and SDO would all be located in a line—similar to that shown in the illustrated answer to question 3—from the side and from the top.
5. SDO goes around Earth once every 24 hours, so there will be about 21 eclipses in the 3 weeks of eclipse season (3 weeks is 21 days). There will be far fewer eclipses by the Moon, as it is moving around Earth too, meaning it has fewer nodes.

Summary Self-Test

1. **(a)** The Sun, Moon, and stars change their positions because Earth is moving around the Sun, and the Moon around Earth.
2. **a, b, c**. Motion of the stars through space moves them too slowly to be detectable to the eye on Earth.
3. **(a)** Use Figure 2.15. In this problem, the Sun and Moon are on opposite sides of Earth.
4. **(a)** The north celestial pole is an extension of Earth's North Pole, so if you are standing at the North Pole, the north celestial pole will be pointing straight up.
5. **(c)** Use Figure 2.8.
6. The seasons are caused by *the tilt of Earth's axis*.
7. **(b)** Our seasons are due to axial tilt, so if there is very little tilt, there are almost no seasonal changes.
8. **(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 2.17, it is sunset, or on the western horizon.
9. **(b)** We do not see eclipses every month because the Sun, Moon, and Earth only line up about twice a year.
10. **a, 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.

Questions and Problems

Multiple Choice and True/False

11. **True**: The celestial sphere is the imaginary sphere of the sky.
12. **False**: Eclipses only happen two times a year.
13. **True**: The phases of the Moon depend on the relative positions of the Moon to the Sun (what part of the Moon is lit) and the Moon to Earth (how much of that lit half we can see).
14. **False**: If a star rises north of east, it will set north of west.
15. **True**: All stars as viewed from the North Pole are circumpolar.
16. **(e)** Seasons happen because both (b) days are longer in the summer and (c) light is more direct in the summer.
17. **(d)** On an equinox, the ecliptic crosses the celestial equator, the Sun rises due east, and one has exactly 12 hours of daylight.
18. **(b)** The Moon is in a "tidal lock" with Earth so it spins at the same rate as it orbits.
19. **(e)** Using Figure 2.17, the Moon must be in the third quarter phase.
20. **(a)** A lunar eclipse happens when *Earth's* shadow falls on the *Moon*.
21. **(d)** Use Figure 2.15. The full Moon is at the meridian at midnight.
22. **(d)** This is the definition of zodiac.
23. **(d)** There are only circumpolar constellations at the poles (see Figure 2.8).
24. **(b)** is the only answer possible.
25. **(d)** In the Tropics, all of these are correct.

Conceptual Questions

26. It is not possible for the phases of the Moon to be caused by shadows, as the full Moon phase would have to appear as a new Moon, since in this position Earth's shadow could block it.
27. The north and south celestial poles are extensions of the North and South poles of Earth. There are no "eastern" or "western" poles on Earth, so by extension, there are no such celestial poles. Another way to think about this is that the celestial sphere revolves around its poles (north and south), so there can't be another axis about which it revolves.
28. 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.

29. If Gemini is high in the night sky in the winter, then it is high in the daytime sky in the summer, which we can't see. Thus, during the night it is behind Earth. This is why we can't see Gemini in the summer or Sagittarius in the winter.
30. At the vernal equinox, the Sun rises due east, sets due west, and its maximum height in the sky will be equal to $90° - L$, where L is the observer's latitude.
31. The average temperatures on Earth lag a bit behind the formal change in seasons since it takes time for the Earth to heat up or cool down. Thus while 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.
32. The full Moon crosses the meridian around midnight, and the first quarter Moon rises (that is, on the eastern horizon) around noon. To answer these, use a figure like Figure 2.15.
33. (a) Over the course of one orbit, Earth will stay in a fixed position in the observer's sky, as the same side of the Moon always faces Earth. (b) The phases of 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.
34. The 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 doesn't 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, while 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.
35. A total eclipse of the Sun casts a very small shadow on Earth and thus can only be seen from very narrow strips of Earth, while the partial shadow covers a much larger area and can thus be seen by many more observers.
36. To see an eclipse at each full or new Moon requires that the Moon's orbit be in the same plane as Earth's orbit around the Sun. Because this is not the case, we only see eclipses on those occasions when the two planes line up, about twice a year.
37. A full lunar eclipse is caused by the solid part of Earth blocking the Sun's light. However, Earth's atmosphere is larger, and dust and gas particles in our atmosphere can still reflect some sunlight toward the Moon. Because most of the blue light is scattered out of its path to the Moon, what arrives at the Moon is mostly red, causing the reddish tinge. However, this color and brightness is dependent on how much dust, pollution, or water vapor is in the air, thus the color of a total eclipse doesn't always appear the same.
38. For 3 years, we ignore the extra $\frac{1}{4}$ of a day, but we add in the accumulated $\frac{4}{4} = 1$ day as an extra day in February (February 29) every 4 years, calling this a "leap day" and the year a "leap year." Notably, the year is not exactly 365.25 days, so we account for that extra difference by not having leap years at the turn of the century, unless it is also the turn of a millennium.
39. Moonlight is merely reflected sunlight, so to argue that a vampire is killed by sunlight but not moonlight only makes sense if one uses the same suspension of disbelief to believe that (1) vampires exist and (2) that reflected sunlight off of the Moon does not harm them.
40. The longest day of the year in the Northern Hemisphere is the summer solstice. On an airplane, you might ask a flight attendant for a lemon and a lime and show the path of the Sun along the ecliptic using the two.

Problems

41. **Setup**: We know that it takes 24 hours for Earth to make one revolution, so using $d = vt$, we can find the circumference of 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 $v = 1{,}670$ km/h at the equator, then the total distance traveled in 24 hours is 1,670 km/h × 24 h = 40,080 km. Earth's radius is then

$$r = \frac{C}{2\pi} = \frac{40{,}080 \text{ km}}{2 \times 3.14} = 6{,}382 \text{ km}$$

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 textbook. Second, it is about 3,000 miles from New York City to Los Angeles, and there are three hours of time change between them, which means there are about 1,000 miles, or 1,600 km, per hour of change.

There are 24 time zones total, so the circumference of Earth is about 24,000 miles, or 38,000 km. This is close to what we found, so it is a reasonable sanity check.

42. **Setup**: To solve this problem, use Figure 2.15.
Solve: If the waxing crescent is rising in the east, the time is mid-morning. If the Moon moves in its orbit over a few days, then it will be close to the first quarter, which will rise around noon. So we see that the Moon rises a little later each day. It takes about 29 days to complete a lunar month, and there are 24 hours in a day, so the Moon rises about $24/29 = 0.8$ h, or $0.8 \text{ h} \times (60 \text{ min/h}) = 48$ min. later each day.
Review: This reader thinks the best way to check this is to go out and see for yourself! It is a perfect naked-eye observing project that works from anywhere, whether a dark rural town or a bright city.
43. **Setup**: To solve this problem, use Figure 2.15.
Solve: According to our figure, the full Moon is opposite the Sun. So if the Sun is setting, then the full Moon is rising, meaning the full Moon is *not* anywhere near overhead.
Review: This reader thinks the best way to check this is to go out and see for yourself! It is a perfect naked-eye observing project that works from anywhere, whether a dark rural town or a bright city.
44. **Setup**: For this problem, use Figure 2.8.
Solve: The tropic is always 23.5° from the equator, and as I am in Australia, I am at latitude −23.5°. Figure 2.8 shows us that if you are at latitude L, then stars within L degrees of the celestial pole are circumpolar. Thus, all stars within 23.5° of the Southern Cross will be circumpolar.
Review: One can verify this trend by looking at the middle column of Figure 2.9.
45. **Setup**: For this problem, use Figure 2.11.
Solve: On the equinox, the highest the Sun will be 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: Figure 2.19 shows this situation as described.
46. **Setup**: For this problem, use Figure 2.10 and note that panel (b) corresponds to the summer solstice in the Southern Hemisphere.
Solve: As 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. 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 2.8a and 2.11b, which will show the Sun 23.5° above the celestial equator and, hence, your horizon.
47. **Setup**: For this problem, use Figures 2.8b and 2.11b.
Solve: (a) Answers will vary with latitude but should look like Figure 2.8a. (b) Combining Figures 2.8b and 2.11b, 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, use of 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.
48. **Setup**: For this problem, use Figure 2.8b.
Solve: If I am living in the United States (the Northern Hemisphere), then as shown in Figure 2.8b, I can see a star in the southern part of the celestial sphere if it is more than L degrees from the south 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, use of this tool is the best way to review the answer. It is worth investing in at least one of these for every introductory class.
49. **Setup**: For this problem, use Figures 2.10 and 2.11.
Solve: If the tilt of Earth changed to D degrees, then the maximum height of the Sun above the celestial equator would also be D degrees. Because the tropics of Cancer and Capricorn are D degrees away from our equator, and the Arctic and Antarctic circles are D degrees away from the poles, we see that

for this problem, the tropics would be at latitudes ±10° and the circles at ±80°.
Review: Imagine Earth had no tilt; then where would the tropics and circles be? Now tilt 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.

50. **Setup**: Refer to Figure 2.17 but change the drawings as directed.
Solve: (a) The Moon will now be too small in angular size to cover the Sun, so total solar eclipses are no longer possible. (b) Earth's shadow is still very large, and the Moon will fully pass through it, so total lunar eclipses will still happen.
Review: You can try this at home using a light and ball, like Figure 2.14, except use the lightbulb as the Sun, the ball as the Moon, and your head as Earth.

Exploration

1. It is noon for the person in the simulation.
2. The Moon is new.
3. The Moon is at the meridian in this person's sky.
4. In waxing crescent, the right side of the Moon is illuminated.
5. This waxing crescent Moon will be observable after sunset.
6. A little over 7 days have passed between new and first quarter Moon.
7. At this instant, the Moon is at the meridian.
8. An astronaut on the Moon would see Earth in the third quarter phase.
9. An observer sees the Moon in the *full* phase, overhead, at midnight.
10. An observer sees the Moon in the third quarter phase, rising in the east, at *midnight*.
11. An observer sees the Moon in full phase, *setting in the west*, at 6 A.M.