

## Victor Kennedy

University of Maribor

Faculty of Education, Department of English and American Studies

# Astronomical References in Chaucer: What Can Modern Students Learn from Studying Ancient Texts?

Summary

One of the problems in the field of English literature studies is that, with compartmentalization and specialization, it becomes introspective to the point where it devolves into the study of metafiction and metacriticism. At its heart, however, literature has to be about something: Thackeray claimed its subject is human nature, but human nature is based in the interface between human and nature. This paper explores some of the problems in the interface between human knowledge, institutions, and nature, and will offer an example of cross-disciplinary, historical study to illustrate a well-known but, to most modern readers, impenetrable medieval text, Chaucer's *Treatise on the Astrolabe*. It ends with three recommendations: look to history, cross boundaries between academic fields, and use practical, as well as theoretical, teaching methods.

**Key words:** Chaucer astronomy, astrology, astrolabe

# Astronomski napotki pri Chaucerju: česa se lahko današnji študenti naučijo iz starih besedil?

Povzetek

Eden izmed problemov študija angleške književnosti je njegova introspektivna usmerjenost v raziskovanje metafikcije in metakritike, ki je posledica drobljenja stroke na specializirane in področne interese. V osnovi, namreč, književnost nujno govori o nečem. Thackeray trdi, da je njegov predmet človeška narava, toda ta je odvisna od medsebojnosti človeškosti in narave. Prispevek se dotika nekaterih vprašanj povezanosti človeškega védenja, institucij in narave ter predstavi primer meddisciplinarne, zgodovinske obravnave znanega, a večini bralcev nedoumljivega srednjeveškega besedila Geoffreyja Chaucerja z naslovom *Treatise on the Astrolabe*. Avtor sklene svoje razmišljanje s tremi priporočili: upoštevaj zgodovino, glej čez meje akademskih polj in uporablaj praktične pa tudi teoretske metode učenja.

**Ključne besede:** astronomija, astrologija in astrolab pri Chaucerju

# Astronomical References in Chaucer: What Can Modern Students Learn from Studying Ancient Texts?

## 1. Introduction

When we study Chaucer's *Miller's Tale* in my first year medieval English literature course, I find that many of my students know quite a lot about astrology, but very few of them know anything about astronomy. I find this distressing: it has often been argued that the imbalance in knowledge, and concurrent clinging to ancient superstitions and junk science, is a symptom of a breakdown in our educational system. In contrast, Florence Grimm pointed out in 1919 that Chaucer himself knew more about astronomy than the average modern person does (Grimm 1970, 3); in a series of essays, Edgar Laird and Donald Olson have demonstrated that astronomical references in Chaucer's works are accurate and based on observation, not on second-hand sources (Laird and Olson 1990; Laird and Olson 1996). This paper will explore some of the problems past and present that have caused lapses in our knowledge and weaknesses in our educational system, and will propose a solution based on practical applications of historical and cross-disciplinary instruction, using the example of Chaucer's *Treatise on the Astrolabe*.

2. Post-Enlightenment mythology tells us that we have progressed from the time of the "Dark Ages", but anyone who reads medieval literature knows that this claim is often exaggerated. Our knowledge has suffered, and continues to suffer, periods of setback caused by wars, political pressure, and wilful ignorance. Scientific progress, like knowledge in general, has not been steady or linear, but instead has consisted of giant leaps of understanding built on discoveries that changed our world view in a generation or less, followed by eras of steady progress built on these insights, and, sadly, times of reversal. The history of science shows non-linear progress interrupted by divergence within belief systems, which can be roughly characterized as conflicts between science and superstition, innovation and tradition, and discovery and authority, both within the scientific community and within society in general. Progress is encouraged by educational approaches based on the scientific method: new ideas are tested by peer review and constant re-evaluation of current theory; students and scientists learn by doing, and from their mistakes. Progress is slowed by vested interests in politics, the Church, and business; by dogma, hidden agendas, secrecy, and "saving the appearances" (Koestler 1989, 51); and by educational methods that depend on memorization of officially sanctioned works of authorities, which are often both written and published by committee (Gingerich 1990).

It is often lamented that in the modern world there is a perceived split between the sciences and the arts resulting in a lack of progress, or even regression, caused by weaknesses in the educational system; some argue that the break is historical, caused by the Church during the Renaissance; others that because of the ever-increasing amount of knowledge, it is impossible

to become expert in and stay abreast of new developments in more than one field. While there is some truth to these arguments, the schism is essentially a voluntary one, caused by lazy thinking and teaching habits, and essentially illusory. It is clear, though, that in many countries, fewer students pursue the sciences, and many people know little about science. Thus, even otherwise well-educated people still today hold on to outmoded beliefs and superstitions, despite the availability of modern scientific education.

History shows that mistaken beliefs have been held for long periods of time. Such mistakes can stem from lack of knowledge, but often they persist even after better explanations for observed phenomena have been proposed. This seems irrational, but there are often conflicting influences at work. In his history of science entitled *The Sleepwalkers*, Arthur Koestler gives a non-scientist's view of astronomy from ancient Greece to Newton.

The main conflict in Koestler's account of the history of astronomy is that between the proponents of an earth-centred and a heliocentric universe. Aristarchus (310 B.C.) proposed a theory of the heliocentric universe, but the philosophical, religious and scientific establishments preferred the more conservative views of Plato and Aristotle, and Aristarchus's heliocentric theory was ignored for 1700 years until Copernicus. In the face of observational evidence, one is tempted to ask, how could scholars ignore the evidence in front of them? Koestler maintains that there was a "divorce of reason from belief" (Koestler 1989, 53) in the thinking of Plato and Aristotle. At the end of the age of Greek culture and civilization, leaders and intellectuals preferred to focus on ideals instead of reality. Later, Roman thinkers were more interested in politics and military theory than abstract philosophy and science, and scientific discovery took a back seat to the requirements of political and military leaders for astrological predictions. After the fall of Rome, scholarship found a refuge in the Arab world, but Arab scholars also focused on practical measurement rather than cosmological theory. When classical learning was reintroduced to the west by Arab scholars around the 13<sup>th</sup> century, cosmological speculation began to flourish again, but for three centuries logical, simple systems were obscured by dogma.

**3.** As modern readers, we are tempted to question the motives and abilities of our ancestors, for with hindsight it is easy to look on their elaborate systems of epicycles and equants, compare them to the simpler model of the heliocentric universe, and ask how they could have so deceived themselves. Robert Park argues that many people partook of a kind of wilful blindness, a "controlled schizophrenia" (Koestler 1989, 77), which in its modern form Park describes as "pathological science" (Park 2000, 9). The Christian worldview of the Church was so strong that mathematicians and physicists were forced to compartmentalize their thinking to accommodate both their scientific and religious beliefs. This led to the technique of "saving the appearances", a privileging of theory over observational evidence (Koestler 1989, 77). Contrary to popular modern belief, however, Renaissance scholars were seldom persecuted by the Church for their scientific research, but were actually encouraged in their work. Most of the time, science and religion coexisted peacefully; the Jesuits, for example, were among the foremost astronomical researchers of the Renaissance. But there were extreme cases: "saving

the appearances” came to a head during the trial of Galileo, who was urged by Pope Urban to continue to research, publish, and teach his theories concerning the Copernican universe, so long as he made it clear that this theory was only hypothetical. Galileo refused, and precipitated the banning not only of his own works, but those of Copernicus as well. Despite Galileo’s later recantation, the resulting schism between science and religion became practical, not merely theoretical, and has lasted ever since.

4. In the history of ideas, the balance has often tipped back and forth between scientific and religious belief systems. One famous example of a balanced outlook is that of Johannes Kepler, who was driven to his discoveries by strong religious beliefs; in the search, which a modern commentator would probably consider mistaken, for a harmonious relationship of spheres, he discovered the three laws which provided Newton, another devoutly religious man, the foundations of his revolutionary system of physics. Newton and Kepler, though, were able to accept the results of their work. Not all of us are so open-minded, and conflict occurs when we are unable to discard outmoded ideas and prejudices.

Some current reasons for widespread misunderstandings in and about science have recently been characterized by Park as “voodoo science”; Park’s thesis is that many people are misled, not solely by the difficulties of modern science, but by inadvertent and wilful ignorance. Park defines three categories of voodoo science: pathological science, junk science, and pseudoscience. “[S]cientists, no less than others, are inclined to see what they expect to see ... This is pathological science, in which scientists manage to fool themselves”; junk science uses “arguments deliberately intended to befuddle jurists or lawmakers with little or no scientific background” and “consists of tortured theories of what could be so, with little supporting evidence to prove that it is so”; finally, “Ancient beliefs in demons and magic still sweep across the modern landscape, but now they are dressed in the language and symbols of science ... This is pseudoscience. Its practitioners may believe it to be science, just as witches and faith healers may truly believe they can call forth supernatural powers” (Park 2000, 9–10). Common acceptance of voodoo science results from the extreme separation of and boundaries erected between intellectual disciplines. Many scientists, for example, know little about law, and many lawyers and judges know little about science. Important court cases can be decided on the basis of expert testimony, but both sides to a dispute can find expert witnesses to testify in support of either side of an argument. Laymen, unfamiliar with a field of knowledge, find it impossible to decide among competing expert testimonies.

Breakdowns between fields of knowledge can lead to denigration of the value of other ways of viewing the world. Those who feel threatened by other viewpoints often retreat into extreme reactionary conservatism. One might think that the attitudes of rigid conservatism and the willingness to impose them on educational systems evident during the Middle Ages and Renaissance are a thing of the past, but a look at the news and any time spent in a university shows this is not true. Dependence on established authority is not limited to authoritarian

regimes, as can be seen in current debates in the United States between scientists and religious conservatives about such topics as the teaching of evolutionary theory and “creation science” in schools. For example:

Irritated that his state earned an A for its treatment of evolution in science education from the Fordham Foundation’s study *Good Science, Bad Science: Teaching Evolution in the States*, authored by science education expert Dr. Lawrence Lerner, South Carolina Senate Republican Mike Fair has introduced legislation in the hopes of downgrading the state’s ranking. Senate Bill 153 calls for creating a 19-member committee that would hear testimony from top scientists and report to the General Assembly on “whether alternatives to evolution as the origin of species should be offered in schools,” reported *The Greenville News* on May 1, 2003 (Scott, May 8, 2003).

In another example, school boards in Kansas recently replaced the teaching of evolution with instruction in “creation science” (i.e., the “theory” that God created the world in six days, 4,000 years ago) in some districts which, according to many university faculty members and admissions officers, greatly decreases the likelihood that graduates of such schools would obtain admission to most American universities (Smillie 2000).

**5.** The attempt to silence scientists and replace science teaching with fundamentalist religious instruction is not limited to Middle Eastern theocracies, but while trying to turn back the clock on the modern world may be comforting to those who feel threatened by technological progress, it is, as Jared Diamond argues in *Guns, Germs, and Steel: the Fates of Human Societies*, a recipe for disaster (Diamond 1999). While studying alternatives to accepted theories is an accepted way to test them, trying to ignore them is not. Taking a historical perspective, however, puts current thoughts, attitudes and beliefs into a larger context and not only shows how we got to where we are today, but gives us an opportunity to learn from the mistakes and successes of the past. By looking to history we can see how our current situation arose, and how fields of knowledge have diverged. One way to constructively understand the modern world is to study the knowledge and methods of the past, and to try to recreate the predecessors of modern tools and instruments, to better comprehend how we arrived at our current state of knowledge. The astrolabe, for example, is an ancient astronomical instrument that connects East and West, past and present, and, in Chaucer’s writing, science and art, the three main connections that comprise the subject of this essay. The astrolabe, an instrument that could reasonably be said to be the predecessor of both the clock and the computer, was one of the most important instruments available to astronomers for over a millennium, from its development around the beginning of the 5<sup>th</sup> century until the 18<sup>th</sup> century. Reading its history gives an overview of the development of science, mathematics, and engineering over the last 1500 years; using one gives insight into the basics of what used to be called celestial mechanics, and into the way scientists and humanists of the middle ages and Renaissance perceived the world around them. An early Arabic treatise on the astrolabe was written in Baghdad by ‘Ali ibn ‘Isa, one of Caliph al-Ma’mun’s astronomers, and later Arabic treatises describe how the instrument could be used to solve problems in astrology, astronomy and timekeeping. Many of

these treatises were translated into Latin in the 12<sup>th</sup> and 13<sup>th</sup> centuries, and in about 1390, these formed the sources for Geoffrey Chaucer's *Treatise on the Astrolabe* (Gingerich 1986).

6. Chaucer's *Treatise* is an example of a body of scientific knowledge brought into one culture's scientific heritage from another through translation. However, in writing a practical manual, Chaucer depended as much on the physical astrolabe before him as on his sources for his writing, and he corrected some errors and questioned the assumptions of his sources (thus avoiding some of the errors of modern textbook writers (Gingerich 1990; Pasachoff 1990; Chandler 1999)). Chaucer's *Treatise* was an exercise in science education, not a work of scientific discovery. In the Preface, Chaucer addresses the work to his son, Lewis, and explains that he is writing this work because his son is too young to understand Latin or Greek, but is old enough to understand the scientific principles behind the use of the astrolabe.

That this is in fact an instructional text is further emphasized by the reference in Part I to a "sphere", a globe which Chaucer had used to show Lewis the motions of the Sun, Moon, and planets. It is clear from the scale of the gradations on its rete (the rotating scale on the front of the astrolabe) and face that the astrolabe Chaucer gave Lewis was a small, student model, not a large one of the type used by professional astronomers of the time.

Chaucer was not a scientist, but a scholarly man in the modern sense of the term "Renaissance man". He was a courtier, poet, and administrator, for much of his career charged with the responsibility of the customs office, in his early life a soldier, and in his later, a diplomat. The range and depth of his knowledge is formidable. He was also a translator, as shown by the fact that *A Treatise on the Astrolabe* mentions his sources, *Compositio et Operatio Astrolabii*, by Messahala, an 8<sup>th</sup> century Arabian astronomer, and *De Sphaera*, by John de Sacrobosco, both available to Chaucer in Latin. Unlike many of his contemporaries, Chaucer had a critical view of "authorities" and the concepts they promoted: while he quoted and approved of his scientific sources, in the *Treatise* he refuted the practice and theory of astrology, as he did elsewhere in "The Franklin's Tale", one of the fictional *Canterbury Tales*:

another craft. . . Of the operations  
touching the eight and twenty mansions  
that longen to the Moone, and swich foleye  
as in oure days is nat worth a flye (ll. 1133–36)

In the introduction to the *Treatise*, Chaucer announces that the finished work will contain five parts: Part I is a description of the astrolabe (this is in effect an instruction manual to accompany the astrolabe that Chaucer had given his son) and the function of all its parts. Part II is a series of 40 practical exercises, much like the problems set in a modern-day physics or astronomy textbook. These problems and solutions are exercises for using the astrolabe to find times, latitudes, longitude, the position of the Sun, Moon, and stars, and predictions of their positions. An additional set of problems was added in a supplement in 1397, including exercises based on geometrical measurement of the height of buildings using the Sun's shadow.

Unfortunately, the *Treatise* was never finished; Robinson speculates that this may have been because of the death of Chaucer's son before the work was finished, but records from the 14<sup>th</sup> century are incomplete, and there is some controversy over this. It may be that, as with *The Canterbury Tales*, Chaucer just never found the time to complete it. The introduction goes on to describe three more parts that were never written, or, if they were, have not survived. Part III was to be a table of longitudes and latitudes of fixed stars; a table of declinations for the Sun; tables of longitudes for cities and towns; tables for setting clocks, to find the altitude meridian. Part IV was to be a theory of celestial motions, including a table of the motions of the Moon and planets. Part V was to be a theory of astrology, and, given his comments elsewhere, one can speculate that this was intended to be a more complete debunking.

Interestingly, Chaucer's poetic works make extensive use of themes, characters, and motifs from classical mythology and astrology at the same time his prose works, and to some extent, his fictional narrators, satirize contemporary belief in them. As a courtier, he was writing to please an audience, part of which was more credulous than he was himself, but which contained some very sophisticated listeners, including the king himself; today his work is appealing for its subtle use of irony and satire, which his audience may or may not have grasped. As with modern fiction, this does suggest that Chaucer saw fiction as operating on different truth-rules from other modes of writing. Certainly his *Treatise*, addressed to his own son, is neither satiric nor ironic, but clear and plain-spoken in both its scientific instruction and its criticism of astrology.

7. An example of Chaucer's mixture of narrative modes, common in medieval and Renaissance literature, can be seen in his poetic dream vision, *The House of Fame*. For the most part an allegory on fame and vanity, Part II contains a meditation on perception and understanding based on scientific principles (ll. 729–82) in which notions of gravity recognizable to anyone familiar with modern-day physics are related to the philosophy of Aristotle and Plato, and then to the kind of analogy and metaphor used in literature and common knowledge. In this section Chaucer explains, as do modern literary theorists and psychologists, how we use analogies based on what we already know in order to understand what we don't. For example, in lines 788–821 Chaucer uses waves spreading in a pond as an analogy for the spreading of knowledge (and rumour). In lines 935–63 he points to astronomical references to the Milky Way in ancient myth, and in 990–1018 he mentions the sources of astronomical references and names in mythology and poetry.

Combining scientific, literary, and popular cultural modes was a technique used in the nineteenth century by writers such as Coleridge to explore difficult issues in philosophy, and today popular science writers and scientists who write in order to popularize scientific concepts still favour this method. An excellent example can be seen in the writings of biologist Stephen Jay Gould, who uses architectural metaphors to illustrate principles of evolution (Gould and Lewontin 1979). In research, as well as education, there is cross-fertilization of ideas between disciplines. Koestler wrote approvingly of the use of different modes of thought in research,

and concluded that it is an essential part of scientific discovery. Philosophers, as well as poets, have often written of the benefits of metaphor and analogy in imaginative creativity.

This is where the astrolabe can come in handy in developing imagination and creativity. Modern science and technology have progressed far past the stage where an astrolabe is of any practical use for navigators or astronomers, but it can still be of use for teachers, not only in the sciences, but the arts as well to illustrate and help visualize basic concepts that can be obscured by instruments using more advanced technology. Today's research projects use giant telescopes and space telescopes, and collect data at many wavelengths, while astronomy education uses the internet, as well as planetarium and simulation software, and amateurs and home educators have access to computers, telescopes, and equipment far more advanced than that available even to professional scientists of previous centuries. On the other hand, one could argue that our culture is so dependent on technology that our use of technology interferes with, or masks deficiencies in, real understanding. Using a simpler technology from a time long past can clarify some of the principles that modern instruments can hide.

There are strong arguments in favour of learning the basics well. Many teachers hurry through their lessons quickly, citing the need to cover the curriculum for the mandatory final examinations. As a result, unfortunate students who cannot keep up or fall behind for some reason become hopelessly lost and confused. In the end they learn nothing but a dislike of the subject, and forget everything they have crammed and memorized for examinations in the "ram, remember, regurgitate" system (Gadpaille 2004). A different philosophy of education concentrates on the quality of material learned over quantity. Learning basic concepts well provides a foundation, as well as a motivation for later, possibly independent, learning.

Owen Gingerich's idea of learning by using the historical method is shared by many science teachers who use astrolabes in elementary and high school science courses (Gingerich 1990). Plans for building these are available on many school web sites, along with exercises that illustrate their use. A working reproduction made of laminated cardboard is available from Janus, an American company, together with an instruction manual very much like Chaucer's, although written in modern English. One can see the resemblance here between medieval humanistic instruction and contemporary student-centred teaching.

The Janus astrolabe comes in a package containing two laminated cardboard astrolabes, a classical reproduction of the kind used in Chaucer's time, the other a modern adaptation, with a diameter of 18 centimetres, and a 57 page instruction manual. The astrolabe is configured for the user's latitude and longitude. Features and operation are described and explained in the text, which contains an introduction to the astrolabe, followed by a description which includes instructions on how to read an astrolabe with explanations of the altitude/azimuth plate, rete, ecliptic and rule.

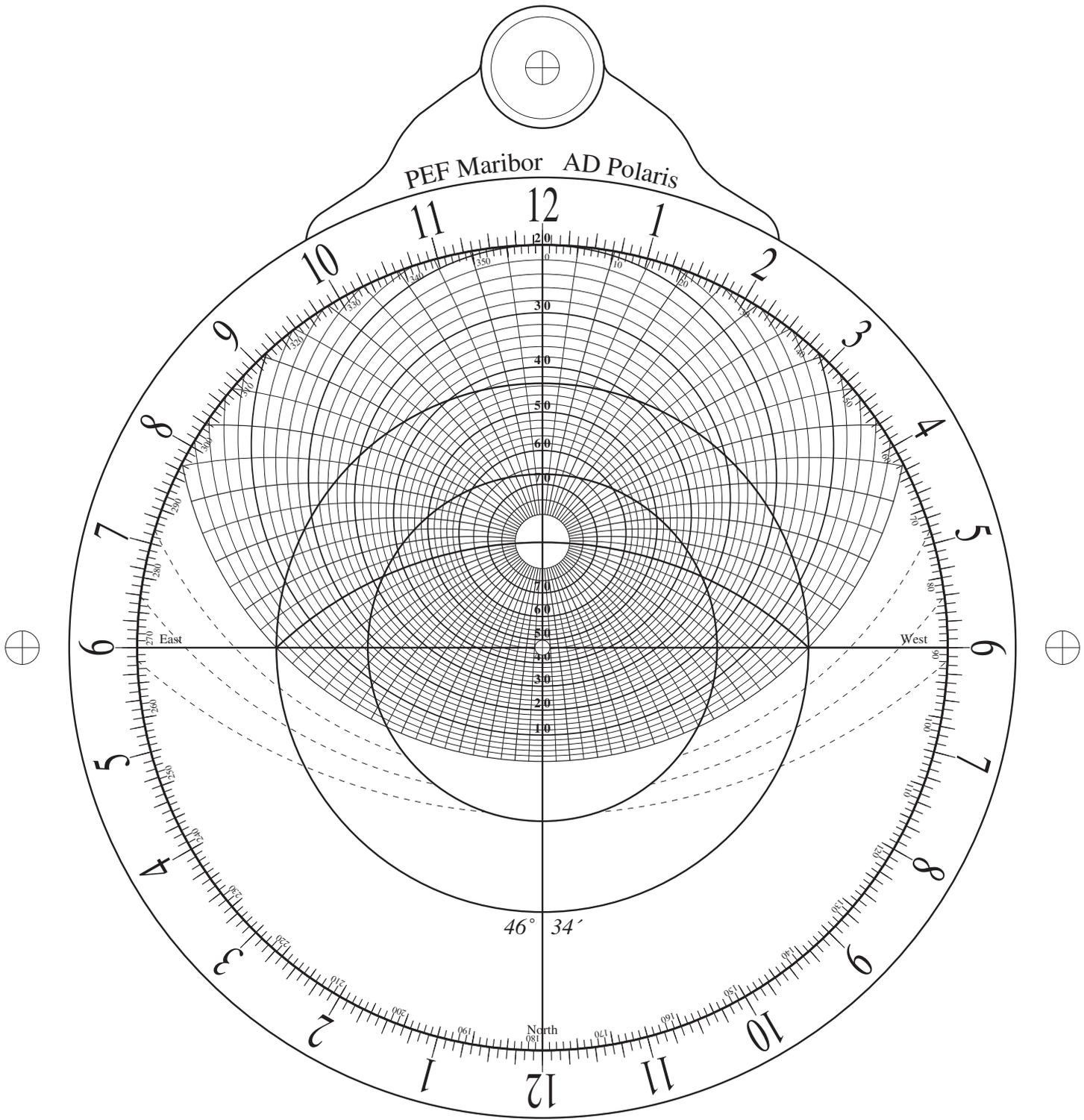
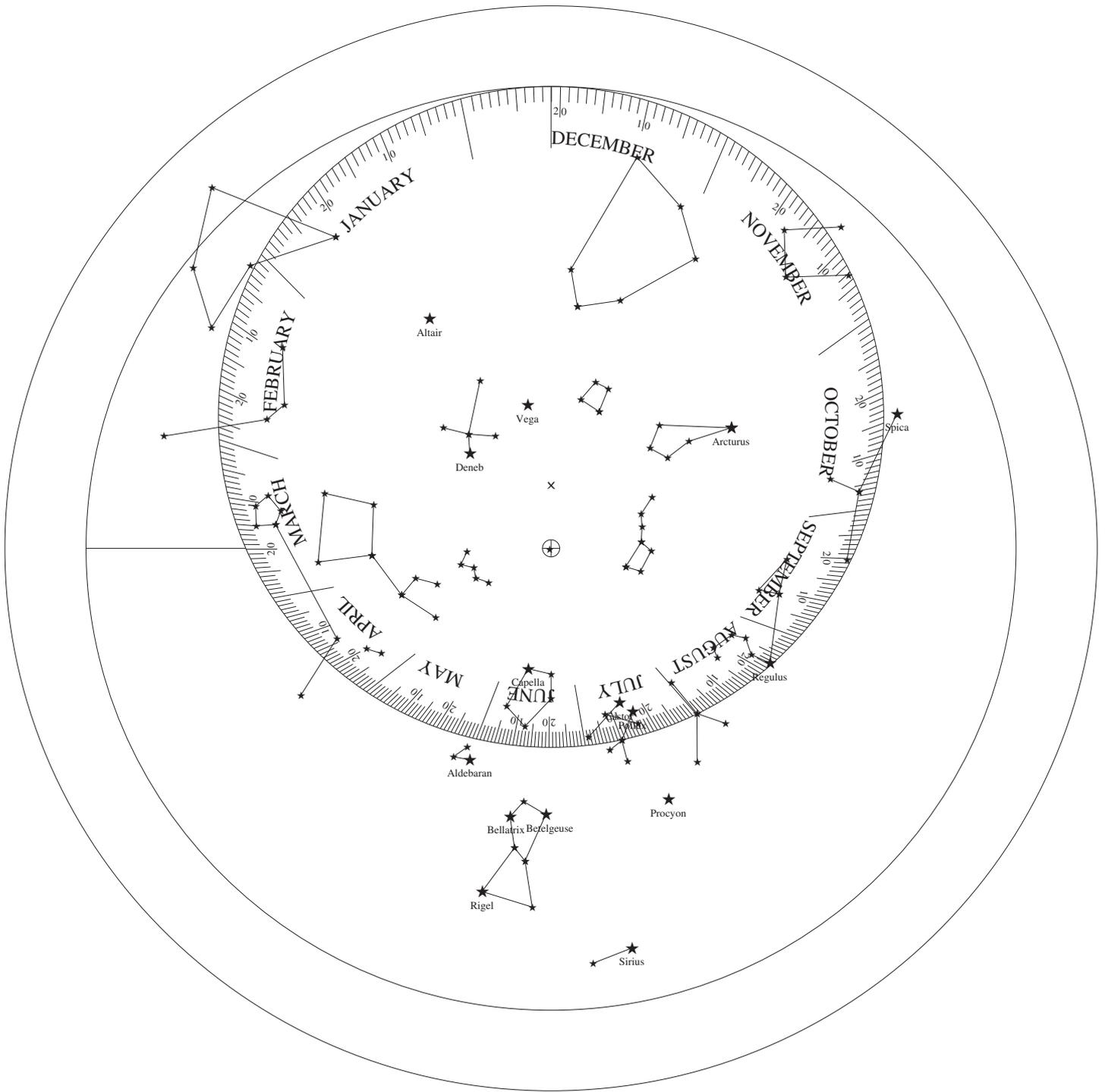


Figure 1: Janus modern astrolabe (front)



PEF Maribor AD Polaris

2006

Figure 2: Janus modern astrolabe (back)

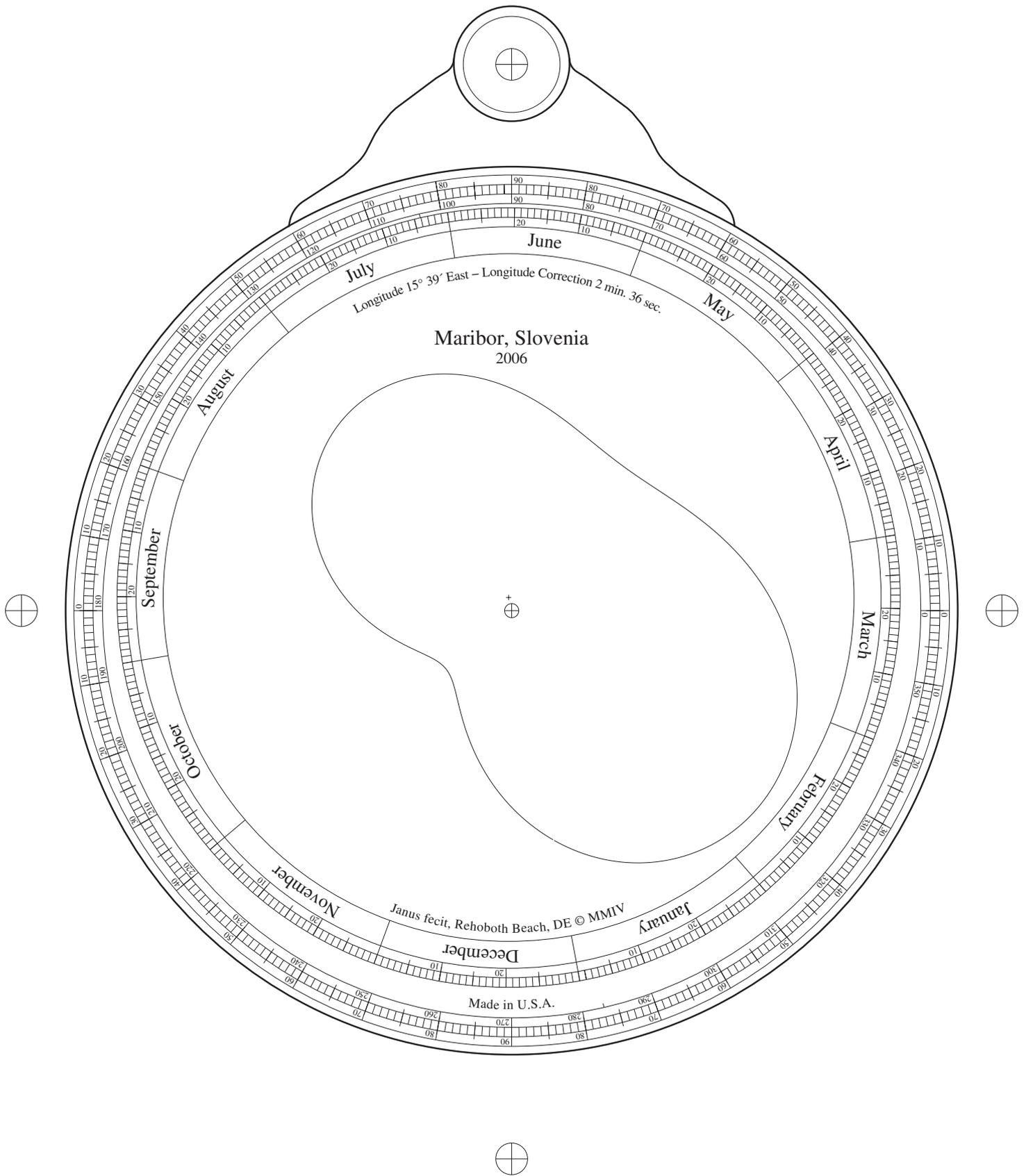


Figure 3: Janus modern astrolabe (rete)

Using the astrolabes with the instruction manual is fairly straightforward. For example, Chaucer set his son a simple problem:

22. To know in speciall the latitude of oure countre, I mene after the latitude of Oxenford, and the height of oure pool.

Understond wel that as fer is the heved<sup>1</sup> of Aries or Libra in the equinoxiall fro oure orisonte<sup>2</sup> as is the cenyth<sup>3</sup> fro the pool artik; and as high is the pool artik fro the orisonte as the equinoxiall is fer fro the cenyth. I prove it thus by the latitude of Oxenford: understond wel that the height of oure pool artik fro oure north orisonte is 51 degrees and 50 mynutes; than is the cenyth fro oure pool artik 38 degrees and 10 mynutes; than is the equinoxiall from oure cenyth 51 degrees and 50 minutes; than is oure south orisonte from our equinoxiall 38 degrees and 10 mynutes. Understond wel this rekenyng. Also forget not that the cenyth is 90 degrees of height from oure orisonte, and oure equinoxiall is 90 degrees from our pool artik. Also this short rule is soth, that the latitude of eny place in a regioun is the distaunce fro the cenyth unto the equinoxiall (Chaucer 1957, 555).

Modern students, however, may find that the language interferes with the concepts and fail to “understond wel this rekenyng.” The same problem, translated into modern English, is set in Janus’s manual:

What is the maximum and minimum altitude of the Sun for 46° 32’ north latitude?

The answer to this question requires only the plate. The sun’s maximum altitude is when the Sun is at the summer solstice and its declination is equal to the latitude of the Tropic of Cancer. Look at the latitude of the Tropic of Cancer at the Meridian and note that it is about 66.9°. This is the maximum altitude of the Sun for the latitude. You can confirm this answer with a little arithmetic. The sun’s altitude for a latitude = 90° - (latitude – Sun’s declination). The minimum declination of the Sun is about –23.26°. Do the same for the minimum altitude (answer: 20° 2’) (Morrison 2003, 30).

This takes longer to read than to do, but it is a useful exercise for anyone interested in learning not only about Chaucer, but also about the medieval and early Renaissance worldview. I suspect that many modern English scholars know of Chaucer’s *Treatise*, but have not read it closely. However, practicing some of the exercises described in the text can clarify concepts which were clear to him but may have been opaque to us. In this case, knowledge comes through doing. Learning is not just an abstract, intellectual acquisition of knowledge; there are other avenues to knowing, and different learning styles among students.

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1 head  
2 horizon  
3 Zenith

The experience of using such an instrument is valuable not only to students but to teachers as well. Going out under the sky, looking up, measuring the Sun and stars and comparing them to the mapped version, then rotating the rete and rule to perform calculations, give a much more tangible and visceral impression of how the Earth's rotations, revolutions, and seasonal variations affect the sky than performing exercises in a textbook, or even finding objects with a good computer planetarium program. While educational in their way, the latter two methods remain abstractions compared to manual observation and calculation with the astrolabe. Learning how to use it gives a concrete appreciation of the knowledge and sophistication of our ancestors. By using the astrolabe one can come to understand Chaucer's *Treatise*, leading to a better appreciation of the astronomical references in his other works, including "The Miller's Tale", "The Wife of Bath's Prologue and Tale", "The Franklin's Tale", "The Merchant's Tale" and "The House of Fame", and to a deeper understanding of the world view of other medieval and Renaissance writers.

**8.** We can read about the medieval and Renaissance world, but we cannot actually experience it. We can, however, recreate some aspects of it and experience those. Most teachers would agree that active learning beats passive learning. Richard Feynman described his exposure to the Brazilian university system: "After a lot of investigation, I finally figured out that the students had memorized everything, but they didn't know what anything meant... Finally, I said that I couldn't see how anyone could be educated by this self-propagating system in which people pass exams, and teach others to pass exams, but nobody knows anything" (Feynman 1985, 212, 218). There are many possible sources of error in education, including uncritical acceptance and copying of authoritative works, and mistakes introduced in the editing process. One of the main problems with knowledge transmitted through textbooks, lectures, and even the World-wide Web, is that until it is internalized by practice and experience, it remains second-hand and abstract. It is difficult to find and correct errors in abstract information. Learning by doing, in addition to reading, is a better educational method because concepts become much more firmly embedded, and mistakes become easier to recognize. Renaissance scholars rediscovered the knowledge of classical Greece and Rome, but until scientists and academics moved beyond the discovery phase and began to actively experiment and question the authorities, the knowledge they had discovered remained static. Similarly, active participation, including questioning and critical examination, remains the best method of education in modern schools and universities.

## 9. Conclusion

Koestler calls the major characters in his book, Copernicus, Kepler, Galileo and Newton, “sleepwalkers,” because they were not fully aware of the consequences of the system of thought they collectively developed. Copernicus was of the medieval world view, the other three of the Renaissance; together they inspired the age of the Enlightenment, and built the foundation of the modern world view. Each was working in a particular environment, divided in its religious and scientific beliefs, and the vision of reality they constructed helped overthrow both sets of beliefs. The problems they faced, however, are much like the problems discussed above that still plague our society and educational system. Koestler points out that much of the error in Copernicus’s writing stemmed from the fact that he did very little observing himself, preferring to work with observational data he had found in the published works of generally accepted scientific authorities, data, it was later discovered, which were inaccurate. It was the much more accurate data collected by Tycho Brahe, who questioned the findings of his predecessors, that allowed Kepler to finally substantiate Copernicus’s theory.

Clearly, the modern world view is made up of similarly divergent sets of beliefs. It is the interplay between divided belief systems, and the urge to consolidate them into one, that drives much research and discovery: the twentieth century quest to unite quantum mechanics and relativity is a good example. Only the abandonment of old conceptual systems allows the acceptance of new ones, however, and the more established and entrenched such systems are, the more inertia that must be overcome. The transition is not an abrupt one, however, but more like a metamorphosis:

As we observe the workings of the mind of Kepler (or Paracelsus, Gilbert, Descartes) we come to realize the fallacy of the belief that at some point between the Renaissance and the Enlightenment, man shook off the ‘superstitions of medieval religion’ like a puppy getting out of the water, and started on the bright new road of Science. Inside these minds, we find no abrupt break from the past, but a gradual transformation of the symbols of their cosmic experience – from anima motrix into vis motrix, moving spirit into moving force, mythological imagery into mathematical hieroglyphics – a transformation which never was, and, one hopes, never will be entirely completed (Koestler 1989, 262).

Over time, knowledge is lost, suppressed, and distorted in many ways. We are handicapped in our search for understanding by biological, social, and cultural baggage, prejudices, and habits of thought. Multiple educational approaches, including practical, historical and theoretical are necessary if we want to teach clearly and well and overcome these handicaps. Practical experience in particular helps to avoid distortions and mistakes created when theoretical material is uncritically repeated and reproduced. Adherence to one teaching method is as dogmatic as anything we may criticize our ancestors for doing. Combining different approaches to education is like looking at something from different points of view; in doing so, one gains perspective and deeper understanding.

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## Appendix

### Astrolabe exercises – May 7, 2004

#### Telling the time by the elevation of the Sun

1. Hold the astrolabe by the ring at the top so that the Sun casts a shadow from the screw protruding from the back. Set the rule parallel to the shadow, and read the Sun's elevation from the scale on the outside edge.
2. On the front of the astrolabe, align the edge of the rule with today's date on the rete (the transparent plastic circle).
3. Turn the rule and the rete together so that the point where they intersect aligns with the circle corresponding to the elevation of the Sun (in degrees), marked on the meridian line (which runs vertically: north-south).
4. The end of the rule now points to the hour marked on the outside edge of the astrolabe (note: add an hour for daylight savings time).

#### Finding the time of sunrise

1. With the rule on today's date on the rete, turn both until they intersect with the horizon on the east side of the face (on the astrolabe face, the outsidemost circle of the dark shaded circles at the south end).
2. The end of the rule now points to the hour when the Sun will rise (again, add an hour for daylight savings time).

#### Finding the time of sunset

1. With the rule on today's date on the rete, turn both until they intersect with the ecliptic on the west side of the face.
2. The end of the rule now points to the hour when the Sun will set (again, add an hour for daylight savings time).

#### Telling the time at night

1. First, you have to find the elevation of a star. Assume we are out at night and we can see the star Arcturus in the east (follow the arc of the handle of the Big Dipper to find the bright star Arcturus).
2. Holding the astrolabe by the ring at the top, sight along the rule on the back of the astrolabe to Arcturus, and read the elevation from the scale on the outside circle. Let's say it is 50°.
3. Find Arcturus on the rete on the front of the astrolabe, and turn the rete so that Arcturus is on the 50° circle (read the scale on the vertical line that represents the meridian).
4. Turn the rule so that its edge is on the current date (May 7<sup>th</sup>) on the outside scale of the rete.
5. The rule (on the east side) points to 8:55 p.m. (add an hour for daylight savings time)