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# Sources of Misconceptions in Astronomy

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## ABSTRACT

In this paper I describe a program I have begun to identify misconceptions about astronomy and to understand their origins and how they are replaced with new concepts. I begin by describing the protocols used for each part of the project. The data for this work comes from undergraduate college students at the University of Maine who take the (non-mathematical) Introductory Astronomy course I teach. In three semesters of this work 396 students have so far participated in the misconception-gathering part of the program. Of these, seventy-five were also involved in focus groups and writing about the origins and replacement of their misconceptions. Of the 5,500 misconceptions stated by the cohort, I have identified 553 separate misconceptions. Many of these misconceptions are described in various contexts below. I end by presenting a set of internal and external origins of these misconceptions I have derived from the lists and from the focus groups.

## INTRODUCTION

Astronomy is a derivative science. It has its own features, such as planets, moons, stars, and galaxies, but these and other members of the astronomical menagerie derive their properties from other sciences. Physics provides, among other things, the concepts of gravitation to pull matter together, electromagnetism explains the radiation of light and other types of photons, nuclear physics explains the transformation of matter into energy via fusion, atomic physics explains the binding of atoms and molecules, and plasma physics describes the behavior of gases in stars and space. Chemistry explains the spectral features of stars, interstellar gas and galaxies. It also describes the chemical reactions that occur in space. Biology plays roles in explaining the apparent absence of life on other planets, as well as the presence of biological molecules, such as amino acids, in meteoritic space debris. Geology, generalized from the properties of the earth, is applied and expanded to explain the surfaces, interiors, and atmospheres of the other planets and moons in the solar system. Mathematics, of course, plays crucial roles in all of these areas. As a result of all this complexity, there are misconceptions about astronomy coming not only from its conspicuous features, such as the earth, moon, and sun, but also from the underlying sciences. While not unique in this respect, it does complicate the challenge facing the astronomy educator, who must help students replace preconceived ideas pertaining to this field.

Student understanding of astronomy is made even more complicated by the fact that virtually all the data about objects in, and energy from, space is acquired remotely. Therefore, to believe in the observations, students often need to comprehend the fairly complex, remote data acquisition process used in astronomy. The long range and alien nature of astronomy means that it is hard to incorporate much "meaningful" learning especially at the introductory level. Physicists, chemists, biologists, and geologists can often study their source material up close. Astronomers only have limited samples of the light and other electromagnetic radiation emitted or reflected from astronomical objects to use in creating and evaluating their theories of the universe (the notable exceptions being Moon rocks and meteorites). Since it is well established that overcoming misconceptions is done most effectively by hands-on discovery, the remoteness of astronomical objects makes it that much more challenging to overcome misconceptions. Also, to understand the normal development process of science, students need to understand the scientific method (of creating and testing scientific theories). I have found that many of the students in my introductory college astronomy course are leery of astronomical information precisely because they do not understand one or more steps in this process. It is because astronomy has such a rich base of potential misconceptions that I decided to try and identify their origins before addressing the question of consciously and systemically trying to help my students remove them.

In pursuing them and their origins, I use the definition of misconception as a resilient concept held to be correct, but that is actually at variance with accepted scientific knowledge. Resilient here means that the concept is incorporated in a person's conceptual framework and therefore resistant to change. Because they are woven into conceptual fabrics, many misconceptions help prevent further correct understanding of related topics. The description of "conceptual barriers to learning," by Hawkins, Apelman, Colton & Flexner, cited in Confrey (1987) helped me focus on an operating definition.

For the past eighteen months I have been working with students taking the above-mentioned introductory college astronomy course in an effort to understand the origins of their misconceptions about astronomy. I will describe the methodology I am using shortly. In the process, the students have shared with me over five hundred, fifty misconceptions they held prior to taking the course. In this paper I report on a set of origins of astronomical misconceptions that derives from their lists and from interviews I held with small groups of students. The origins, listed below, can be used to explain virtually all the stated misconceptions. This set is certainly not unique; other categories of internal and external error leading to misconceptions can certainly be identified or constructed. Nor is this set necessarily complete, although it has been satisfactory in explaining the misconceptions on hand, a list that is continually growing. It is also important to point out that the list of origins is heterogeneous, some deriving from sources external to the holder of the misconception, some internal, and some with both internal and external characteristics. The justification for these categories of origins, rather than ones that are based entirely on mental processes, say, is discussed in more detail below.

## RESEARCH METHODOLOGY

### Misconception Lists

The course, Introductory Astronomy, AST-109, taught at the University of Maine, has 260 students each semester. It is a survey course, based on three lectures per week, and is taken by students from all majors and many motivations, from those needing to fill their science requirements (a 1 credit lab is optional) to curious engineers and science majors. My interest in the misconceptions brought to AST-109 by the students was piqued by reading A Guide To Introductory Physics Teaching (Arons, 1990) and The Initial Knowledge State of High School Astronomy Students (Sadler, 1992). The first step in collecting misconceptions was to give students the option of getting 3% extra credit in the course by turning in a list of ten conceptions about astronomy that they had coming into the course which were changed as a result of taking the course. In that first semester 90 students submitted lists. I accepted the statements as misconceptions based on the language used. Statements explicitly or implicitly beginning with: "I had thought that ... " were considered to be statements of previously held misconceptions. I did not include for further use statements that began, "I didn't realize that ... ," or the equivalent. In the second and third semesters of this research I collected 179 and 129 lists, respectively. [I have come to realize that it would have been useful to have students also put down their perception of how they came to believe those concepts. I did this with the students in the focus groups, described below, but not with all students. I will require all students in the future to format their submissions with an assertion and statement of what they recall as its origin.]

The misconception lists were then combined so that independent misconceptions could be isolated. In the first semester this led to a list of 276 separate misconceptions. The second semester added 141 and the third semester added 137, for a present total of 553 separate misconceptions. While I did all the collating, two colleagues agreed with the groupings in over 98% of the cases. The ten most commonly cited misconceptions are listed in Table 1.

TABLE 1.

1. I had thought that Pluto is the farthest planet from the sun {Actually Neptune until the year 2000} 209

2. I had thought that stars actually twinkle. {Changes in the density of the earth's atmosphere act like changing lenses for starlight, causing the positions of stars to appear to vary.} 170

3. I had thought that Saturn is the only planet with rings. {All the jovian planets have rings.} 156

4. I had thought there are 12 zodiac constellations. {Zodiac constellations are those through that the sun appears to move in throughout the year. Ophiuchus is the thirteenth} 128

5. I had thought all the jovian planets {Jupiter, Saturn, Uranus, Neptune) have solid surfaces {They have surfaces of liquid hydrogen and helium} 127

6. I had thought the asteroid belt is an area like we see in star wars, very densely filled. {Actually much less densely inhabited} 99

7. I had thought we see all sides of the moon each month. {We always see the same side of the moon.} 95

8. I had thought summer is warmer because we are closer to the sun then. {Actually due to the tilt of the earth, as discussed in detail in the text.} 94

9. I had thought constellations are only the stars we connect to make patterns. {The patterns are called asterisms. All the stars in a bounded region of space are included in that constellation, regardless of whether they are part of the familiar asterism. The entire sky is divided into 88 constellations.} 89

10. I had thought a shooting (sometimes "falling") star is an actual star whizzing across the universe or falling through the sky {They are actually pieces of space debris falling through earth's atmosphere} 68

**Table 1 Caption.** The ten most commonly-stated misconceptions about astronomy. Corrected explanations are in curly brackets. Numbers at the end of each statement are total number of students asserting the misconception.

## MISCONCEPTION WORKSHOPS

### Defining the Focus

The 275 separate misconceptions accumulated from the first semester were used in the succeeding two semesters as the basis for discussion by focus groups of between three and nine students. (In return for finishing all elements of the "misconception workshop," the students received a complete letter increase in their course grades.) In these groups students discussed with me the origins of their misconceptions about astronomy and how their misconceptions were changed in light of new information. The project worked as follows: At the initial meeting each semester, two groups of twenty students were given the original list of 275 misconceptions. While the students knew that the focus of the project was on their misconceptions about astronomy, they were not told which of the statements in the list were misconceptions. (In fact the statements were all misconceptions, but none of the 80 students involved in the workshops realized that at the time they examined the list.) The students were given the instructions as reproduced in Table 2.

**Table 2.**

AST-109 Misconceptions Workshop

Please do the following as honestly as possible; It will not reflect badly on you nor will it hurt your grade in any way if you believed or believe astronomical misconceptions. Your name will not be used in any of the work stemming from this workshop.

A) After the number for each of the following statements, please write:

C if you believed it only as a child

H if you believed it through high school

N if you believe it now

L if you believed it, but already learned otherwise in AST-109

If you never thought about a certain statement, please consider it now: Write P if the statement sounds plausible or correct to you. Write W if you think it sounds wrong. Leave it blank only if the question is out of the range of your present knowledge.

B) Home assignment: If you believe a statement is wrong today, please briefly correct it in the space below it.

**Table 2 Caption**: Instructions for Misconception Workshop questionnaire

Since these instructions are quite involved, I repeated them several times and answered questions as they arose. Everyone finished considering the statements (part A) in fifty minutes or less. I then made copies of the statement lists and had the students take their own lists home. Their home assignment (part B) over a two week period was to consider each statement that they presently think wrong and write a sentence or two describing what they think the correct statement should be. The reason for this last step is that although the students may not have exactly the misconception as stated in the list, they may harbor related, incorrect ideas about these matters. In several instances that did turn out to be the case. For example, to the statement "Saturn's rings are solid," one student disagreed, writing, "They are probably made of gas." (Actually made of pebble to boulder-sized debris.) To the statement "Saturn has only one ring," this same person wrote, "I think it has 2 rings." (It actually has hundreds or perhaps thousands of ringlets.) Another student corrected "Sunspots are where meteors crash into the sun," with, "sunspots are minor fiery explosions on the sun's surface." (Actually sunspots are where the sun's magnetic fields push through the sun's surface, thereby rarifying the gases there.) Another student changed, "The sun is at the center of the galaxy," to, "The earth is at the center of the galaxy."

**Focus Groups**

I then choose from the 275 original misconceptions 37 of the ones most commonly held by the students in the group. By topic, these were categorized as pertaining to the sun, the solar system, the earth, the Moon, Saturn, stars, galaxies, black holes, or general astronomy. After the students had completed their first home assignment we reconvened in the same groups of 20. I then told the students that all of the statements they had considered were misconceptions. I have only a qualitative measure of their response, which was a combination of disbelief, amazement, and embarrassment. I then told the students to chose any 3 misconceptions that they had ever held from the final list of 37 upon which I wanted to focus. I asked them to write essays about where they had first learned these misconceptions and where they had "unlearned" them. This activity was designed primarily to get the students thinking about the misconceptions and the issues of origins and removal. While I did collect and evaluate the essays, I have relied more on the subsequent recorded discussion groups for information.

Twenty focus groups met during the fall and spring semesters of the

1992-1993 academic year. They contained between three and ten students each; only those students who were writing on the topics to be discussed that day were present. Each session lasted fifty minutes and was recorded with the students' permission. The discussion centered on the origins and termination of misconceptions in only one or two of the topic areas listed above. The format for each session is as follows: without reading the paper s/he had written, a student was asked to discuss their earliest memories of the misconception. They were encouraged to remember the circumstances under which they had acquired it. After finishing this, I asked the rest of the students who had harbored the same misconception to comment on the origins of it for them, too. The idea here was to have the students stimulate their memories by discussing the same issue from different perspectives. The conversation often fed on itself, with the original student frequently adding more comments as s/he heard what others had to say. When the discussion waned, I asked the student who had presented the origins of the misconception formally to now speak on how s/he had found out the concept was incorrect and how s/he had replaced it. The process of group discussion was then repeated.

After completing discussion by the group and final remarks by the student who had made the initial statements, another student discussed the misconception s/he had brought to the group (or the first of their misconceptions if they had brought more than one). The entire cycle repeated. Each student made a presentation even if they were talking about the same misconception that was discussed by other students and even if they had been involved in the previous discussion. In this way, I hoped to elicit as many recollections from each student as possible. This process continued until all the students had presented the origins and ends of their misconceptions. At the end of each session, I collected the papers the students had written on the misconceptions covered that day. I have begun transcribing the tapes, but that work is not yet complete.

**DATA ANALYSIS**

My immediate goals were to identify both the origins of misconceptions and how students (at least perceive) that they replaced these concepts with others. I found that misconceptions were sometimes replaced with other misconceptions. For example, one student who had thought that Saturn's rings were solid ribbons learned otherwise in high school. However, the replacement concept was that the rings were made of gas. (As mentioned above, most of the rings are believed to be pebble to boulder-sized debris.) For the purposes of this paper, I focus on the origins of the misconceptions. The list of origins of misconceptions presented below was developed from the information gained from the focus groups, along with comments from the students in the normal AST-109 course, from student lists of misconceptions, and from my own experience. The information from the students taking the astronomy course proper, but not participating in the focus groups, was acquired from two activities: First, I noted and evaluated the questions they asked in class. Although the class was large (over 250 students), most sessions included more than a dozen questions from a variety of students. Second, I analyzed the mistakes they made on exam questions (filtered for test value using the difficulty factor and discrimination index of each question). Using this information, along with my own experiences, I have constructed a set of origins of misconceptions about astronomy that accounts for virtually all the 553 misconceptions gathered over the three-semester period.

When students in the focus groups discuss their perceptions of the origins of their misconceptions, they usually concentrate on the superficial sources that come to mind. These factors include the factual misinformation the receive from family, teachers, friends, television, theology, books, media, and science fiction books and movies; language misunderstanding (meaning that words in everyday use have specific uses in science that the person hadn't understood. For example, a reasonable, nonscientific interpretation of a supernova is a bigger nova, but in fact the two types of explosions are completely unrelated); untrained observations and the resulting naive reasoning about the observations that begins in early childhood. On this latter point, students generally stated that the reasoning that occurred in their childhoods seemed perfectly sound at the time. Examples of naive reasoning include over-generalizing about the other planets from the properties of the earth, and the belief in the uniqueness of the earth. I incorporate some of these student explanations directly in the list of origins below. These origins include theology, factual misinformation, over-generalization, and uniqueness.

However, as this list of origins evolved, I found it useful to include a variety of meta-cognitive categories, including reasoning based on incomplete information, on incomplete understanding of the scientific process, on incomplete (as different from erroneous) reasoning, on sensory misinterpretation, and on the use of the simplest explanation that appears to explain an event.

**Internal Misconceptions**

After creating a list of origins that accounted for the 553 misconceptions about astronomy, certain patterns became apparent. Many of the misconceptions can be identified as coming from the misconception-holder's own analysis of observations or from their own reasoning processes. These I categorize as internal origins of misconceptions. For example, I propose that each of us has a Personal Cosmology, a conceptual framework in which we hold broad ideas about the formation of the universe, earth, and life. This cosmology develops from several sources, of course, but it represents a relatively well-defined, resilient set of conceptions by the time people become young adults. If a certain misconception is due to the difference between a personal cosmology and the cosmology accepted by astronomers today and if I cannot find a more specific origin for the misconception, I categorize it as due to an erroneous personal cosmology. If the same misconception could be traced directly to religious teachings, say, then I listed the category as theology. An example of this latter is the belief that the earth and life were formed in six days.

**External Misconceptions**

I categorize as external those misconceptions that arise from information that has been pre-processed before we receive it and which we tend to accept with minimal analysis. These include information received from the media, from authority figures and authoritative books, from cartoons, and from science fiction. I think it useful to include a set of external categories among the origins of misconceptions because all of us do accept so many facts on our trust in the veracity of external sources. Cartoons and science fiction are two particular cases worth further comment. While they generally apply at different ages, both of these categories present the viewer or reader information that they are unable to judge on its scientific merits.

Children don't know enough about the laws of physics to determine whether the motion of a cartoon character through the air, say, is realistic or not. Since such motion is often not scientifically correct, children develop skewed ideas of ballistic motion and the force of gravity. These physics misconceptions then become misconceptions about astronomy when applied to objects in space. Similarly, most people lack the information and scientific training to judge the validity of many of the gizmos (e.g. phasers) and effects (e.g. beaming down) that they see or read about in science fiction. There is a general and (in my opinion) excessive suspension of disbelief about science fiction. Not knowing any better, this leads many people to develop misconceptions about astronomy. Examples are given below in the science fiction category.

**Internal/External Misconceptions**

There are two origin categories that have both important internal and important external aspects. These are the ones that originate with external information, but which we evaluate and process extensively before accepting and incorporating into our conceptual frameworks. I call these two "Inaccurate or Incomplete Observations" and "Incomplete Information." They differ in that information comes to us pre-processed by others, while observations are direct perceptions of events. I classify the Inaccurate or Incomplete Observations as internal/external because there is often natural filtering of observations before it enters our brain analogous to the filtering of information by other people before they share it with us. For example, 22 students said they thought that all stars are white. A number of factors, twinkling and small apparent sizes of stars prominent among them, do make it difficult to perceive the range of colors that different stars have. Unless a person is motivated to look carefully or is naturally methodical, most people don't notice the colors.

Before presenting the categories, two final comments are worthwhile. First, some of the 553 misconceptions were assigned more than one category when they were seen to derive from different sources. For example, I assigned the misconception that "All the stars were created at the same time," the categories of theology, factual misinformation, and incomplete reasoning. This latter category covers correct reasoning about star formation from gas clouds, but that does not take into account all the physics and other basic science that allows for star formation to have continued up to the present. And second, some origins are often special cases of more general ones. For example, over-generalization is often a result of erroneous reasoning. I indicate an origin is often a special case of another category by referring back to the more general category in the title line.

## INTERNAL SOURCES OF MISCONCEPTIONS ABOUT ASTRONOMY

**Erroneous Personal Cosmology** (EC) Internal

Cosmological concepts and misconceptions are those that deal with the origins, sizes, and ages of the universe, the solar system, the stars, and the earth. I call the conceptual framework we each develop to explain the global features of the universe a "personal cosmology." Within our personal cosmology we each have explanations for how the universe began and how life on earth came about. It may also contain our personal belief on how the solar system formed, where the earth came from, and the origin of the stars and Milky Way, the disk-shaped galaxy in which the solar system resides. When we encounter a question about the universe that we have never addressed explicitly, the conceptual framework of our personal cosmology is where we look first for an answer. As an example of this latter point, suppose you were asked where the earth is located with respect to the Milky Way galaxy, part of which we see in dark locales as a band of light across the night sky. Referring to your personal cosmology, you might respond that we are at the center of it, outside it completely, or perhaps in a spiral arm. These are the assertions made by my students. (In fact, the solar system is located about half way between the center and the visible edge, <u>between</u> two spiral arms.)

As mentioned above, one can find both internal and external sources for our personal cosmologies. There are many incorrect concepts about the global issues pertaining to the universe that people learn or develop. I classify cosmological misconceptions as due to inaccurate personal cosmologies unless I have explicit information about the external source of that misconception. For example, many people today think that the solar system, the Milky Way galaxy, and the universe are each much smaller than we now know them to be. This misconception appears based on a lack of specific information, coupled with the use of human-sized distances in relating to the stars. Similar misconceptions occur when referring to the distances between galaxies, to the masses of stars and galaxies, and to the speeds of stars in galaxies, and to the speed of galaxies through the universe, among other things. An external source of cosmological (and other) misconceptions is erroneous or incomplete definitions. Forty-five students stated, "I thought the galaxy, the solar system, and the universe are the same thing." Rather than include this type of misconception here, I categorized it as coming from Erroneous Definitions (below).

**Erroneous Reasoning** (ER) Internal

Facts, correct or not, exist in our minds to be used. On the one hand facts come from external sources either directly as observations of nature or indirectly as filtered through teachers, parents, and others. On the other hand, facts come from the scientific reasoning we do. Scientific reasoning is that set of thought processes that leads to insights about nature (correct or otherwise). Scientists do much of this reasoning mathematically. To be useful, scientific reasoning must yield results consistent with the laws of nature. If, for example, I use the assertion that the force on an object is equal to the object's mass times its acceleration, I will draw conclusions that accurately predict the motion of real objects (ignoring the Galilean issue of idealistic versus realistic modeling). If, on the other hand, I use in my reasoning the assertion that the force acting on an object is equal to the object's mass times its velocity (Aristotelian physics), I will draw conclusions and make predictions that are inconsistent with behavior in the real world.

The acquisition of informal or naive physics, often based on Aristotelian and other incorrect laws, leads many people to draw incorrect conclusions about astronomy and other fields of science. For example, one of my students asserted the prior belief that comets can only move across the sky because they have built-in rockets. This person argued that a comet's tail is the stream of ejected matter from the rocket and without the rocket going, the comet would stop (Aristotelian physics).

**Incomplete Reasoning** (IR) Internal

Often people reason correctly as far as they go, but they do not include all the scientific facts pertaining to the subject at hand. As a result, they draw incorrect conclusions that lead to misconceptions. This source of misconception deserves to be considered separately for novices and experts (c.f. diSessa 1983). Novices in astronomy and physics reason qualitatively, using experience and intuition to draw new conclusions. Experts' reasoning, while often qualitative, is guided by the quantitative constraints of the mathematical framework that define astronomy and physics. When a problem is too complex for "back of the envelope" calculations, scientifically trained people will reason as completely and correctly as they can, but then will often extrapolate to new situations qualitatively and without the benefit of formal scientific facts to support their results. In other words, without due care even their thinking can become naive.

Consider this difference between a novice and an expert reasoning about the future size of the sun. A novice might deduce that as the sun burns up its fuel, it cools down. Since the cooler an object is the smaller it get, the sun should therefore be shrinking over time, becoming smallest when the fuel is all gone. The expert could come to the same, incorrect conclusion through a different route: as the sun fuses the hydrogen in its core into helium it loses mass (by converting mass into energy as explained in Einstein's $E = m c^2$). With lower fusion rates, the outward force created by fusion would decrease while the inward, gravitational force would remain essentially constant. Therefore, the outer layers would move inward, decreasing the sun's size. (There is much more physics working inside the sun. Because it was omitted here, the reasoning fails. In fact there is evidence that the sun is actually growing in size. At the end of its life it will expand so much as to envelop the earth.) This failure on the part of the expert to include all the physics leads to classifying the expert's error as incomplete reasoning.

From the "expert" point of view, incomplete reasoning indicates a failure to either fully consider each term in the equations or due to use of a simplified set of equations that do not give the full picture. From the novice point of view, it means not following the implications of all the physical elements of the problem. Consider two more examples. One student listed as a misconception he had that the larger a star's diameter is, the more mass it must have, compared to a physically smaller star. His reasoning is that the greater the volume, the greater the mass that can be packed into it. From an "expert" perspective, the star's mass is equal to its volume time its density. As a novice, the student failed to consider the possibility that different stars can (and do) have different densities, with larger stars often having significantly lower densities than smaller stars. As a result, large stars such as red giants often have lower masses than some physically smaller Main Sequence stars.

Second, 11 students asserted that they had thought Polaris would always be the North Pole star. They knew that this star is (essentially) over the earth's north rotation pole and they had no reason to believe that fact would change. Expert analysis of the earth-moon-sun system using the full mathematics of the situation shows that in fact the spinning earth is being forced to change the direction in which its rotation axis points (this effect is called precession). As a result, Polaris will drift away from the north pole. (In 13,000 years it will be replaced by Vega as the north star.) In this instance, the incomplete reasoning originates in a lack of understanding of the full equations describing the earth-moon-sun system.

**Choosing Simplest Explanation** (SE) Internal

A related source of misconceptions is the propensity of people to choose the "simplest," and therefore usually the first, plausible explanation that comes to mind. As such, this origin is often a subcategory of either Incomplete or Erroneous Reasoning, as described above. I use this category (SE) when the logical route to the misconception clearly stems from choosing the obvious, albeit incorrect or incomplete, explanation of a phenomena. For example, by analogy with the fact that the closer you are to a fire, the more heat you feel, most people assert that the reason summers are hotter than winters is because during the summer the earth is closer to the sun, our source of heat. First of all, this is not true. The earth is closest to the sun in January, so the assumption that we are closest to the sun during our summer is incorrect. Even if a person didn't know this, the failure of the logic of our being closer to the sun causing summers could be reasoned out by those people who know that the lands of the southern hemisphere have the opposite seasons to lands in the northern hemisphere: if being closer to the sun is the cause of our summer, it should be the cause of their summer, too. But then they should have summer at the same time we do. The point here is that this second step of reasoning is often omitted -- incomplete reasoning – leaving the person with the idea that the closer the earth is to the sun, the warmer the season. (The primary cause of the seasons is the tilt of the earth's axis relative to the path of the earth's orbit around the sun. When the earth's northern hemisphere is tilted towards the sun, the periods of daylight are longer and the sun is higher in the sky. These two factors work together to make the days warmer. The opposite occurs when the northern hemisphere is tilted away from the sun; then there are fewer hours of sunlight each day and the sun is lower in the sky when it is up. This explains the difference in seasons between the hemispheres, of course, because the two poles of the earth are tilted more towards the sun in opposing halves of the year.)

**Incomplete Understanding of the Scientific Process** (IP) Internal

The process of doing science includes many features that are not well understood by the public. These include expressing science in mathematical terms, making predictions from these mathematical theories, testing predictions, modifying or replacing theories that make incorrect predictions, using computers to explore the complexities of modern scientific theories, making accidental discoveries, and creating new technology to help understand nature, among others. Science is incomplete in that it does not explain everything in any particular discipline. It is also not definitive in that theories change as experiments and observations improve. However, most people envision scientific information as complete and certain. Once a lay people has learned a scientific theory or observation, s/he often assumes it to be correct even long after it has been disproved and scientists in that field have embraced a new theory. (Just being told a scientific concept they believe in is incorrect is often not sufficient to re-direct thinking. Experiencing the new concept first hand is often essential in changing concepts.)

Not knowing what most astronomers do, many people envision them as white-haired men and women, cricks in their necks, spending long, cold nights looking through telescopes in hope of finding new objects in space. In the realm of professional astronomy, nothing could be farther from the truth.

In fact less than a quarter of professional astronomers use optical telescopes. And all research telescopes have electronic devices to record the light passing through them. Astronomers don't actually look "through" the telescope at all.

Astronomers fall into three groups: observers, theorists, and computer modelers. While there is some overlap, most astronomers focus their careers in one of these areas and few of the observers actually use <u>optical</u> telescopes. The majority of observational astronomers use telescopes that collect other types of electromagnetic radiation: radio waves, infrared, ultraviolet radiation, x-rays, or gamma rays. The vast majority of an observer's time is spent analyzing with computers the mounds of data collected by the telescopes. Also contrary to popular notion, most of that data is not even in the form of photographs. Rather, it is spectra that give information about chemical composition and motion.

Here are some further examples of misconceptions about astronomy created by these incorrect impressions about science and scientists. One student thought that astronomical determinations of masses, distances, and ages of stars is entirely speculative. Another student thought that astronomers are unable to make predictions about the future. Along a similar vein, another student thought that astronomers couldn't predict eclipses.

**Language Imprecision** (LI) Internal

A major culprit in creating misconceptions about astronomy is the assigning of rigorous, scientific meanings to words which have a variety of "everyday" uses. In normal usage, most words have several meanings and we overcome imprecision in our language by taking into account the context in which words are used, as well as adding verbiage to clarify matters. In science, virtually every word has a single, rigorous usage. The problem arises when an everyday word gets incorporated into the science lexicon. Even when hearing it in a scientific context, people naturally associate the word with one or more of its everyday definitions. For example, the word "hole" in black hole evokes the image of a two-dimensional hole like a bathtub drain. This has become the almost universal conception of a black hole: a drain or vacuum cleaner in space. When questioned in detail, most of my students assert that to enter a black hole you must be "above" the drain. Below the drain you would not see nor be able to enter the black hole. This is also the description of black holes used in numerous science fiction movies. However, it is incorrect; a black hole is spherical and can be entered from any direction.

Among the innumerable other confusing words are "black" in black hole (Black holes can cause the emissions of powerful streams of particles and radiation from just outside their boundaries. As a result, small black hole are actually powerful beacons in space.); comet "tail" (actually the tail never trails behind the comet, but always points away from the sun); "shooting star" (it is not shooting but, rather, falling and it is not a star at all; it is space debris burning up in the earth's atmosphere); "spring" tide (doesn't just occur in the Spring; the spring tides are the highest tides which historically were said to "spring" up towards the moon); "pulsar" (which often creates the image of a star swelling and shrinking -- pulsing -- whereas pulsars are actually rotating neutron stars with magnetic fields that send out "pulses" of radiation), and Saturn's "rings" (which are often thought of as solid belts or rings, but which are actually composed of millions of rock-sized pieces).

A somewhat more sophisticated example of the problems created by language imprecision involves the concept of a "red hot" object. Most people do not test the implicit assertion that red hot objects are the hottest ones. While it is certainly true that a red hot piece of iron is hotter than a dull, grey piece, it is also true that the same piece of iron glowing orange, yellow, white, or blue is hotter than when it glows red. As a result of language imprecision in this case, 14 students asserted that they had thought red stars were hotter than yellow, white, or blue ones.

**Erroneous Definitions** (ED) Internal

There are many words that have limited meanings even to non-scientists, but most people never get the meaning correct in the first place. Common among these are "constellation"; "sun" (often interpreted as a special kind of object, rather than as an extraordinarily ordinary star); the "asteroid belt" (visualized by most people today as filled with closely-spaced asteroids such as depicted in the "Star Wars" scenario. In fact, the asteroids are typically six million miles apart.); "meteor," "meteoroid," and "meteorite" often taken to all have different meanings (a meteor is space debris passing through the earth's atmosphere, a meteoroid is space debris destined to someday strike another body, and a meteorite is space debris found on the earth); and "solar system," "galaxy," and "universe," which are often used interchangeably (solar system describes the sun and all objects gravitationally bound to it, a galaxy is a group of between millions and trillions of stars plus gas and dust clouds gravitationally bound together, and the universe is all matter, energy, and space).

**Sensory Misinterpretation** (SM) Internal

Sensory information here refers to original data; that is, data that has not been pre-processed by anyone else. Sensory information is not expressed to us in words open to language imprecision, erroneous definitions, or any of the misinterpretations by other people that the previous sources of misconceptions are liable to. Nevertheless, we often misevaluate sensory data and create misconceptions as a result. This occurs partly because our senses are not ideal and partly because we evaluate and filter sensory input using the conceptual frameworks relating to what we perceive.

Our senses pre-filter the data that enters our brains. For example, our eyes have several layers of discriminators in them. Among other things, our eyes are not uniformly sensitive to all the colors of the rainbow, being most responsive to yellow light. Sensitivity to color falls off in an essentially Gaussian curve towards both red and violet. Therefore, what we perceive as the color of each object is not its true color, if for no other reason than the intensities of all the colors from it are changed in our eyes before the color information enters our brain. The same applies to the other senses, as people who differentially lose sensitivity to pitch know all too well.

Analyzing and incorporating sensory data into conceptual frameworks is not the same as analyzing and incorporating data received from other sources, such as books, teachers, and others. The difference lies in the degree of acceptance of the two types of input. While we tend to accept raw sensory data as containing unfiltered information about nature, we usually weigh the information we receive from human sources by the veracity of the source itself. For example, we are more likely to accept what we are told from a teacher than what we read in a comic book. I include this category, then, because it reflects a different set of filters than information pre-processed by other people.

Examples of misconstrued perceptions include observations that the sun, planets, and stars appear to orbit the earth (they certainly appear to do so); that the sun appears yellow (The sun emits all colors of the rainbow but it mostly emits in the blue-green part of the spectrum. If our eyes were sensitive to all colors equally, the sun would have a aquamarine appearance); that the moon gives off its own light (It doesn't. Moonlight is reflected sunlight); and that stars twinkle (They don't. The change in stellar brightness is actually changes in the density of the earth's atmosphere. Such changes cause the incoming starlight to change direction every half-second or so. This refractive effect is what we interpret as the twinkling of stars.)

**Over-generalization** (OG) Internal

Invalid generalization of information causes many misconceptions. As we are taught the basic information about astronomy, such as that there are nine planets or that seven planets have moons, most of us tend to fill in details we have not been taught. This is often done by extrapolating properties from the earth and earth's moon onto them. For example, although we are told that the planets have different sizes, unless told otherwise, most people imagine them to also have solid surfaces with continents surrounded by oceans of water. In fact, however, Jupiter, Saturn, Uranus, and Neptune all have liquid surfaces. Even when told this, the mind works by comparison to earth. Just told they are liquid, most of my students conclude that the liquid is water. It is actually a soup primarily of hydrogen and helium with traces of other elements.

Here are two examples of over-generalizing about moons. When asked, most of my students thought that all the moons in the solar system are spherical, like our moon. In fact, most of them are highly irregular in shape, as seen in Phobos and Deimos, the moons of Mars. At least thirty-five of the sixty-odd known moons look more like potatoes than they do our Moon. As another example, most students don't think about the internal structure of the Moon prior to a course in astronomy. When asked to describe the inside of the moon, most students say its insides are similar to the earth's, i.e. molten, with its core at its center. (In fact, it is apparently solid throughout, although it is layered like the earth's interior, and its center of mass or core is offset from its geometrical center.)

**Uniqueness** (UN) Internal

Assuming the earth, moon, and sun are unique creates misconceptions that are often the opposite of those generated by over-generalizing. The origins of these misconceptions frequently originate in childhood. The fact that the earth is presently the only known object in the universe on which life exists suggest to many people that our world is unique among astronomical bodies. Similarly, the Moon is the only body that we can see with our naked eyes that has craters; none of the other planets or moons have many, if any, craters when viewed through telescopes from earth. Belief in the uniqueness of the earth and moon can be considered a secondary source of misconceptions inasmuch as this idea originates in others such as sensory misinterpretation and incomplete observations. I give it a separate category because students use uniqueness in their explanations or assertions.

Here are some examples of how uniqueness leads to misconceptions; 2 students thought our moon is the only body with craters, 7 students thought the earth is the only body in the solar system with water, 13 students said they thought the moon was the only object in the solar system that went through a cycle of phases, 49 students thought that our moon is the only moon in the solar system, and 14 students thought the earth is the only planet with an atmosphere. All of these assertions are incorrect.

**Permanence** (PE) Internal

Another example of where conceptual frameworks bias the analysis of information is in the area of permanence. It is a common belief, even among non-religiously oriented people, that now that we are here, human life will be around forever. This is apparently a generalization of the childhood belief in, or expectation of, permanence. As adults, many people generalize permanence to include astronomical bodies such as the earth, sun, and stars. This generalization comes in part from the fact that most people go through their entire lives without seeing any significant changes in the heavens. At least as far as the astronomical bodies are concerned, this belief in permanence is completely unfounded. Astronomers see stars exploding every year. We also see new stars forming. In about five billion years the sun will expand and envelop the earth, heating it until it becomes lifeless. The sun will then explode. All the other stars in the universe will also either explode or turn off quietly, too. The belief in permanence results in erroneous reasoning. Since belief in the permanence of the sun, the other stars, and the earth is (apparently) such a clearly identifiable source of misconception, I include it as a separate category.

Here are some common misconceptions I assign to this category: 36 students said all stars last forever, 4 students said stars never change size, 7 students said stars are fixed in space, 9 students said comets last forever, 4 students said the day has always been 24 hours long, and 48 students said the sun would last forever.

## EXTERNAL SOURCES OF MISCONCEPTIONS ABOUT ASTRONOMY

**Theology** (TH) External

Theology is an important source of the misinformation that is used in constructing many personal cosmologies. It also contributes to erroneous reasoning. I categorize a misconception as due to theology only when I have explicit information from student interviews and papers that the misconception came to them through this source; I would have assigned these misconceptions to other categories if theology had not been specifically identified as contributing to them. In some instances where theology played only a minor role in developing a misconception, I assign multiple origins to the misconception. Here are some examples of misconceptions that have theological origins: 20 students thought all the stars in the universe were created at the same time, 36 students thought all stars last forever (I classify the origins of this misconception as TH/FM/ER/PE), 29 students thought that the earth or solar system was at the center of the universe (classified PE/SM/TH), and 11 students thought the universe would last forever.

There are also misconceptions with roots in theology that do not fit into any other category. As I was not actively looking for theological roots of misconceptions, I came across only a few that students in focus groups volunteered. There are, I am certain, many other non-cosmological astronomical misconceptions grounded in theology that I have yet to catalogue. The only ones I have detailed information on concern black holes. Some Catholic parents and religious leaders use the physically real black hole for a variety of behavioral and theological purposes. Several of my students brought up in the Catholic religion were threatened by their parents with being sent into a black hole if they misbehaved. Others told me that black holes were created to hold the souls of fallen angels. Still others said that black holes are where the spirits of infants reside for whom souls are not available. When a soul becomes available, the spirit leaves the black hole. Besides the obvious teleological aspects of black holes as repositories for humans and their abstractions, it is very interesting to me how the use of black holes for these purposes makes them and, by extension, astronomy personally menacing.

**Science Fiction** (SF) External

Science fiction creates innumerable misconceptions about astronomy. Since this genre began in 1634 with the publication of Johannes Keppler's Somnium (c.f. Bleiler, 1990), people have willingly suspended their disbelief about the laws of nature in order to be entertained by physically implausible, but exciting, stories. In the defense of science fiction, it is worth noting that even though ideas presented in these works are often considered incorrect when written, they end up becoming accepted as fact. Unfortunately for the general perception of astronomy, much science fiction actively violates the established and proven laws of nature. For example, the densities of atoms and molecules in interplanetary space is so low and their temperatures so high that perceptible sound does not travel through it. The creaking and groaning of combat spacecraft that we hear on innumerable movie and television space adventures just doesn't occur. However, many people believe sound does travel through space. This was also asserted by 8 of my students.

This brings us to the point that misconceptions about astronomy brought about by science fiction have increased dramatically in the past few decades because of successful television series such as the Star Trek sagas, and because of cinema successes such as the Star Wars and Star Trek adventures. One of the most notable examples of misconception demonstrated by the movies was in the Star Trek movie "The Empire Strikes

Back" in which the heros are seen flying through an "asteroid field" of gigantic, closely-spaced rocks. In the real universe, the gravitational forces created by such rocks would cause them to collide and either coalesce into a single planet-like mass or to pulverize each other and become space dust. Nevertheless, 99 of my students listed this as their vision of the asteroid belt. Other science fiction-based misconceptions include 23 students asserting they thought Mars has life on it now, 5 students asserting that they thought the canals of Mars were made by intelligent life, 5 students saying they thought Jupiter is nearly large enough to be a star (a la Arthur C. Clarke's 2001 -- it actually has 75 times too little mass), 8 students saying we could voyage through vast distances of space via black holes, and 7 students saying we could voyage travel through time by entering a black hole.

**Factual Misinformation** (FM) External

All of us have received incorrect information from sources whose statements we normally accept as true. These people include teachers, parents, friends, books, and other ostensibly factual authorities. For example, a child first learning the order of the planets from the sun is likely to be told by a teacher or parent that Pluto is the most distant planet. In fact, that was true until 1978, when Pluto's highly elliptical orbit took it closer to the sun than Neptune. Neptune is presently the farthest planet from the sun, and it will remain so until the middle of the year 2000. The point is that most parents and teachers who answer that question for children today learned the order of the planets before 1978 (or were themselves taught by someone who learned before 1978). And most adults did no learn or have not internalized the shift in order of the planets that has occurred since they were first taught. As a result the authority figures pass on incorrect information.

It would serve no purpose to separate the specific sources of factual misinformation into separate categories. This category (FM) is designed to focus attention on the way the information is received (from an authority) and scrutinized and processed (often minimally). I consider this category a derivative source of misconceptions. That is, factual misinformation is data that has been heavily pre-processed by others before we receive it. Also, given its source, we often tend to accept this information more readily than we would assertions from sources about whom we are more skeptical.

Indeed, coming as they do from authority figures, such misconceptions may well serve as the foundations for entire, albeit scientifically-invalid, conceptual frameworks.

Here are some other examples of misconceptions that originate from factual misinformation: 128 students had been told there are 12 zodiac constellations (Zodiac constellations are those that the sun passes through. There are 13, the least known one being Ophiuchus); 48 students had been told that the north star, Polaris, is the brightest star in the sky (that distinction goes to the sun, of course. Sirius is second brightest.); 14 students had been told that the asteroids in the asteroid belt had been part of planet that had been destroyed; one student had read that Mercury was in synchronous rotation around the sun (Synchronous rotation in this case means the same face of the planet always faces the sun. Mercury was believed to be in synchronous rotation until 1965. The prevalence of out-of-date books on astronomy in grade schools helped propagate this misconception.)

**Media Minimalism** (MM) External

News reporting is a process in which information is heavily filtered and abbreviated before we receive it. Incomplete news coverage creates misconceptions. It is also in the nature of virtually all new services to provide information that raises our interest and keeps our attention. As a result, the news about science we actually receive is often the most sensational, rather than the most important parts. For example, we may be told in the media that a certain quasar is the farthest known object from earth. On the surface that is an interesting discovery. But much more important in putting this object in perspective with other quasars and other distant objects is the unusual spectrum of electromagnetic radiation it emits. This latter information tells us there is some unexplained activity in the quasar, although exactly what is unknown. News about the spectrum is much less exciting and less comprehensible to the non-scientifically trained public than the fact of the quasar's extraordinary distance. Spectral information is therefore often glossed over or omitted entirely.

The public learns only limited and often distorted information from the news media. This filtered, biased, incomplete, and often inaccurate information is then incorporated into existing conceptual frameworks. The conclusions drawn or extrapolations made from this knowledge are often incorrect; it has created new misconceptions. A contemporary example of limited media coverage and the misconceptions that result from it concerns the issue of the earth's stratospheric ozone layer and its depletion. It is now well established that CFCs and related human-made chemical compounds are destroying ozone in the earth's upper atmosphere. Ozone blocks the sun's dangerous ultraviolet radiation from reaching the earth's surface. As a result of the ozone depletion, more ultraviolet radiation is reaching the surface now. From this information, many people create an inaccurate framework of concepts about the ozone "issue." Here are a few common nodes in that framework: Once it is depleted, ozone is not replenished (in fact, the sun's energy continually creates ozone from oxygen atoms and molecules in the earth's atmosphere); the ozone layer is a thin stratum in the atmosphere (misconception caused in part by the use of the common word "layer"; the ozone is actually dispersed over the entire upper atmosphere -- the stratosphere. It is densest in a 12 mile-thick region centered about 17 miles above the earth's surface.); under normal circumstances the ozone content of the air is appreciable -- in some vaguely-defined sense (in fact if all the ozone in the earth's entire atmosphere were compressed to be the same density and pressure as the air we breathe, that "layer" of ozone would only be an eighth of an inch thick!); and, the ozone at the earth's surface that sometimes makes respiration difficult is from the ozone layer (most of the lower atmosphere ozone is created by chemical reactions involving pollutants.)

The Hubble space telescope has also been the object of media coverage, especially because it was found that the mirror was incorrectly ground. Here are two misconceptions about Hubble that have resulted from media minimalism: the Hubble space telescope is virtually useless (in fact, over 80 percent of the planned observations have been successfully made even with the defective mirror); warpage of the Hubble space telescope's mirror is inches or feet (in fact it is less than a thousandth of an inch).

**Cartoons** (CA) External

One of the major external sources of misconceptions about science in general and astronomy in particular for young children are cartoons.

Animators have done considerable damage to young intuitions about nature. For example, a common cartoon ploy is for the bad character to run off a cliff or have a branch blow out from below them. Invariably, the character is shown suspended in midair for several seconds until the impact of what has happened is clear to both them and the young audience. They then proceed to fall at constant, albeit fast, speeds. Similarly, when the bad guy rushes off a cliff, they tend to stop moving forward, pause, and then fall straight down, rather than move continuously in a parabolic arc. As a source of misconceptions for my students, cartoons tended to be obscured by other factors because they happened in early childhood. Other things, such as factual misinformation and inaccurate observations, often replaced the cartoon perceptions as explanations for misconceptions. The relevance of cartoons emerged from the focus group discussions where I encouraged students to follow the origins of misconceptions as far back as they could. Often, when cartoons were finally mentioned by one student, several students would spontaneously confirm that the cartoons (often the same cartoons) had affected them, too.

## MISCONCEPTIONS WITH SIGNIFICANT INTERNAL AND EXTERNAL COMPONENTS

**Inaccurate or Incomplete Observations** (IO) Internal/External

There are a variety of reasons people observe things inaccurately. These include not knowing what to look for (a person believing that all the "stars" in the sky are isolated objects is ill-prepared to notice that many of them actually have close, bound companions); not being sufficiently interested to make careful observations; being distracted by certain characteristics of what they see; categorizing what they see inappropriately; and being biased by what they have been told (Few people bother to ascertain that the north star is the brightest star in the sky. This is a common, albeit incorrect, assertion that is relatively easily disproved on a clear night.). This origin of misconceptions is different from sensory misinformation (SM) because IO refers to the collecting of data, whereas SM is the result of misinterpretation of the data. For example, it is reasonable (although incorrect) to conclude from observations that stars twinkle. Stars certainly do appear to change brightness as we watch them. Without a great deal of analysis, our minds interpret twinkling as changes a star's intrinsic brightness. This conclusion is therefore a misconception based upon sensory misinformation, SM, rather than on inaccurate observations. Conversely, observing the "sword" of Orion most people would say they see three stars. In fact, a closer examination, even with the naked eye, shows that the middle star is a fuzzy blob (actually a system of interstellar clouds), rather than a star. I classify this misconception about Orion's sword as based on inaccurate observations (IO).

Here are some further examples of inaccurate or incomplete observations: 10 students asserted that they thought they saw the same constellations throughout the year (the visible constellations change throughout the year); 22 students say they perceive all stars as white; 37 more said they perceive all stars as having the same color (without specifying what color that was); 7 students said they thought no planets are visible with the naked eye (in fact, you can see Mercury, Venus, Mars, Jupiter, and Saturn when they are "up" at night); 2 students thought that the moon sets during the daytime and rises every night (in fact, the moon is sometimes up during the day and sometimes up at night); and a student said that she thought the moon always rises at the same time every night.

**Incomplete Information** II (External/Internal)

Finally, there are many facts about astronomy that people have never learned but are called upon to use "out of the blue." Many people will make assertions in response to questions that they do not have enough information to answer. For example, most people don't know whether any planets besides Jupiter have features like the Great Red Spot. Using a variety of thought processes, such as assuming uniqueness, generalizing, recalling science fiction and other things they have read, and just plain guessing, many people will make incorrect assertions about this matter which then becomes a misconception for them (in fact, Saturn, Uranus, and Neptune all have such features from time to time). I call this source of misconceptions frame filling in that, when asked, people often fill in their incomplete conceptual frameworks with information derived from insufficient information.

Here are examples of misconceptions that sometimes result from a lack of information: Jupiter is the only planet with spots; Saturn's rings are made of gas (actually pebble to boulder-sized debris); the solar wind is constant throughout the years (actually sporadic on a daily basis and cyclic on an 11 year cycle); and, most of the matter in the universe has been accounted for (actually no more than 10% has been located). Seeing astronauts floating in the Space Shuttle leads many people to believe that there is no gravity in space (the lacking external information is that the Shuttle and its crew are orbiting the earth on a path in which centrifugal force balance the gravitational attraction from the earth. If the Shuttle was momentarily suspended over the earth and released, it would be pulled downward by gravity and the crew would be forced against a side of the vehicle.)

## SUMMARY OF ASTRONOMY MISCONCEPTION ORIGINS DISCUSSED IN THIS PAPER

In the following list, the two letters preceding each category are an identifier used to label each misconception. The number following each origin indicates the total number of times I used that origin in explaining a misconception. Since some misconceptions were assigned more than one origin, the total number of uses of all origins (680) exceeds the total number of misconceptions identified (553).

**Internal Categories**

ER Erroneous Reasoning 69

EC Erroneous Cosmology 41

ED Erroneous Definition 19

IP Incomplete Understanding of the scientific process 7

IR Incomplete Reasoning 96

LI Language Imprecision 32

OG Over-Generalization (sometimes subcategory of ER) 71

PE Permanence (sometimes subcategory of ER) 15

SE Choosing Simplest Explanation (sometimes subcategory of IR) 67

SM Sensory Misinterpretation (sometimes subcategory of ER) 63

UN Uniqueness of the earth, moon, and sun (sometimes subcategory of ER) 26

**External Categories**

CA Cartoons 1

FM Factual Misinformation 102

MM Media Minimalism 5

SF Science Fiction 28

TH Theology 13

**Internal/External Categories**

II Incomplete Information 6

IO Inaccurate or Incomplete Observations 19

## DISCUSSION

In an effort to identify correctable sources of misunderstanding about astronomy I have proposed a set of origins for the over five hundred, fifty specific misconceptions about astronomy I have collected over the past year and a half. The resulting study suggests that misconceptions about astronomy originate from both internal and external sources. The use of both internal and external categories for origins, as well as two tiers of some internal categories, may appear complicated and less elegant than a system based upon one of the traditional learning theories in which the reasons for acquiring knowledge are focused either internally or externally. However, I am trying to develop a list with practical applications for dealing with specific sources of misconceptions. I hope these categories will focus attention on explicit causes of misconceptions so that remediation can be refined and directed.

At this point, I am not prepared to make an assertion as to the list's validity or usefulness in other realms of science. However, as noted at the beginning of this paper, astronomy draws heavily from physics, chemistry, and other "basic" sciences. This makes astronomy susceptible not only to misconceptions based on observations of, and theories about, objects in space, but also to misconceptions derived from misunderstanding of these other sciences. This suggests that the applicability of the proposed list of origins should be considered for other sciences.

This research on the origins of misconceptions about astronomy is the beginning of a larger program which also includes investigating how incorrect ideas can be replaced. I inadvertently took the first step in that direction when I asked my students on the first day of class in each of the last three semesters to make lists of their misconceptions. As a result, I discovered that throughout the course they were consciously comparing what they heard from me with what they had thought previously. I had not seen that activity in the previous groups of students taking this course. This indicates to me that meta-cognitive activity does provide focus to people as they replace misconceptions with accurate information.

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