Chapter 6

Textbooks

Two papers on astronomical textbooks through history begin the textbook section. Following, we reproduce here two of the three papers on personal experiences of authors of American astronomy textbooks, who discuss the factors that motivate and influence the process of writing and publication. A discussion of textbooks for developing countries follows; a summary of an additional discussion is included in the chapter on developing countries.

FIVE CENTURIES OF ASTRONOMICAL TEXTBOOKS AND THEIR ROLE IN TEACHING

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At the turn of the century, astronomy was required of every senior in what is now the American University of Beirut, for the reason that "the heavens declare the glory of God"; this was especially appropriate for what was then the Syrian Protestant College. And in the late Middle Ages, astronomy was one of the seven liberal arts, a required part of every basic university education — for much the same reason. Thus, for many centuries, astronomy was considered essential for what every educated person should know. The organizers of this colloquium thought it would be informative to learn more about the historical background to our colloquium and asked if I would speak on the history of astronomy teaching over the ages. I demurred at such an overwhelming topic, which would require a major research program, and have offered instead something about the history of astronomy textbooks, because this subset provides answers to at least some of the broader questions of how astronomy has been taught.

I begin with a venerable textbook whose popularity remained unabated for several centuries. It is the *Sphere* of John of Hollywood, or Sacrobosco in his Latinized form, a thin manual of spherical astronomy composed in Paris around 1220. The *Sphere* was among the earliest science books printed, an incunable (that is, pre-1501) edition appearing in 1472. It is sometimes said that Sacrobosco was the all-time best seller among the authors of astronomy texts. In its heyday, in the sixteenth century, something over 100 different editions were printed, slightly more than one

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a year. Typical press runs for popular books in those days were about a thousand copies. So, including a few editions from the fifteenth century and a few more in the seventeenth, I would guess that perhaps as many as 200,000 were printed. There are among us authors of popular texts who have surpassed Sacrobosco's success.

By our present standards the *Sphere* of Sacrobosco is painfully elementary and narrow. Its four short chapters begin with a topic found in every astronomy textbook since then, namely, the spherical nature of the Earth. In the sixteenth century, a key center for astronomy teaching was the Lutheran University of Wittenberg, and many of the Sacrobosco editions were produced there. It is interesting to examine how the arguments for the spherical Earth were actually displayed in these editions. That the Earth was round in a north-south direction depended on the aspects of the stars such as the observed height of the pole. That the Earth was round in an east-west direction could be demonstrated by comparative times of a lunar eclipse as viewed from different longitudes. At first, these points were made with small and rather busy diagrams, but beginning in 1538 the books incorporated pages with moving parts, the so-called volvelles, to aid the student's comprehension. From then on, virtually every edition produced anywhere in Europe carried the same three volvelles. The second volvelle actually did double duty, for it helped to introduce the material in Sacrobosco's second chapter, on the equator, ecliptic, the zodiac and so on (see Fig. 1).

Sacrobosco's third chapter continued with the rising and setting of stars throughout the seasons. Like modern texts that attempt to attract non-scientists with enrichment from cultural material, Sacrobosco's chapter is illustrated with numerous poetic quotations, from Virgil, Ovid, and Lucan. For example, he quotes a line from Virgil, "And the dog, yielding to the adverse star, sets" to illustrate the heliacal setting of Sirius as the seasons advance.

In contrast to the cheap, small, octavo-format texts that were probably required at major universities, some editions of the *Sphere* were on a larger scale and often very attractively printed. There were also translations into the vernacular — German, French, Italian, Spanish, English — generally substantially edited to include fresh material.

Sacrobosco's treatment of planetary motions came in a very short final chapter. It was so perfunctory that a demand quickly arose for a more advanced text to explain, qualitatively, the nature of Ptolemy's epicyclic models. An anonymous text called the *Theorica Planetarum* soon described Ptolemy's geocentric planetary system. By the middle of the fifteenth century, Georg Peurbach undertook a revision, which he called the *New Theory of the Planets* — not a new theory, just a new book. Thus, alongside the Sacrobosco there were also many editions of the *Theoricae Novae.* As was the case with Sacrobosco, Peurbach's brief work attracted commentators who explained and expanded the text. One of the best was the edition produced by Erasmus Reinhold, the senior professor of astronomy at Wittenberg and the leading astronomical pedagogue in the generation following Copernicus. In fine Wittenberg tradition, his version included two volvelles to exhibit the Ptolemaic epicycle on a movable deferent disk.

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Fig. 1. Sacrobosco's Sphaera *(Wittenberg, 1538), the first edition with moving parts. The motto "No day without its lines" is an ancient proverb cited by Erasmus; traditionally it meant no day without its special work, but here as a pun it refers to the daily linear path of the sun shown below the movable part.*

With the mention of Copernicus comes the question of how new material was introduced into the curriculum. Copernicus' 1543 *De Revolutionibus* was far too technical and much too expensive to serve as an undergraduate textbook — it cost about $150 by modern standards — but it went into the hands of most university astronomy professors, who undoubtedly alluded to Copernicus in their lectures. In Italy, the Jesuit astronomer and professor at the Gregorian University in Rome, Christopher Clavius, enlarged the Sacrobosco by an order of magnitude, so much so that it has to be considered his own textbook and no longer a mere edition of Sacrobosco. In the revised edition of 1581, he mentioned the Copernican astronomy at least indirectly, saying that Copernicus had made astronomers realize that the Ptolemaic arrangement might not be the only one. Clavius revised his textbook half a dozen times, and in the edition placed into his collected works (which was much too monumental to be carried around as a textbook) he even mentioned Galileo's new telescopic observations.

Michael Maestlin, the astronomer at Tubingen University and best known as Kepler's teacher, produced his own new, independent textbook in 1570. It contained scattered references to Copernicus, but nothing about the heliocentric cosmology.

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Nevertheless, Maestlin regularly discussed Copernicus in his classes, and there the young Johannes Kepler first learned of Copernican astronomy. Kepler himself ultimately produced a squat, fat textbook containing more words than any of his other writings. Called *The Epitome of Copernican Astronomy*, it is generally believed by historians of science to have been one of the most widely used texts of the early seventeenth century, but they are wrong. Just because a historian of astronomy once said so does not make it true. I think it unlikely that a text that went through only two printings in that century had a widespread use as an assigned university text. Maestlin's pocket-sized volume went through seven editions, for example.

The really common text from the middle of the seventeenth century seems to be Pierre Gassendi's *Institutio Astronomica.* The French cleric's book was reprinted both on the Continent and in England. It naturally began with the standard material on the sphere, but it also mentioned the phases of Venus (newly discovered by Galileo) and had an extensive discussion of the Copernican and Tychonic systems. Gassendi's book served as an early astronomy text at New England's Cambridge, which meant that Harvard men not only learned about Tycho as well as Copernicus, but they also could read Galileo's *Starry Messenger* and Kepler's *Dioptrice*, which came in the same volume.

By the time Newton's *Principia* was published in 1687, the Tychonic system was a dead issue, although this would not prevent Lalande, nearly a century later, from including several pages of refutation even in the abridged version of the text. More of that presently, but first we must note that Newtonian physics placed a new and heavy burden on the astronomy teacher. Never before had there been so much difficult mathematics that really spoke to a physical understanding of the heavens. The early English textbook authors did not hesitate to treat their students to ample doses of geometry. David Gregory, John Keill, and William Whiston all included the standard topics of spherical astronomy, but added plenty of mathematics as well as timely new topics such as planetary satellites and comets. The English version of Whiston's Cambridge lectures, published in 1728, began, as did Sacrobosco, with the size and shape of the Earth. He next took up diurnal motion and precession, followed by Huygens' photometric method for deducing the distances of the fixed stars. The unsolved problem of trigonometric parallaxes loomed large, with a discussion of Robert Hooke's attempts to observe them. For the fourth lecture, there was apparently not enough material on nebulae, so Whiston immediately turned to the ellipse and Newton. With that, he had plunged deeply into planetary motions, which fill the heart of his text. By the seventeenth lecture he discussed planetary satellites, and in the next, the rings of Saturn. What amounts to Kepler's third law was shown here in numerical form, but completely anonymously, with no mention of Kepler. There was also the method for finding the velocity of light from Jupiter's satellites, all of this showing the strong influence of Huygens.

If we skip to later in the seventeenth century, the most remarkable textbook is Joseph-Jérôme de Lalande's multi-volume compendium, literally a mini-encyclopedia of astronomy. His abridgment, the *Abrégé d'astronomie* of 1774, provided the information on a more tractable scale. As usual, it started with the

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spherical form of the Earth and the height of the pole. But early on it mentioned stars, including variable ones. The planetary system and theory of motions occupied a significant part of the volume. At the outset he stated Kepler's three laws in the order we use them today. Now Kepler never considered them in one place nor did he number them, so it is something of a mystery as to when this ordering took place. Lalande implied that the threefold numbering was already in use, so I wonder if it was introduced by LaCaille. Since, of the two, Lalande was the more original, perhaps he invented the 1-2-3 order without claiming credit.

Lalande, a vehement atheist, took several pages to refute the objections against the heliocentric cosmology, saying "I respond with the utmost pleasure to the objections Tycho Brahe had against the Copernican system." He also took a crack at Riccioli, the Jesuit who, a century earlier, had defended the Catholic opinion on the Copernican doctrine as it related to Galileo's trial, and he mentioned that certain Copernican books were still included on the latest edition of the *Index of Prohibited Books* — in fact, they didn't disappear until the edition of 1838. To us all this seems anachronistic, but perhaps it is like including a section against astrology or against a 6000-year-old Earth in a modern astronomy textbook. Elsewhere, Lalande included a short section on aberration, which had been found by Bradley in 1728, and he briefly mentioned the problem of parallax but nothing about Huygens' photometric method. At the end he included what is today a familiar parting shot: a section on the plurality of worlds.

Space does not permit a review of all the significant textbooks of the past two centuries, but let me mention what I believe to be the most important astronomy text of the nineteenth century: John Herschel's *Outline of Astronomy*, first published in 1849 as a considerably expanded version of his *A Treatise on Astronomy*, which had appeared in 1831 in the Cabinet Cyclopaedia. Herschel's *Outlines* appeared in fourteen revised London editions between 1849 and 1883. Herschel began with the shape of the Earth, a distant echo of Sacrobosco, but he quickly turned in other directions: refraction, stellar parallax, and then instruments, terrestrial map making, celestial cartography and so on. As for Kepler's laws, he first mentioned the third "as it is called" and then gave Kepler's original order for one and two, that is, calling the law of areas Kepler's first law and the ellipse Kepler's second law, contrary to our present convention. With commendable modesty he described the discovery of Uranus by his father, and he recounted the advantage of the Leverrier-Galle team in having a relevant star chart to aid in discovering Neptune, an advantage that cost the Englishmen Adams and Challis the priority. There was a substantial section on planetary perturbations and a discussion of binary star orbits. Of 600 pages, 100 were devoted to sidereal astronomy, including star clusters and the nebulae in Andromeda, Orion, and Argo (that is, the Eta Carina nebula).

The most important American textbook of the last century was Charles Young's *General Astronomy*, first issued in 1888. Explicitly targeted for the general "liberally educated" student, it nevertheless had a level of mathematics almost never found in our contemporary American astronomy texts (see Fig. 2). A cursory glance at Young's 1900 edition shows about 100 out of 600 pages devoted to stars, nebulae,

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and cosmogony — cosmogony for Young meant Norman Lockyer's meteoritic hypothesis of solar heat — just about the same ratio as in Herschel's 1849 *Outlines.* But that initial page count is slightly misleading, for Young devoted 90 pages to his own specialty, the sun, which included a large section on spectroscopy, topics that were then beginning to be called *astrophysics.*

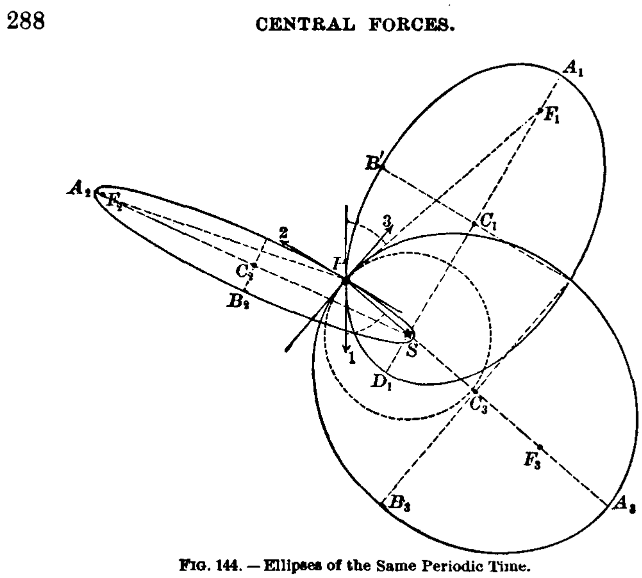

Fig. 2. "Ellipses of the Same Periodic Time" illustrating the mathematical level of Charles Young's General Astronomy *(Boston, 1900).*

The direct successor to Young's college-level text was another from Princeton: Russell, Dugan, and Stewart's two-volume *Astronomy.* Although it was considered too long and detailed for many American colleges, it was nevertheless extremely influential. For the first time the universe of stars and astrophysics (Volume II, 1927) got as much space as the solar system (Volume I, 1926). Secondly, because of Henry Norris Russell's involvement, it included many ideas on the cutting edge of astronomical research. As an example, the second volume included the temperatures of stars from Cecilia Payne's 1925 Harvard thesis, and the statement that "Miss Payne concludes that 'the uniformity of the composition of stellar atmospheres appears to be an established fact."' In fine print the text goes on to consider the puzzling behavior of hydrogen lines, which indicated how very abundant hydrogen must be. Payne, like Russell, Shapley, and the other astronomers of that time, firmly believed in the homogeneity of the universe and therefore assumed that iron, the most abundant element on the Earth, should also dominate in the cosmos at large, despite the baffling results of her analysis. Not until two years later did Russell conclude that hydrogen really was immensely abundant in the universe, and not just a thin layer of light nuclei blanketing the outside of the sun. Surprisingly, this section of the book passed unchanged when the authors undertook a somewhat cursory revision

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of the second volume in 1938.

Not until 1945 was the first volume of "RDS" brought up to date. Because an index to the entire work appeared in the second volume, the publishers, Ginn and Company, allowed Russell and Stewart to revise the first volume as much as they wanted as long as they did not change the pagination of any of the index entries! This head-in-the-sand attitude so discouraged the two surviving authors that it effectively killed the most important astronomy textbook of our century. No full revision of the astrophysics section was ever undertaken.

The second half of the twentieth century has seen a vast proliferation in textbooks, especially in North America, where there continues to be a huge demand for non-mathematical and engagingly illustrated introductions to astronomy. While volumes with a level of mathematics as high as Charles Young's *General Astronomy* are still scarce, at least there has been an unparalleled opportunity to explore fresh ways of presenting both old and new material. I still find two of the American texts from the 1950's particularly memorable in their attempts to replace a somewhat "cookbook" approach with a physically motivated presentation: Wasley Krogdahl's *The Astronomical Universe* (1952) and Otto Struve's *Elementary Astronomy* (1959). Their viewpoints, out of the mainstream defined by the principal texts of that time, have insinuated themselves at least indirectly into several of today's leading guides for beginning astronomy students.

Even if astronomy is no longer required of every university student, probably more students have studied astronomy in the last fifty years than in all the previous centuries combined, more different astronomy textbooks have been printed, and probably in larger quantities than the combined total of all previous eras.

Discussion

C.R. Chambliss: *How was the delicate question of the Copernican versus Ptolemaic hypothesis handled in astronomy texts in Catholic nations such as France in the seventeenth and early eighteenth centuries? I believe that Cassini never publicly accepted the heliocentric system, for instance.*

O. Gingerich: Gassendi at mid-seventeenth century presented both the Copernican and Tychonic cosmologies, I think without a strong commitment. A century later, Lalande, a militant atheist, waged war on those who had defended a fixed Earth. At the end of the eighteenth century, a professor at the Gregorian University in Rome, Settele, had trouble getting an imprimatur (Catholic license to publish) for his heliocentric astronomy textbook, which created a scandal resolved only by a papal decree that finally had the effect of removing the Copernican books from the *Index of Prohibited Books.*

J.-C. Pecker: *It is interesting to note that the abridged versions of textbooks were often named "Astronomie pour les dames": this was the title of one of Lalande's books, an excellent introduction to astronomy for the beginner — of all sexes! It is true, I believe, in all languages in the eighteenth and nineteenth centuries.*

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O. Gingerich: Yes, there was a whole genre of this form of book. In England there was even *The Ladies Almanac*; in it William Herschel first appeared in print.

INTRODUCTORY ASTRONOMY TEXTBOOKS IN 19TH AND 20TH CENTURY AMERICA

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1. Introduction

A survey of 138 introductory-astronomy textbooks spanning 152 years reveals growing consensus regarding each topic's proportion, with some clearly gaining space at the expense of others. The tables in the texts cite curious numbers, claim too many significant digits, neglect to note uncertainties, and are frequently inconsistent with, or badly behind, the research of the times. This study investigates apportionment of topics, planet and star data tables, and categorization of nebulae.

To probe the student/textbook interaction, I used one copy of each of 40 recent introductory textbooks when teaching astronomy in Fall 1986. Students swapped books each session. Texts' treatments were surveyed in daily recitation as well as term papers comparing and contrasting them on specific topics. Most books sound much more positive than current data justify. There was lots of confusing phrasing, shoddy proofreading, and careless assembly of data tables. A few books are shamefully erroneous. There are numerous impressive examples of the imperfection and transience of "textbook learning." The biggest and most pervasive sin was writing in the passive voice "Official Style" of interminable sentences laden with prepositional phrases. Illustrations, while important, are secondary to phrasing. Students need and use chapter summaries, glossaries, and indices. About half prefer paperbacks and half hardbacks. Students rated the books for appropriateness to their needs. The experience may stimulate others to develop controlled experiments to probe the student/textbook interaction.

2. Topics in Textbooks

A text is a worthy, good-faith reference, but in 20 years it will be hopelessly inadequate, and in 100 years, laughable. As knowledge of astronomy has grown, so has the number of topics and the amount of data that could be presented. Thus, the proportions of various topics have changed over the centuries. The accompanying graph demonstrates some of the changes.

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