INSTRUCTOR'S MANUAL

21st Century Astronomy

FIFTH EDITION

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BEN SUGERMAN

Goucher College

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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 miles/70 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.