CHAPTER 1

Our Place in the Universe

INSTRUCTOR NOTES

Chapter 1 introduces students to our location in the universe, concepts of distance and time, and the measures and methods of astronomy. Major topics include:

- our cosmic address; that is, the hierarchy of structures from the Solar System to our supercluster.
- relevant and relative distance scales, including the light-year, and relating those scales to an equivalent time.
- the scientific method and relevant vocabulary, with an emphasis on distinguishing a scientific *theory* from an *idea*.
- mathematics as a way to recognize patterns and how to read a graph of a linear relationship.
- unit conversion and scientific notation.

Students enroll for introductory astronomy courses for many reasons, but the most common one would be to fulfill a general education requirement. We have found that in a large lecture hall (say 200+ students) of a major university the spread of educational backgrounds can be large. We teach incoming freshmen with no major declared to graduating seniors who have majored in a science, technology, engineering, and mathematics (STEM) field. For an open enrollment, 2- or 4-year college, we have students who are earning college credit while still in high school, students who are also working full time, and some who are raising a family along with attending school. Returning students may not have had any exposure to basic math for a decade or more.

The goal of this first chapter is to ease all of these students into their study of astronomy. It captures their interest by covering our cosmic address and translating huge distances into terrestrial time examples for a better grasp of large numbers. Too often we hear the phrase "it's just a theory" as a way of dismissing facts that are personally unacceptable. Here the concepts of questioning, predicting, testing, disproving, and more about the scientific method are presented in a way that is relatable to everyday occurrences. Students are given practice with scientific notation and the graphing of data. The mathematics are presented as the language of as well as a valuable tool for science.

For many of our students, this is the last formal science course they will ever take. We have included learning outcomes that have them 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 not only through discussion of the scientific method but also of the various logical fallacies (presented in the Exploration). 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, we 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? (LG 1)
- 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 barely 100 years). (LG 1)
- Thousands of years ago people recognized that there were patterns in their lives that they became curious about and wanted to understand better: seasonal changes in the height of the Sun at noon, rising and falling of tides and rivers, eclipses, and motions of the planets, to name a few. Have students make a list of patterns that they have recognized that link them to science. (LG 2)
- Find items in the classroom, including students and their possessions, that are not just hydrogen and helium. What elements make up those items? What are the possible sources for those elements? This is a good way to link the study of astronomy to the periodic table. (LG 3)
- 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. (LG 4)

- 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 students make a list of examples where they had to collect data to learn something or to explore the unknown. Share in pairs and then with the class. (LG 5)
- Discuss differences and similarities between a well-known scientific equation (for example, $F = ma, E = mc^2$) and a world-renowned work of art. What processes went into creating each? How are they used? (LG 5)

TEACHING CHAPTER-OPENING ACTIVE LEARNING FIGURE

The Active Learning Figure for this chapter introduces how actual observing and taking of data enhance learning. Recording the movement of the Sun along either the eastern or western horizon when its location is just below that horizon helps students recognize the reason for the seasons. Quarter systems will have the possibility of 3 months of observations; semester systems, around 4 months. The solstices, where the Sun pauses as it switches direction, can be generally avoided.

Students will need to find a spot where they have a clear view of either the eastern or western horizon and that they can access freely. They can take pictures or make drawings—methods the artistic students will appreciate. The activity suggests only three observations; however, students will get a better idea of the time that they need to return to their spot by making more observations and noting the pattern.

This activity may not work well for regions where the weather does not clear for weeks at a time, because then students will have to have both fairly clear skies at the same time the Sun is just below the eastern or western horizon to make their observations. The continuity of the Sun's motion will not be so obvious.

ASTROTOUR ANIMATIONS

None for this chapter.

ASTRONOMY IN ACTION

None for this chapter.

TEACHING READING ASTRONOMY NEWS

If you would prefer to save the article in the textbook about the detection of gravitational waves 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. Was the 2012 prediction based on a theory, an observation, a hypothesis, a physical law, a physical principle, or none of these? Explain.
2. There were two competing ideas about what would happen on December 21, 2012. The first said the world would end. The second said nothing would happen. Which choice did the principle of Occam's razor support? Why?
3. How did 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 did and did not fit with each step of the scientific method.
4. What happened to this "theory" on December 21, 2012?
5. What was the likely motivation for progenitors of "2012-ology"? How did the motivation bias their ability to look at the prediction scientifically?
6. What hypothesis was offered for the immense popularity of apocalypse claims? Was this hypothesis scientific? Explain.

Suggested Answers to Evaluating the News

1. The only observation made was that the Mayan Long Calendar's roughly 5,000-years-long cycle ended in 2012. The prediction of dire changes approaching had no basis on theory, hypotheses, or physical laws or principles.
2. The prediction that stated that nothing would happen supports the principle of Occam's razor as that is the simplest explanation. Any prediction of the world ending would bring up questions of how, when, and why, all unanswerable.
3. The individuals involved made the observation that the Mayan calendar ended on a given date. A number of hypotheses were made. Predictions were definitely made. That's where any relationship to the scientific method ended because the predictions were not testable in advance of the ending date.
4. This "theory" was voided because nothing happened. Occam's razor still stands.

5. Self-promotion and the desire for more followers and more donations were most likely the strongest motivations for the progenitors of 2012-ology. Because the date was bound to come and go, they needed to market their "theories" as fast and as loud as possible. No time for testing even if it were possible.
6. "When events leave us feeling powerless and confused, we are more open to new claims about the disorders of the world," he (Professor Emeritus Guthrie) said. "If people persuade enough others to accept their answers to this crazy world, it can become a movement, for better or worse." Professor Guthrie is an anthropologist, a scientist who studies societies and people. Professor Guthrie presented a testable hypothesis.

LEARNING ASTRONOMY BY DOING ASTRONOMY: COLLABORATIVE LECTURE ACTIVITIES

The *Learning Astronomy by Doing Astronomy* workbook activities that are relevant to Chapter 1 are introduced here. For more information, please see the *Learning Astronomy by Doing Astronomy* workbook, the *Instructor's Manual* for the workbook, and the PowerPoint clicker question slides associated with the workbook. Our goal is to have complete coverage across all topics in an introductory astronomy course.

Activity 1: Mathematical and Scientific Methods

This activity reviews the mathematics that students may encounter in this course. This activity helps with tools such as working with logarithms, the small-angle formula, scientific notation, or scaling exercises, like those used to find the scale of a map; laboratory techniques concerning measurements; measurement uncertainties; and statistical analysis. In the first six sections, students review specific mathematical topics and laboratory techniques. These sections include explanations and practice problems. In the last section, students pull multiple concepts together to analyze images of three galaxies. Activity 1 covers the majority of math concepts presented in the workbook. Each individual activity has a set of preactivity questions that tutor students on the math included. Specifically, students will:

- Demonstrate knowledge of the essentials of mathematics through practice and review of:
  - scientific notation and powers of 10;
  - algebra;
  - logarithms;
  - the small-angle formula;
  - the use of scale factors and scaling;
  - statistics and uncertainties in measurements.
- Describe the process of science and the scientific approach as personally experienced.

Activity 2: Astronomical Measurements: Examples from Astronomical Research

In this activity students explore the relationship among apparent brightness, luminosity, and distance and learn to manipulate more advanced equations used in astronomy. Specifically, students will:

- apply the small-angle formula.
- distinguish between apparent magnitude and absolute magnitude and relate them correctly to the concepts of apparent brightness and luminosity.
- relate the ratio of distances to the brightness ratio for stars of equal luminosity.
- solve for the distance to a star using the parallax angle.
- find absolute magnitude from apparent magnitude and distance.
- demonstrate proficiency in manipulating more advanced equations used in astronomical research.

SIMULATIONS

None for this chapter.

CHECK YOUR UNDERSTANDING SOLUTIONS

1.1 Smallest to largest: Earth, Sun, Solar System, Milky Way Galaxy, Local Group, Laniakea Supercluster, universe. See Figure 1.1.

1.2 **(c)** All of the laws of physics are the same in each place. The cosmological principle has not been falsified.

1.3 **(a)** A negative slope in a graph that plots distance versus time indicates that the car is approaching; the distance to the car is decreasing.

END-OF-CHAPTER SOLUTIONS

Evaluating the News

1. The box in Figure 1.7 that supports the results stated in this article is the one that states: "Test supports hypothesis; make additional predictions and test them."
2. Einstein predicted the presence of gravitational waves in 1916. The results from September 2015 were published and announced in February 2016. A century had passed, a time gap not unusual for monumental discoveries in science.
3. Once the instrument was operational and turned on, the initial detection was made "right out of the box."

4. The amount of time shown in Figure 1.12 is 0.20 seconds, a short amount of time in which to make a detection. This tells us that there is a strong likelihood that many detections will be made in the future. (Statistically, it would be highly improbable that we just happened to turn on the instrument precisely when a gravitational wave event was passing by if such waves were very rare.)
5. Each kilometer of the arm stretches by 10^{-21} km as a gravitational wave passes by. The arm is 4 km long, so the total stretch is 4×10^{-21} km. This is about 0.001 times the size. This is difficult because of the extreme smallness and the possibility that noise is greater than the detection.

Questions and Problems

Test Your Understanding

1. **False:** A mega-light-year is 1,000,000 light-years.
2. **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.
3. **True**: We build our understanding by watching and explaining patterns.
4. **False**: A theory is "a carefully constructed proposition . . . of how the world works." It is never a guess.
5. **False**: Scientists never stop testing a theory, because it is just our best explanation at the time. A better one can always come along.
6. **(b), (d), (a), (c), (e)** It started with the Big Bang. Stars formed and fused the hydrogen to helium and heavier elements in their cores. When stars died, these elements were redistributed into the interstellar medium, from which the Solar System and we were formed.
7. **(c)** The Solar System has just one star and no galaxies; galaxies are made up of stars.
8. **(d)** The Sun is the center of our Solar System. It is just one of the billions of stars in our galaxy, which is one of the billions of galaxies in the universe.
9. **(a)** A light-year is the distance that light travels in 1 year.
10. **(c)** 8.3 minutes $\times$ 1.5 AU = 12.45 minutes. Have students use reasoning to reach the answer first.
11. **(d)** The Big Bang made mostly hydrogen and helium and a very small amount of lithium and beryllium.
12. **(b)** 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 disproved. Each model was correct at the time, given the data we had available. The models we have today are more correct than previous ones as our knowledge of the universe increases.
13. **(c)** This is a just a restatement of what is given in the chapter.
14. **(a)** The universe is understood to be homogeneous and isotropic on its largest scales.
15. **(c)** There are 1,000 billionths in 1 millionth.
16. Micrometer (10^{-6} m), millimeter (10^{-3} m), kilometer (10^{3} m), megameter (10^{6} m).
17. **(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.
18. **(a)** We generally place *time* on the horizontal axis, meaning *car value* would be on the vertical one in this case.
19. **(a)** *Time* is usually the independent variable, and so on the horizontal axis. *Brightnes*s is what we are measuring as the variable dependent on time.
20. **(c)** The brightness is increasing with time, so the slope will be positive unless it is being measured in magnitudes.

Thinking About the Concepts

21. Tau Ceti e, Tau Ceti, Milky Way Galaxy, Local Group, Virgo Supercluster, Laniakea Supercluster. See Figure 1.1.
22. Answers will look like Figure 1.1. Differences in scale compare city versus state versus country.
23. Answers will vary. For example, the distance from the Sun to Neptune (30 AUs, light travel time of about 4 hours) is about the same as the time needed to fly from New York City to Los Angeles.
24. About 8.3 minutes. This is the amount of time it takes for light that leaves the Sun to reach us.
25. 2.5 million years. This is the amount of time it takes for light that leaves Andromeda to reach us.
26. 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.
27. *Falsifiable* means that something can be tested and shown to be false/incorrect through an experiment or observation. Some examples of unfalsifiable ideas might include religious beliefs, political views, and emotional statements. Students may have a wide variety of these and other ideas, but all sacred cows are usually considered to be unfalsifiable by the people

holding those beliefs. Falsifiable ideas include cause and effect and logic.

28. 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.
29. A *hypothesis* is an idea that might explain some physical occurrence. A *theory* is a hypothesis that has been rigorously tested.
30. This might suggest that one of the fields has an incorrect theory, basis, measurement methods, or understanding, and the two fields need to be carefully considered to reconcile this discrepancy.
31. (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.
32. 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.
33. Answers will vary. Depending on 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.
34. The cosmological principle essentially states that the universe will look the same to every observer inside it.
35. Answers will vary. We have found that beginning college students have had minimal experience in creating concepts maps, and the activity of developing them on their own will take a lot of time. We have had success in mapping the main and key concepts and then having the students finish by connecting those concepts with the linking action words or phrases. We have even given them a list of linking action words or phrases and had them place them correctly. This approach leaves more time for comparisons and discussions. Having students go through this exercise at the start of the term should enable them to become more independent in creating concepts maps and thus reach a higher cognitive level.

Applying the Concepts

36. In scientific notation, 86,400 is 8.64×10^4; 0.0123 is 1.23×10^{-2}.
37. **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 we travel 60 miles per hour, then the distance from Smallville to Metropolis is 60 miles, or 1 hour. We walk a block in about 2 minutes, so because there are 10 blocks from Clark Street to Lois Street, it will take about 20 minutes to walk. If we call the time to walk a block a "timeblock," then it takes us 10 timeblocks.
    Review: One timeblock is 2 minutes, so 10 timeblocks are 20 minutes, which we originally found.
38. **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, whereas by foot it takes 50.9 days. Note that these values assume we 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.
39. **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 8.3 minutes to reach Earth, then it takes $8.3 \times 2 = {\sim}17$ minutes to go twice as far.

Pluto is 40 times farther from the Sun, so light takes $8.3 \times 40 = 332$ minutes, or $332/60 = 5.5$ 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.

40. **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 universe.

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

41. **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 just about everyone to imagine.

42. **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 $= 10\text{ mm} \times 60 = 600$ mm, or 0.6 meter. The Moon is 1.25 light-seconds away, or $1.25 \times \dfrac{1}{6}$ 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, whereas 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.

43. **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 h $\times \dfrac{1\text{ day}}{24\text{ h}} = 20$ 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.

44. **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: $v = \dfrac{d}{t} = \dfrac{384{,}000\text{ km}}{3\text{ days}} \times \dfrac{1\text{ day}}{24\text{ h}} = 5{,}333$ km/h. This is about $\dfrac{5{,}333}{800} \approx 6.7$ times faster than a jet plane.

Review: Using the result from problem 43, we have to travel $120/3 \approx 6.7$ times faster than a jet plane, which agrees with our solution.

45. **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 and the Andromeda galaxies, with the Triangulum galaxy adding a bit more stars.

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. The Triangulum galaxy adds just another 40 billion stars.

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

EXPLORATION

This exploration asks students to consider the logic behind a variety of statements, many of which they had not considered before. Besides the examples given in the exploration, ask students to come up with one of their own examples that can be classified as one of the logical fallacies included here.

Exploration Solutions

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, because we are assuming that our performance on the first event must influence the next.
3. This is a biased sample, or small-number statistics, because we assume that our small circle of friends represents everyone.
4. This is an appeal to belief, where we argue that because most people believe it, it must be true.
5. By attacking the professor, rather than the theory, we are committing an *ad hominem* fallacy.
6. This is an example of begging the question (a bit of a syllogism, too) where the proof of the assertion comes from another person's assertions.