Culturally relevant College-Level Astronomy Courses for non-science majors

by

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Introduction

In its recommendations on what understandings and ways of thinking are essential for all citizens, the American Association for the Advancement of Science (AAAS) states that "most Americans are not science literate" (AAAS 1990) noting:

> "Science literacy ....has many facets. These include being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology and the sciences depend on one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics and technology are human enterprises and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and societal purposes." (AAAS 1990 p. xvii)

A similar definition of science literacy was given by the National Academy of Sciences (NAS) in their National Science Education Standards (NAS 1996).

In a prescient paper, Arons (Arons 1973) noted that most general education courses fail in having an impact in producing a scientifically literate public because they almost invariably confront the student with little more than a stream of technical jargon that is presented much too rapidly and in too high a volume to allow for any significant understanding of ideas, concepts or theories. The pace and volume also precludes the development of any sense of how concepts and theories originate, how they come to be accepted and how they connect with experiences other than the ones alluded to in the text.

He suggested there are two ways in which positive features can be injected into introductory college-level science courses. One of these involves giving students time to study and develop a genuine scientific understanding of a limited number of significant scientific ideas by a synthesis of their own experience and thought. The second resides in consciously bringing more articulate historical, philosophical and sociological content into these science courses.

With few notable exceptions (Sadler and Shapiro 1990, Zeilik 1998), very little has been done to implement Arons' suggestions in college-level astronomy courses for non-science majors. In light of the recommendations by the AAAS and NAS, it is worthwhile repeating and expanding upon Arons' comments in the context of such courses.

Understanding Ideas vs. Memorizing Facts

Data regarding the initial knowledge state of the 45 students entering my section of the college-level astronomy course during Spring ‘01 (Townsend 2001) indicate that about 6% of students can respond adequately to the question “Why does the Moon have Phases ? ” with a short answer along the lines of

> “ The moon has phases because when it orbits the Earth the sunlight hits one side of it just as it does the Earth. But viewing the Moon from the Earth we can only see parts of the lit side depending on where the Moon is in its orbit about the Earth.”

About 15% of the students can respond adequately to the question “Why do we have seasons ? ” with a short answer along the lines of:

> “We have seasons because the earth is on an axis (tilted) and as it orbits, the Sun’s rays hit it at different angles and cause seasons”

No students could respond adequately to the question ”Why do we believe that the Earth orbits the Sun when the evidence is to the contrary ?”, although 15% of the students echoed Aristarchus’ idea (Arny 2000) when they noted that the belief was based on the fact that “The Sun is much bigger than any of the Planets.” Very little numerical data exists regarding the initial knowledge state of students in these general education courses, but comparison with what is available (Comins 2001) indicate that these numbers are typical.

In a typical course in astronomy these students, and their peers elsewhere, would be exposed to a stream of vocabulary and notation representing the end results of astronomical inquiry. Confronted by this stream they will dutifully listen, read the assigned text, and try to memorize words and phrases so they might recognize them on a multiple choice test. However, the jargon that they acquire is not knowledge or understanding because they and their peers still would not be able to adequately answer the above questions or others like them (Schneps, 1993).

If we wish to do more than render lip service to generating a wider public understanding of science, we need to give students a chance to follow the development or growth of several significant concepts and theories so that they themselves address the questions “How do we know....?”, “What is the evidence for...?” in the context of these concepts and theories. In this way they will be given an opportunity to develop a genuine scientific knowledge of the world and scientific habits of mind (AAAS 1990, pg. 203).

The need to inject these positive features into these astronomy courses becomes much more urgent when we realize that a significant number of students within these courses are pre-service teachers who will eventually be expected to teach astronomy concepts to children in the K-12 schools (Deming and Hufnagel 2001). How can they adequately teach what they do not truly understand (AAAS 1990 p. xv)?

Pace and Understanding

If we want to produce some measure of understanding in our students, in the sense that they can answer the above questions, we must give them time to understand. They must have time to look at the evidence, think about the ideas and experience for themselves some of the steps by which scientists achieved these insights.

This means that we need to "slow down" and " cover less" in these college-level astronomy courses. We can get so wrapped up in beautiful up-to-date words, names and insights that we lose all awareness of how impenetrable the whole subject of astronomy is to a newcomer and how long it takes to develop some understanding of necessary concepts. It seems to me to be pointless to subject students to lectures on stellar nucleo-synthesis, quasars, pulsars, black holes and the big-bang theory when they have no idea of the reason for the seasons (many believe it is due to the variation of the Earth-Sun distance) or of the phases of the Moon (many believe the unilluminated part of the Moon to be the Earth's shadow).

The parts of astronomy that are exciting to the instructor can wait for a later time, they should yield to a need to develop true understanding of some of the fundamental ideas of astronomy in the mind of the student (AAAS, xvi).

The Big Questions

We can gain this needed time by focusing on the "Big Questions" in these courses of astronomy: *What are the apparent motions of the sun, moon planets and stars? Is there a pattern to such motions that can allow the astronomer to predict where they will be at a future date and time?*

Such knowledge is needed to allow students to discriminate between observation and inference and for the construction of models for the apparent diurnal motion of the Stars, Sun and Moon; the monthly cycle of the phases of the Moon, and the annual motion of the Sun. The AAAS highly recommends such collection of data and its thoughtful analysis (AAAS 1990, pg. 201). The discovery of patterns and their synthesis in Plato's model (Arons 1977) will illustrate for the students the economy of scientific thought, in which a complex phenomenon can be understood by the application of a few principles. Duhem (Duhem 1954) notes that this economy of thought is one of the aims of science. Moreover learning this model and reasoning with it will allow students to use "scientific knowledge and ways of thinking for personal and societal purposes" (AAAS 1990, p. xvii).

Why do we assert the Earth revolves around the Sun when the immediate evidence is to the contrary? This question involves students in the fascinating story of the move away from the Geocentric to the Heliocentric view of the Universe. They will need to look at the questions the ancient Greeks and Copernicus and his followers addressed. Very few students have any conception of the reasons for this change from a Geocentric to a Heliocentric view. Neither do they consider viewing it as mankind's discarding of the notion of the centrality of our location in the Universe discarding of the notion that the Heavens and objects in it were made of a different substance and obeyed different natural laws from those of objects in the terrestrial sphere growing awareness of the mutability of the Heavens and the Earth.

The Copernican Revolution was a profound turning point in intellectual history. The personal outlook of every individual toward themselves and their place in the Universe has been deeply conditioned by this heritage from Copernicus, Kepler, Galileo, Newton and other seventeenth century natural philosophers (AAAS 1990 p. 145).

How does the Heliocentric view of the Universe account for the apparent motions that are observed in the sky? The ability to account for the observed phenomenon is the standard of validity for a scientific model. Students need to see how the Heliocentric model explains the apparent motions they have learned about. There is no need to pursue subtle issues and refinements such as the variation in the length of the solar day or the precession of the poles (except with individual students who may raise specific questions); but the basic features of the apparent motions can be accounted for in a way that is accessible to the average student. In exploring the features of the Heliocentric model students can also gain an understanding of why the Moon has phases and the “reason for the seasons”.

It also needs to be noted that it has never been made clear to most students that there are circumstances in which one cannot discriminate between alternate models and that if this is the case, the alternate model is as equally valid as the one they may prefer. Comparing the Heliocentric explanation of a phenomenon with the Geocentric allows this principle to be brought out.

Why do we believe that the Universe is 15 billion years old? What is the evidence and upon what assumptions is this belief based? Mankind’s grasp of the extent of a cosmological time which so vastly transcends our own temporal experience is another of the great revolutions in intellectual history. The personal outlook of every individual toward themselves and their place in the universe is also conditioned by this heritage from Hubble, Einstein, Gamow and the other twentieth century astronomers. Educated persons should be aware of such a heritage in its historical and intellectual terms, not in the mere assertion of end results. Such an awareness will allow them to address some of the issues of science’s relation to other modes of knowledge in an informed way.

Why do we assert that the Sun is located in a certain place in the Universe? What is the evidence and upon what assumptions is this assertion based? Again our growing awareness of the relationship between the Earth and the Heavens - our grasp of the extent of distances which so vastly transcends our own spatial experience - is another of the great revolutions in intellectual history. This heritage from Herschel, Bessel, Shapley and other astronomers has also influenced the personal outlook of every individual toward themselves and their place in the universe.

In addressing these five questions, for the reasons mentioned, the students will have looked at the evidence for the critical insights of astronomy; to think and consider the ideas they represent. In doing this they will have an opportunity to address the questions “How do we know....?", "What is the evidence for...?", "Why does it occur ?" in the context of these ideas. They will thus have been given an opportunity to gain a genuine scientific understanding of the most significant ideas in astronomy.

The Many-Faces of the Scientific Process

Students also need to acquire a mature and intelligent perspective towards the methods, processes, successes, and limitations of science. These can be developed only by coupling conceptual understanding with an articulate discussion of how the concepts or theories originate and develop, how they are validated, what limitations they have exhibited, what connections they have revealed among apparently unrelated phenomena, and what role they have played in social or intellectual history and in our view of mankind's position in the universe. The knowledge that science is a human enterprise and knowing what this implies about its strengths and limitations is an important facet of scientific literacy.

Opportunities to examine these facets of the cultural phenomenon that is science abound at almost every turn if we but take the time to look. Kepler provides an ideal study in the development of a scientific theory. As Koestler notes in his biography,

> "The manner in which Kepler arrived at his new cosmology is fascinating.......Fortunately, he did did not cover up his tracks, as Copernicus, Galileo and Newton did, who confront us with the result of their labors, and keep us guessing how they arrived at it, Kepler was incapable of exposing his ideas methodically, textbook fashion; he had to describe them in the order they came to him, including all the errors, detours, and the traps into which he had fallen. The New Astronomy is written in an unacademic , bubbling, baroque style, personal, intimate and often exasperating. But it is a unique revelation of the ways in which the creative mind works. " (Koestler 1960 p.123)

Kepler's six year struggle to arrive at the laws of planetary motion, so justly named after him, is succinctly outlined by Koestler. He brings out the blind alleys Kepler followed, the mistakes made (in some cases benign since their effects canceled each another out !!), the assumptions he needed to make in order to solve the problem, and the time needed to prepare his mind to recognize the solution he was seeking. Koestler thus gives the student an opportunity to stand back and examine what happened, to relive some of the intellectual experience undergone by one of the founders of modern astronomy.

Starting with this as a background, one can then move through the stages in the evolution of Kepler's Laws, showing how their meaning and significance have changed. They had a central place in developing the Newtonian synthesis and this synthesis in turn developed them and reinterpreted them in a much broader sense than Kepler could have imagined. This history generates a modest self-consciousness about the process of definition and reinterpretation of a scientific concept; enormously increasing the students' understanding regarding the origin of ideas in science and their subsequent development.

Further examples, especially from nineteenth and twentieth century astronomy where autobiographies are more common, can be used to assist students in acquiring a needed maturity in understanding how theories originate and evolve. In light of such perspectives, students can begin to articulate some sense of why most scientists now view scientific knowledge as mutable and provisional rather than permanent and final. Students then tend to anticipate the idea of limited ranges of validity to successful theories and the need to be prepared to find a deeper regression of unanswered questions behind every answered question.

The proceeding illustration of the epistemological, philosophical and historical aspects of science happens to be a favorite of mine. Teachers should select such incidents that appeal to them so that these aspects of science can be articulated to students in a stimulating and compelling way.

There is also the fascinating, partly scientific, partly sociological problem of validation and acceptance of scientific theories. Students are always amazed that Kepler's Laws were not immediately recognized for what they were, the foundation of modern science. Even Galileo refused to accept Kepler's ideas, Koestler notes,"Galileo's famous Dialogue on the Great Systems of the World, published another eight years later [after Kepler's Epitome Astronomiae Copernicanae, a textbook of his system] still holds fast to cycles and epicycles as the only conceivable form of heavenly motion." (Koestler 1960 p. 236).When they are reminded how independent a thinker Galileo was in other areas, the nature of science as a human enterprise is brought before the student.

The philosophical problems concerning the "reality" of entities that transcend our senses (for example atoms, molecules, electrons) also need to be addressed. Consideration of these problems would allow students needed exposure to the difference between observation and inference. An understanding of this difference is so important in developing a student's understanding of how science relates to other modes of knowledge in such areas as the age of the Universe, the origin of life, and so on.

What is to be Done

Teachers of astronomy courses for non-science majors need to be made aware of the inadequate nature of these astronomy courses as they are presently taught. These astronomy courses are failing to have an impact in producing a scientifically literate public. Moreover, research on student learning in this area of general education courses needs to be encouraged. Very little research is being done on the learning achieved in these courses (Sadler and Lightman 1993, Zeilik et al. 1997, Zeilik and Briscard 2000, see http://solar.physics.montana.edu/aae/). The information provided by such research is essential for meaningful instruction, since it is very helpful in guiding student learning and in developing curriculum materials.

Teachers of these courses need to be urged to experiment more widely with methodologies in which lecturing is limited to occasional pulling together of concepts and subject matter after students have encountered them in some form of laboratory experience (real or virtual) and to the discussion of historical, philosophical and sociological ideas after the students have learned enough subject matter to make the discussion meaningful. A limited number of topics or concepts need to be covered at a slow pace so the students can adequately reflect on the material.

A large class situation is not a barrier to implementing these features. Demonstrations that are relevant to concept formation need to be used, even if these have to be based on the virtual sky of a computer program (Policoff 1995). These can then be the basis of many illustrative questions and problems that are discussed after students have had a chance to think about them. One can also use many home observations and experiments coupled with reflection on what has been done - it is the reflection that is important - to implement these features. Much better materials need to be written for these courses. Some excellent materials are beginning to be produced:

- The Project STAR materials (see www.starlab.com) are quite exceptional in their conceptual development and inquiry based format. Their material on the location of the Solar System in the Universe (Sadler and Shapiro 1990) gives a particularly fine development of the evidence and assumptions associated with the concept.

- The interactive exercises of Zeilik (Zeilik 1998) are a well thought out attempt to increase student's conceptual understanding of astronomical concepts using a cooperative learning approach.

- The inquiry based materials of McDermott et al. (McDermott et al. 1996) are an excellent re-implementation of Arons (Arons 1977) initial insights in developing a true understanding of the apparent motions of the sun, moon and stars.

- Berg and Fry (Berg and Fry 1998) provide an excellent model of how to implement exploration of astronomical concepts in a cross disciplinary situation.

But these are by far the exception , moreover they lack the historical, philosophical and sociological element which I feel is so necessary in these courses. They need to be combined with material such as in Holton and Brush (Holton and Brush 2001) in order to bring out the necessary epistemological, philosophical and historical aspects of science needed to develop true scientific literacy.

Summary

The achieving of a scientifically literate public needs:

- sensibly paced, experience-orientated courses of study so the students can develop a genuine scientific understanding of a limited number of significant scientific ideas by a synthesis of their own experience and thought.
- a conscious effort to bring a more articulate historical, philosophical and sociological content directly into science courses so the students can development a sense of how concepts and theories originate, how they come to be accepted and how they connect with experiences other than the ones superficially alluded to in the text.

I hope to report in the future on my attempts to implement such a course.

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About the author…

Greg Townsend is an Assistant Professor of Astronomy who has been teaching College-Level Astronomy Courses for non-science majors for over 12 years, both as a part-time instructor, a visiting professor, and a tenure track professor. In recent years, he has begun to develop a course along the lines described in this article and hopes to report on its details in the near future.