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Dealing with Disbelieving Students on Issues of Evolutionary Processes and Long Time Scales

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Abstract

Sooner or later, the Astronomy 101 or astrobiology instructor encounters a student who disbelieves, or is at least skeptical of, factual information presented about the age of the Earth, the age of the universe, astrobiology, or biological evolution. Understanding the evidence and current state of our scientific knowledge about these subjects is important for the Astro 101 instructor faced with individual skeptical students. This understanding is also vitally important for those Astro 101 students who are future teachers and have preconceptions that could have a major impact on the thinking of large numbers of future students. This article contains a summary of different types of pseudoscientific beliefs that students have and suggests ways to approach these subjects so that skeptical learners are more likely to consider the facts presented in the astronomy class. Also included are some useful approaches for dealing with the more recent creationist ideas and tactics, such as "irreducible complexity" and "intelligent design"-- especially now that President George W. Bush has expressed support for intelligent design. An appendix catalogs the different forms of creationism and lists some typical questions that their proponents might ask in class, along with suggested answers.

1. TEACHING SKEPTICAL STUDENTS

1.1 Students' Misconceptions and Disbeliefs

Some students bring many misconceptions and suspicions with them into introductory astronomy courses. They may have suffered a lifetime of antiscience propaganda, especially regarding biological evolution. Currently, in fact, about 50% of the population of the United States and Canada are confused or ignorant about evolution (Alters & Alters 2001). Alters & Alters also reported that students who reject evolution

are much more likely than those who accept it to subscribe to misconceptions such as believing that the methods used to determine the age of the Earth are not accurate. Furthermore, in a survey of science education graduate students—those who will go on to careers as schoolteachers or teachers of teachers—20% said that they did not accept evolution (Yoon 1998). While the responsibility for this problem can certainly be shared across several disciplines, Astro 101 instructors have a unique opportunity in their discussions of the evolution of the universe to make sure that important ideas about the process of science and the results of science are clearly conveyed, while carefully debunking whatever forms of pseudoscience arise in class discussions.

For example, many creationists strongly believe that the long time scales discovered by scientists are simply wrong (Brush 1982). Other (noncreationist) students are skeptical simply because they have been given misinformation for a very long time, sometimes from well-meaning and well-loved but ill-informed parents or teachers (Crawley & Arditzoglou 1988; Tilgner 1990). The problem is that long-held objections can keep students from being open to new knowledge and even to scientific reasoning (e.g., Peirce 1957). Instructors' quick, easy answers ("That's just how it is") or sending questioning students to sources they're unlikely to read isn't the best defensive weapon, according to Alters & Alters (2001). Instead, instructors must go on the offensive (perhaps at the beginning of the semester), provide strong student interaction, and confront misconceptions with evidence, especially with students who are not majoring in science. This article will help provide some of that evidence.

Students who perceive an incompatibility between their prior (and persistent) beliefs and those presented in an astronomy class (especially ideas of evolutionary change and long time scales) may object to several scientific findings, sometimes quite vociferously. Other students are silent on the subject but disbelieving all the same, so it may be more difficult to identify them at first. Clearly, it is imperative that instructors be prepared with strategies to recognize indicators of disbelief and to identify educational methods and materials to deal with the sources of students' misconceptions in detail. Furthermore, some of those students are future K–12 teachers, and it is certainly important that teachers get it right.

Antievolutionism is not limited to religious conservatives; it is also found among many Americans who are members of religiously moderate faiths. Many of these people do not realize that their own religious organizations are not literalist (i.e., they do not claim that the Bible requires a literal interpretation) and that their religions have accommodated evolution as the way God created life on Earth (Scott 1995). *Voices for Evolution* (Matsumura 1995) includes statements from the Roman Catholic Pope, Episcopalians, Methodists, the United Church of Christ, Presbyterians, the Lutheran World Federation, and several Jewish groups, all expressing respect for science and for evolution as part of science. Nevertheless, a large number of individuals within these denominations (including many Astro 101 students) maintain their antievolution beliefs.

1.2 Instructors' Responses to Students' Comments and Questions

Many Astro 101 students who are uncomfortable with evolution and the billions-of-years-old ages of the Earth and the universe extend their suspicions to other areas of science. For example, some students hear the term *stellar evolution* and are immediately prepared to reject it because of the *e*-word. They have acquired the belief that long time scales and evolution of any kind are inconsistent with their belief in God. According to a City College of New York poll, 90% of Americans describe themselves as religious (Goldman 1991). If evolution and long time scales are presented as antireligious (which is, in fact, how organizations such as the Institute for Creation Research present these ideas), we can expect many of our

students to reject it. Yet modern scientific ideas can indeed be accepted by people who are very religious, though not usually if they are Biblical literalists. (See the appendix regarding this and related varieties of creationism.) To facilitate this acceptance, Astro 101 instructors can help the religious student work out an accommodation according to his or her beliefs.

Astro 101 instructors vary in their desire to tackle the issues of the scientific process in this area and to discuss the enormous body of evidence for long cosmic time scales and evolutionary change over these time scales. Some instructors tend to avoid these issues because they are not aware of the extent of student misconceptions, because they don't feel qualified to address them, or because they don't think that they can change students' minds on these issues. One instructor commented, "Creationists are a lost cause" (P. Vener, pers. comm.). While that may be true, there are many noncreationist students who are open-minded, but most of what they've been hearing lately has been about creationism or intelligent design. If that's all they hear (including from President Bush!), then that's what they'll believe even though they would be quite willing to listen to—and accept—alternative views. It is for those students that Astro 101 instructors must be able to specifically address questions and challenges on the age and evolution of the universe.

Some students insist that nothing that their instructors say or do can convince them of the reality of evolution and long time scales. Yet it is still possible to reach these students, according to one Astro 101 instructor: "At least [the student] now realizes that many of his arguments . . . are poor ones, much more easily dispensed with than he realized. . . . What he admitted to be a religious belief . . . can't be cloaked in science as easily as he'd previously thought" (J. C. Hunt, pers. comm.). Such an observation indicates that Astro 101 instructors recognize one of the most important aspects of education at any level: that although teaching may end after a semester, learning will continue long after a school year is over. In other words, students will take the lectures, discussions, and even the arguments they had in an Astro 101 class with them throughout life, as they acquire new bits of information and perhaps eventually put the scientific pieces of the puzzle together.

In dealing with students who misunderstand or deny commonly accepted scientific information, the most effective instructional approaches have been found to include treating the student with respect and speaking from the evidence itself, as opposed to teaching from a position of authority (Woods & Scharmann 2001). Students resist giving up what they already "know" (Driver & Easley 1978) and require a clear presentation of the methods that scientists use to discover how the world operates and the level of certainty with which that knowledge is held. It would be most useful to help students learn to apply the same skepticism to their own preconceptions as scientists do about their own views, and to become comfortable confronting their misconceptions (Sudol 2003).

Following are some practical strategies that include both teaching and respect. The instructor can quote experts and representatives from professional scientific organizations, provide excerpts from peer-reviewed journals, and show museum specimens, NASA photos, and so on. Inviting students to triangulate these multiple sources for themselves helps them to see that our knowledge of evolutionary time scales and processes has the acceptance of many groups of people who spend their entire professional lives studying these issues from multiple perspectives. The instructor could also recommend the nontechnical book *Voices for Evolution*, showing that there is no controversy about the notion of long time scales and evolution within the scientific community or even in the teachings of many of the world's major organized religions. Of course, that last point won't matter to a true antievolutionist, someone who adheres to a religion that does not accept evolution under any circumstances. (See McIver 1992 for

additional references on antievolutionism.)

To help Astro 101 instructors with these issues, sample questions from disbelieving students and the author's suggested responses were presented in a previous paper (Bobrowsky 2000), some of which are reproduced in this article. Additional sample questions and answers are also provided in section 3 on newer creationist topics, including intelligent design.

> **Student question:** Since most scientists are atheists, isn't it in their interest to try to use science to disprove God?
> **Possible response:** Some scientists are atheists, some are not. Scientists who are not atheists look at how the universe works and assume that God has a hand in it. Their belief in God does not prevent them from learning about the world based on experiment and observations. The question, Does God exist? is not a scientific question; it is not "falsifiable." Mainstream religions, as opposed to the vocal minority of fundamentalists, support the scientific enterprise and view it as an effective way to appreciate God's handiwork.

A common objection to the known age of the Earth is based on the validity of radioactive dating. It is useful to point out the consistency and success of radioactive dating with other dating methods for rocks and meteorites, and the ordering of the Earth's strata, starting with the first estimates of the ages of Earth rocks by Bertram B. Boltwood in 1907. These estimates were based on Lord Rutherford's 1905 suggestion that radioactivity could be used for measuring geologic time (Turekian & Narendra 2002). Since that time, estimates of the Earth's age have increased in accuracy and, in recent years, numerous independent measurements have yielded the result of 4.55 Gy as the current best estimate for the age of the Solar System (Dalrymple 1991).

Taken further, when a student asks about the age of the universe, as in the example below, the instructor can explain how scientists obtain data and draw conclusions. It can also help to describe how measurements were made, the level of confidence that scientists have in them, and the multiple sources supporting these findings that allow the evidence to speak for itself. A brief interchange might begin something like this:

> **Student question:** How do we really know that the universe is approximately 14 billion years old?
> **Possible response:** We can measure the velocities of galaxies, and we find that almost all are receding. Based on their speeds and distances, it is a simple matter to calculate when the galaxies were all together—that is, when the universe began its expansion. That turns out to be between 12 and 15 billion years ago. Other methods have also been used to determine the age of the universe with similar results. Obtaining consistent results by several different methods gives us confidence that we've got it right. A recent analysis of the cosmic background radiation pegs the age of the universe at 13.7 billion years, which is the most precise age yet determined and, importantly, consistent with the other measurements.

> **Student question:** How do we know that the speed of light hasn't changed over time, leading to an incorrect age for the universe?
> **Possible response:** If the speed of light had changed over time, there would be observable consequences of that change. There would be differences in the spectra produced by light from distant galaxies, and we do not observe any such difference. Also, in no other area do we see any evidence of laws of nature changing over time.

A good resource for discussions about the age of the universe is *An Ancient Universe* (Fraknoi et al. 2004), an illustrated guide explaining how astronomers know that the cosmos is old and that it changes with time. This nontechnical booklet designed for teachers, students, and the public provides an excellent summary of the scientific perspective on the age of the Earth and the universe.

An additional resource is provided in the following section, a list of astronomical arguments made by creationists. Although students may not make these identical arguments, students often refer to creationist Web sites that include such ideas.

2. CREATIONISTS' ASTRONOMICAL ARGUMENTS

In their attacks against evolutionary ideas and the ages of the Earth and the universe, creationists make arguments in the areas of physics, astronomy, geology, biology, and other sciences. To familiarize the Astro 101 instructor with their astronomical arguments, the following list is provided, along with a summary of "what we know," which should be helpful when addressing these arguments.

2.1 The Sun spins too slowly to have formed from the contraction of a protoplanetary nebula.

What we know:
This argument is based on the fact that the Sun contains most of the mass but only 2% of the angular momentum in the Solar System. The original thinking was that if the Solar System had condensed from a gas cloud, most of its angular momentum would be in the Sun. However, our current understanding is that the Sun lost most of its angular momentum by *magnetic braking*. In the early stages of the evolution of the Solar System, the magnetic field of the Sun dragged ionized atoms in the solar nebula with it, accelerating the atoms while slowing the Sun's rotation (see, for example, Morrison & Owen 2003).

2.2 The Sun is losing mass. Changing the mass would upset the fine gravitational balance that keeps the Earth at just the right distance for life to survive.

What we know:
Based on the luminosity of the Sun, mass is being converted to energy at a rate of 4.4×10^{9} kg/s. Over the 4.5 Gyr history of the Solar System, that amounts to 6.3×10^{26} kg—a mere 1/3000 of the Sun's mass. That would not be a problem for "gravitational balance" or for the survival of life on Earth.

2.3 Jupiter's moon, Io, is losing matter to Jupiter. It cannot be billions of years old.

What we know:
The mass loss rate of Io is trivial, and even if it has been going on for billions of years (which may not be the case), it would hardly have had a noticeable effect on the mass of Io. To be precise, the atmosphere of Io is escaping at a rate of ~ 1 ton/sec (Burger & Schneider 1998; Huang & Siscoe 1987). Over 4.5 billion years, that would amount to less than 1% of Io's mass.

2.4 Jupiter and Saturn are cooling off rather rapidly. They are losing heat twice as fast as they gain it from the Sun. They cannot be billions of years old.

What we know:
The average temperature of the interior of Jupiter falls by only about a millionth of a kelvin per year (e.g., Chaisson & McMillan 2004). This is not inconsistent with an old solar system. Saturn didn't start with as much internal heat as Jupiter but could have an additional heat source caused by the precipitation of helium in its interior (Chaisson & McMillan).

2.5 Saturn's rings are still unstable, indicating that they are not billions of years old.

What we know:
The age of Saturn's rings is not relevant to the age of the Earth or the Solar System. The planet can be billions of years old even if its rings formed later. Recent study suggests that the rings are not older than 100 million years (Sobel 1994).

2.6 The decaying magnetic field limits Earth's age to less than billions of years.

What we know:
The Earth's magnetic field has not always been decaying. It is well known that the Earth's magnetic field varies cyclically, as seen, for example, in the parallel bands of alternating strong and weak magnetism in the ocean floor basalts that run parallel to the axis of the Mid-Ocean Ridge. This is explained further by Brush (1993) and references therein.

2.7 The slowing spin of the Earth limits its age to less than the "billions of years" called for by the theory of evolution.

What we know:
The Earth's rotation is currently slowing down at a rate of 0.005 seconds per year (Thwaites & Awbrey 1982), which means that the length of a day (i.e., one Earth rotation) is currently increasing by 0.0014 seconds every century.

At this rate, 370 million years ago, the length of the day would have been 8.1×10^4 seconds long (i.e., 5×10^3 seconds shorter than today). Thus, 370 million years ago, the length of the day was 22.6 hours. The time of 370 million years ago is used here because a study of rugose corals from the Devonian period (370 million years ago) indicated that the year then had 400 days of about 22 hours each. (For a discussion of coral clocks, see Dott & Batten 1976, 248–249.) So there are consistent results at least that far back. Similar calculations were made for stromatolites (algal deposits) dating from the Upper Cambrian period (510 million years ago; Pannella, MacClintock, & Thompson 1968). Plots of the collected data for the entire time span from Recent back through the Paleozoic Era showed a nonuniform increase in days per month going back in time, implying that tidal friction has not been uniform in that period (Strahler 1987).

Therefore, one cannot linearly extrapolate back 4.6 billion years and expect to get a meaningful result for the length of the day or any limits on the Earth's age based on the slowing of the Earth's rotation.

Furthermore, we know that the present rate of slowing of the Earth's rotation is higher than in the past. The present rate of slowing is strongly affected by a resonance mode with the sloshing of the oceans' waters in the ocean basins (Sonleitner 1991; Brush 1983). In the past, there was less resonance and much less slowing of the rotation rate. The most recent calculations (Sonleitner) indicate that the Earth could be 4 to 5 billion years old and not have been spinning excessively fast or requiring the Moon to be any closer to the Earth than 225,000 kilometers.

2.8 The half-inch layer of cosmic dust on the Moon indicates that it has not been accumulating dust for billions of years.

What we know:
This idea is based on a figure of some millions of tons per year of dust landing on the Moon. While widespread among creationist Web sites, this idea is not consistent with recent measurements (Dohnanyi 1972). The rate of dust influx on the moon is 840 tons/yr, not enough for much dust accumulation, even over 4.5 Gyr.

2.9 The Moon is receding a few inches each year. Billions of years ago, the Moon would have been so close that the tides would have been much higher, eroding the continents quickly.

What we know:
If the Moon were constantly receding at two inches per year for the past 4.5 billion years, its orbit would have increased in radius by 142,000 miles. But the rate of recession has not been constant. The current rate of recession is higher than in the past because the tidal force is close to a resonance in the response function of the oceans. So the Moon was never too close (Brush 1983). Some erosion did occur, but that's all right; even while erosion occurs, tectonic activity continually builds up land masses.

2.10 The Moon contains considerable quantities of U-236 and Th-230, both short-lived isotopes that would have been long gone if the Moon were billions of years old.

What we know:
Thorium-230 and Uranium-236 are indeed relatively short-lived radioisotopes, so no Th-230 or U-236 would still exist from when the Moon first formed. However, they can both be produced through the radioactive decay of U-238, which is much longer lived, with a half-life of 4.5 billion years. The U-236 and Th-230 that are on the Moon now formed there only recently and are not part of the Moon's primordial supply. So their presence is not evidence for a young Earth.

2.11 The existence of short-period comets indicates that the universe is less than billions of years old, and there is no known way to add comets to the Solar System at rates that even remotely balance their destruction.

What we know:
Comets didn't originate with the Big Bang; they are left over from the formation of the Solar System and therefore provide no information on the age of the universe. Even if this argument refers to the age of the Solar System, the existence of the Oort cloud satisfactorily explains the frequency of long-period comets and the properties of their orbits. The short-period comets are explained by planetary perturbations that change cometary orbits from long period to short period (Strahler 1987).

2.12 At the rate at which stars in clusters disperse, the star clusters could not have been around for billions of years.

What we know:
For a typical globular star cluster to disperse in a few thousand years, its stars would have to be moving at several thousand km s^{-1}, which is simply not observed. The combined gravity from all the stars in a globular cluster holds them together. Open clusters do disperse, but no one claims that they are billions of years old.

2.13 The galaxy spatial densities (number of galaxies per given volume of space) are literally the same at a distance of four billion light years and in the region around our own system, indicating that if the universe is expanding, it has not been expanding very long. If the universe were 15 billion years old, the spatial density of the galaxies would be very different close in as compared with far out.

What we know:
The spatial density of galaxies has indeed changed. Observations with the William Herschel Telescope (http://www.ing.iac.es/PR/wht.htm) of faint blue galaxies at redshifts of about 2, which are probably in their first phase of star formation, showed that the space density of galaxies in the early universe must have been much higher than it is now. Also, the Stromlo-APM Redshift Survey (Loveday et al. 1992) shows that the space density of galaxies has changed, as seen by galaxy counts at different distances. Studies with the Hubble Space Telescope confirm these results, as do counts of radio galaxies.

2.14 The existence of great quantities of space dust, which by the Poynting-Robertson effect would have been vacuumed out of our Solar System in a few thousand years, indicates that the Solar System is young.

What we know:
The Poynting-Robertson effect causes orbiting particles to slow and fall inward because solar radiation falls slightly more on their leading side, like raindrops hitting the front of a moving car. But the particles

are replenished by comets and colliding asteroids. It takes hundreds of millions of years for the Poynting-Robertson effect to cause centimeter-sized particles to fall into the Sun, so the replenishment need not be particularly rapid. For smaller particles, there is a balance between the Poynting-Robertson effect and radiation pressure, thereby preserving the dust in stable orbits. Gravitational effects of planets can also keep particles in stable orbits (e.g., at the L2 and L3 Lagrangian points).

2.15 The theory of a Big Bang has been shaken with unresolvable inconsistencies, such as an unexpectedly uneven distribution of matter in the universe and a need for dark matter. Several astronomers think it is no longer a valid theory.

What we know:
The Big Bang is supported by a large amount of evidence. First, gravity (and Einstein's general theory of relativity) requires that the universe be either expanding or contracting; it cannot be static. In fact, astronomers observe that the universe is expanding. That the universe is expanding now means that it was smaller in the past. The expansion must have started at some moment in the past. The start of the expansion is what we call the Big Bang. Second, the Big Bang model predicts the existence of a cosmic microwave background radiation that should appear to come from all directions, with a blackbody spectrum and temperature about 3° K. Astronomers observe the cosmic background radiation with precisely those characteristics. The cosmic background radiation is uniform to approximately one part in 100,000. Current scientific models predict that there should be a slight unevenness in the intensity of the cosmic background arising from slight unevenness in matter near the time of the Big Bang. This early lumpiness served as the seeds of the uneven distribution of matter in the universe today. This unevenness in the cosmic background is observed, just as predicted. Third, the Big Bang predicts the observed abundances of primordial hydrogen, deuterium, helium, and lithium. Finally, inconsistencies are not necessarily unresolvable and have mostly to do with details of how galaxies form, not the overall picture of a 14-billion-year-old universe expanding from a Big Bang. The clumpiness of the universe, for example, was not unexpected and is convincingly supported by the discovery of unevenness in the cosmic background radiation.

2.16 If the spin of planets, galaxies, and so on, came from the fact that the Big Bang matter was spinning when it blew up, then the conservation of angular momentum demands that all planets be spinning in the same direction. Because some planets and moons spin in a retrograde motion, the Big Bang is disproved.

What we know:
First, the Big Bang has little to do with to the formation of planetary systems. The Big Bang involved the large-scale expansion of space, while our Solar System formed in just one tiny part of space billions of years after the Big Bang. Rotations on such small scales are not expected to be related to any rotation or expansion of the universe. The denser regions of the early universe gave rise to galaxies containing many turbulent motions. Because these early density fluctuations were apparently random, we expect galaxies to have random orientations and planetary systems within galaxies to have still different, random orientations. Second, the conservation of angular momentum doesn't require that everything spin in the

same direction. It only requires that a change in spin in one object be compensated by an opposite change in spin in one or more other objects. Planets with retrograde rotation are not a violation of angular momentum because other bodies in the early Solar System could account for the compensating spin. Finally, the Big Bang did not work like an ordinary explosion; it was an expansion of space itself. But even if it were a normal explosion, we would expect different spins because when something explodes, pieces fly out spinning in all directions.

2.17 The universe was supposedly formed in the Big Bang, but explosions do not produce order or information.

What we know:
Increases in order can occur in localized areas as long as the total entropy in the universe does not decrease. Also, explosions do produce some order, such as when a nuclear bomb produces a mushroom cloud or when supernovae produce heavy elements, and the shock waves from them compress interstellar gas, initiating the formation of new stars.

2.18 Anisotropies in the cosmic background radiation measured by the Wilkinson Microwave Anisotropy Probe show an axis. The Big Bang proposes no special orientations, so an axis discredits the Big Bang theory, but it is consistent with creationist cosmology.

What we know:
The Big Bang model predicts anisotropies on all angular scales from the very small to the very large (e.g., the octopole and quadrupole maps). The map of the cosmic background radiation by Tegmark, de Oliveira-Costa, & Hamilton (2003) shows an approximate alignment between the octopole and the quadrupole maps, but no other alignment. Such an alignment between two maps could arise by chance or could be the artifact of bias in the data analysis. Furthermore, a slight anisotropy in the large-scale distribution of the cosmic background is fully consistent with Big Bang models, as Goedel (1949) and Hawking (1969) have shown. There is no strong evidence supporting the suggestion that the universe is slightly anisotropic on a large scale, but the idea is not inconsistent with Big Bang theory or Einstein’s general theory of relativity.

2.19 The red shift from distant galaxies has been interpreted as a Doppler effect from the universe expanding. However, it may instead be due to "tired light." Photons age and shift to the red after a very long time.

What we know:
First, the tired-light model does not predict the observed time dilation of high-redshift supernova light curves. This time dilation is a consequence of the standard interpretation of the redshift: a supernova that takes 20 days to decay will appear to take 40 days to decay when observed at redshift $z = 1$ (Goldhaber et al. 2001). Second, according to the tired light model, the density of the universe does not decrease with time (because no expansion occurs), and the cosmic background radiation would have a higher intensity than what is observed (Wright 2005). Third, Tolman (1930, 1934) suggested that the expansion of the universe could be tested by looking at the dimming of galaxy surface brightness with increasing redshift.

In an expanding universe, galaxy surface brightness will decrease with redshift as $(1+z)^{-4}$, but in a nonexpanding geometry, such as the tired-light model, surface brightness decreases as $(1+z)^{-1}$. The tired-light model fails the Tolman surface brightness test (Lubin & Sandage 2001; see also Pennisi 2000). Fourth, there is no known mechanism that can account for tired light. Finally, the Big Bang model explains other observations besides the expansion redshifts. It also accounts for the abundance of light elements predicted from the nuclear reactions that would occur during the first moments of the Big Bang, the spectrum of the cosmic background radiation, the observed isotropy and homogeneity of the universe, and the counts of radio sources and quasars that vary with age, showing that the universe has evolved.

2.20 The Earth is near the center of the universe, at the bottom of a deep gravitational well. Relativistic effects result in billions of years passing in the rest of the universe while only thousands pass near the Earth. This explains how multibillion-year-old stars and galaxies can exist in a universe only a few thousand years old.

What we know:
Gravitational time dilation of the sort claimed would be easily observable. However, we see just the opposite: such time dilation does not exist. This is evident from the periods of Cepheid variable stars (there is no systematic increase of periods with distance from the Earth), from orbital rates of binary stars, from supernova extinction rates, from light frequencies, and so on. In addition, if the Earth were in such a gravity well, light from distant galaxies would be blue-shifted, not red-shifted.

For students who can be persuaded by physical evidence, it is clear that there is more than enough evidence to address the scientific objections that they raise regarding the age and evolution of the Earth and the universe. If a student raises other such questions not discussed here, a good place to start looking for useful information (besides the references herein) is the Talk Origins Archive Web site (http://www.talkorigins.org/).

3. INTELLIGENT DESIGN

3.1 Definitions and Beliefs

In recent years, many creationists have attempted to avoid the term *creationism*, advancing instead the new vocabulary of *intelligent design* (Behe 1996). Among other things, this renaming of creationism has allowed many groups to avoid restrictions on teaching creationism in public schools. Creationist (and even noncreationist) students in Astro 101 are thus likely to have heard of intelligent design and may bring it up, and so a number of sample questions and answers on this topic are provided below.

First, as background, note that intelligent design beliefs vary greatly but generally include the supposition (A) that the action of an intelligent being was involved in the evolution of living organisms and (B) that there is enough evidence of this action to infer that it occurred and should be part of modern scientific thought and teaching (Johnson 2003; see Note 1). While most scientists will not quarrel with someone who holds belief A but not belief B, the claim to which biologists take exception is that in biological systems, there is supposedly *scientific evidence* of design by some intelligent entity. (Note that the term *intelligent design* usually refers to both the beliefs and the arguments.)

Proponents of intelligent design, just like believers in other areas of pseudoscience such as astrology or the magic of crystals, often have a dogmatic commitment to their position and will not or cannot seriously consider alternative explanations even though their arguments are often patently wrong, as any objective examination can easily reveal. (Scientists can also be dogmatic or closed-minded, but the scientific peer review system tends to keep such narrow-mindedness in check.) It is therefore difficult, but still essential, to teach students who hold these beliefs why intelligent design does not stand up as a scientific theory. Conversations with students might include some of the following elements:

Student question: According to Dembski (1998), intelligent design theory is science. So why aren't you discussing it?
Possible response: There are several problems with the idea of intelligent design, which is why it's not taken seriously by the scientific community. For one thing, proponents of it take the unscientific view that if they can't think of how a particular arrangement of matter could have come about naturally, then it must be the result of a deity. That's similar to how people used to think that thunder and lightning were caused by a god. But now we know the physical causes of these phenomena. We should therefore have learned from experience that just because we don't yet have the explanation for some phenomenon doesn't necessarily mean that it was the work of God. (At the same time, nothing in our current understanding of science suggests that God should be rejected.) A second problem with intelligent design is that if, in fact, a certain arrangement of matter was so complex as to require a designer, then the designer would have to be even more complex. You would then be faced with the problem of who designed the designer. The problem would never end, and the idea of intelligent design ends up explaining nothing. Third, organisms contain both nonoptimal characteristics and vestigial organs, both of which would not be expected from a truly intelligent designer. One example of a nonoptimal characteristic is the orientation of the photoreceptors in the retina of the human eye. The light-sensitive parts of the rods and cones are facing the back of the eye, with the neural fibers coming out the front and needing to go out through a hole in the retina to the optic nerve. This creates a blind spot not found in some other animals (Dawkins 1986). The eye has additional maladaptive features as well (Williams 1992). Other examples of nonoptimal characteristics are found in nature's way of jury-rigging new features using available parts—for example, the panda's thumb, which is actually a modified wrist bone (Gould 1980, 1986). Examples of vestigial organs include an ostrich's wings, which are useless for flying, or the vestigial leg bones in whales and snakes. These characteristics would be expected from evolutionary development but not from an intelligent designer.

Student question: Is the universe designed?
Possible response: For the most part, the order and structure we see in the universe are explainable in terms of the laws of physics. Perhaps what you're referring to is that some people have suggested that the laws of nature, and in particular, the values of the physical constants, are "finely tuned" in such a way that allows life to exist. Scientists are well aware of this idea, and that's true of both theistic and nontheistic scientists. However, there's a big difference between fine-tuning and intelligent design. It's not necessarily the case that fine-tuning requires intelligent design. For instance, there could be a multitude of nondesigned universes, and we, of course, find ourselves in one of the types that allows our type of life. (Incidentally, there's no evidence that this is the case; it's just one possibility that has been suggested.) In addition, the argument about fine-tuning assumes that the physical parameters could have taken on any values whatsoever. This might make our universe, if it's the only one, seem very unlikely to have arisen by accident. However, we have no evidence that the physical constants could have taken on any other values than the ones they have. The laws of

> nature—including, perhaps, some higher-level laws of which we are still unaware—may require that the physical constants have the values that they do. Finally, many of the parameters are probably related and therefore could not take on any arbitrary values. For example, at one time, the speed of light, the permeability of free space, and the permittivity of free space were all believed to be independent constants. But the unification of electricity and magnetism showed that they are related. Thus, they cannot be independently varied completely freely. Future unifications in physics may show us that there are even fewer free parameters.

Note that the above fine-tuning argument is also known as the weak anthropic principle. The response that the physical constants are interdependent, making the universe we see not so improbable, was discussed by Kane, Perry, & Zytkow (2000). The fine-tuning argument is also weak because different initial conditions can lead to similar outcomes (e.g., the minimum mass of stars and their formation of heavy elements; Nakamura, Uehara, & Chiba 1997).

Advocates of intelligent design also often cite "irreducible complexity" (Behe 1996) as the scientific evidence that supports their beliefs. Some sample arguments on this topic follow. For more information and links to other resources on intelligent design, see the TalkDesign.org Web site (http://www.talkdesign.org/).

3.2 Irreducible Complexity

Biochemist and intelligent design proponent Michael Behe (1996) based his book *Darwin's Black Box* on the idea that many biological systems are "irreducibly complex" at the molecular level. Behe gives the following definition of irreducible complexity:

> By irreducibly complex I mean a single system composed of several well-matched, interacting parts that contribute to the basic function, wherein the removal of any one of the parts causes the system to effectively cease functioning. An irreducibly complex system cannot be produced directly (that is, by continuously improving the initial function, which continues to work by the same mechanism) by slight, successive modifications of a precursor system, because any precursor to an irreducibly complex system that is missing a part is by definition nonfunctional. (39)

This argument is basically a modern version of the long-since-debunked watchmaker argument, promoted two centuries ago by William Paley (1803). The idea is equivalent to saying that you can't have a watch without a watchmaker. But the argument as applied to biological systems has repeatedly been shown to be inapplicable (e.g., Shanks & Joplin 1999). Yet irreducible complexity proponents (and some Astro 101 students) maintain that the universe—and life itself—has this characteristic. They say that such wondrous and inexplicable things just could not have evolved over millions of years. Actually, for every biological example they adduce, biologists can explain how the system is not, in fact, irreducibly complex. (See http://www.talkorigins.org/faqs/behe/icsic.html for other resources on irreducible complexity.)

Students who have heard of irreducible complexity may thus ask something like the following:

> **Student question:** How could a biological system that is irreducibly complex possibly have evolved?
> **Possible response:** Just because one person can't think of how it could have evolved and therefore labels the system as "irreducibly complex" doesn't mean that it really is. But even if it could be shown that a system is irreducibly complex, there are still ways that it could evolve. An irreducibly complex system is defined as a system that loses its function if any one part is removed, so it only

indicates that the system did not evolve by the addition of single parts with no change in function. That still leaves several evolutionary mechanisms:

- Deletion of parts
- Simultaneous addition of multiple parts
- Change of function
- Gradual modification of parts

All these mechanisms have been observed to occur. Deletions and gene duplications are fairly common (Lynch & Conery 2000; Hooper & Berg 2003; Dujon et al. 2004), and together they make irreducible complexity not only possible, but expected. In fact, it was predicted as early as 1939 (Muller 1939).

An astronomical example of the simultaneous addition of multiple parts is the formation of binary stars. You can't start with a single star, toss in a second star, and have it be captured into a near-circular orbit without having circumstellar matter to circularize the orbit. However, if the two stars form simultaneously out of the same protostellar nebula, then it's very easy to understand their existence.

In short, intelligent design takes the clearly antiscientific attitude that if we can't immediately explain something, we should give up trying to understand it and just attribute it to a "designer." Basically, all gaps in our knowledge would simply be filled by God. That approach would immediately put a stop to the scientific enterprise and the acquisition of new knowledge.

4. CONCLUSION

In schools and in other public discussions, there remains strong social pressure to mix religious ideas with science (Forbes & Long 2000). Unfortunately, many educators never received an adequate education in evolutionary science and, especially at the K–12 levels, may lack support from their colleagues, administration, and the community in their efforts to teach evolution. Consequently, many teachers (and Astro 101 instructors) are afraid to talk about evolution in the classroom, which results in many K–14 students lacking an adequate understanding of the subject. Some of these students will be the teachers of tomorrow, and consequently, this problem is passed on from one generation to the next. We educators can help ameliorate this problem by not avoiding teaching about evolutionary processes and long time scales. When a student asks a question or makes a comment about evolution or the age of the Earth or universe, regardless of whether it has a creationist bent, we can spend time providing a cogent, *scientific* answer, speak respectfully, and encourage further discussion and investigation.

Many students have been taught by eloquent, persuasive, and often charismatic creationists, leaving the students with a very difficult time distinguishing between the false syllogisms that filled their impressionable years and the scientific reasoning that they encounter only for the first time in college-level classes (see also http://evolution.berkeley.edu/). Yet merely citing accurate data or showing slides of what appear to be self-evident illustrations of astronomical phenomena are not necessarily enough when teaching disbelieving students. They require repeated demonstrations, multiple sources of data, and perhaps most important, they need practice in rational thinking and scientific analysis of information. This brief article is an attempt to provide the Astro 101 instructor with useful samples of typical questions from students in college astronomy courses in order to help facilitate the teaching of basic scientific concepts

involving long time scales. Although some very vocal students will seem to be the most difficult to reach in class, it may be the silent disbelievers who pose the greatest challenge because the depth of their misconceptions may never be known and thus never adequately addressed.

It is very difficult, perhaps even futile, to try to persuade some creationist students to abandon their beliefs. However, by understanding the extent of the evidence for biological evolution and its relation to astronomical time scales, instructors can more confidently discuss the issues that students raise and, for those students who are open to new ideas, make compelling cases for these well-established and important facets of science.

Note

Note 1."Our strategy has been to change the subject a bit so that we can get the issue of intelligent design, which really means the reality of God, before the academic world and into the schools" (Phillip E. Johnson, appearing on American Family Radio, January 10, 2003. Johnson is a well-known creationist and author of *The Wedge of Truth: Splitting the Foundations of Naturalism*). back to text

APPENDIX: VARIETIES OF CREATIONISM

Despite many people's tendency to think of all creationists as one group and all evolutionists as another, *creationism* actually refers to a wide range of beliefs (Scott 1999). Because the differences between types of creationism are not minor, the following list will be useful in identifying and understanding the viewpoints of creationist students. Most creationist beliefs are actually mutually exclusive, and many creationists disagree as much with each other as they do with evolutionists. Morris (1985), for example, devotes the last 20% of his book *Scientific Creationism* to attacks on other forms of creationism.

Varieties of Christian creationism are discussed here because Christianity, in its various forms, is by far the most prevalent religion in the United States (approximately 80%, according to the 2001 American Religious Identification Survey, http://www.census.gov/prod/2004pubs/03statab/pop.pdf). However, creationism is considered a relatively minor force in many other parts of the world (Edis 1999; see also Fraknoi 2003 for an excellent list of Web sites that help debunk creationist claims).

In the United States, there is a sort of continuum of creationist/evolutionist beliefs (Isaac 2000; Scott 1999), starting with people who take each word of the Bible literally, moving through those who do accept biological evolution but only under certain conditions, to those who fully accept the current scientific thinking about evolution. (This section is subdivided by beliefs, but because responses would be similar, examples of student questions and possible replies by the Astro 101 instructor will be grouped to cover more than one specialized belief.)

Here, then, is one list of varieties of creationism, from most creationist to most evolutionist (following Isaac 2000):

A.1. Flat-Earthers
A.2. Geocentrists
A.3. Young Earth Creationists
(A.4. Young Earth, but *appears* old)
A.5. Old-Earth Creationists

(A.6. Gap Creationism)
(A.7. Day-Age Creationism)
(A.8. Progressive Creationism)
(A.9. Intelligent Design Creationism)
A.10. Evolutionary Creationists
A.11. Theistic Evolutionists
A.12. Methodological Materialistic Evolutionists
A.13. Philosophical Materialistic Evolutionists

A.1 Flat-Earthers

Flat-Earthers believe that the Earth is flat based on a literal reading of the Bible, such as references to the "four corners of the Earth" and the "circle of the Earth." There are not many flat-Earthers. You probably won't run into one of them, but it's useful to understand how far some people will go to achieve consistency with a literal interpretation of the Bible.

A.2 Geocentrists

Geocentrists accept a spherical Earth but don't agree that the Sun is the center of the Solar System or that the Earth moves. The basis for their belief is, again, a literal reading of the Bible (e.g., Psalm 96:10: "He has fixed the Earth firm, immovable . . . "). You might never meet a geocentrist, and, as with a flat-Earther, arguing with one would probably be futile. Nevertheless, the Astro 101 instructor may feel obligated to mention some of the standard methods by which we know that the Earth is round and the Solar System is heliocentric. (Having discussed this, the instructor may nonetheless marvel at how their students can twist words and avoid logic in order to still hold on to their preconceived notions.)

Student question: How do you really know the Earth isn't at the center?
Possible response: We know on both observational and theoretical grounds. Observationally, remember our discussion about parallax? It would not be observed if the Solar System were geocentric. And observation of the aberration of starlight also shows that the Earth is moving. On the theoretical side—and by theoretical I don't mean speculative, but rather strongly supported information that can be expressed quantitatively and used to make accurate predictions—we have Newton's laws of motion and law of gravity, which together show that the Sun, having 330,000 times the mass of the Earth, must be the central body around which the small bodies revolve.

A.3 Young-Earth Creationists

Young-Earth creationists maintain a literal interpretation of the Bible. They believe that all life was created in six literal 24-hour days and that the Earth is less than 10,000 years old. They will, however, acknowledge that the Solar System is heliocentric and that the Earth is spherical. Young-Earth creationism is one of the more influential varieties of creationism today, and most of the creationist students encountered by the Astro 101 instructor are likely to fall into this category.

Student question: If evolution really occurs, why don't we actually see it happening?
Possible response: Evolution is generally a slow process, but for small organisms that reproduce quickly, such as bacteria or fruit flies, evolution has actually been observed.

Examples of where evolution has been observed by the appearance of new species can be found in Weinberg, Starczak, & Jorg (1992), Dobzhansky & Pavlovsky (1971), and references in Boxhorn (1993). For instance, in 1964, a few individual worms (Nereis acuminata) were collected from Long Beach Harbor, California. They were allowed to reproduce until there were thousands of them, and then a few of those and their offspring were used in laboratory studies for the next 20 years. After that time, the Long Beach area was searched for populations of the worm. Two species were found, and Weinberg et al. performed tests on those two populations and the lab worms as well. They found that the lab worms had evolved to a species different from the two extant field species, based on reproductive isolation and the fact that the lab worms showed different karyotypes (chromosome characteristics) from the field populations.

A.4 Young Earth, but Appears Old

The idea that the Earth is really young but was made to appear old (also known as the Omphalos argument) was first described in a book by Gosse (1857). This view is not uncommon today.

Both the proponents of this idea and the young Earth believers are likely to make similar challenges. For example:

> **Student comment:** Dates from radioactive decay assume that the decay rates are constant, but there is no evidence for this assumption. All processes in nature vary depending on various conditions, and we should not expect radioactivity to be different.
> **Possible response:** That decay rates are constant is not an assumption; it is in fact supported by a great deal of evidence. For instance, radioactive elements are produced in supernovae, and these produce gamma rays whose frequencies and fading rates are predictable based on present decay rates. These predictions turned out to be correct for SN1987A, which is 169,000 light years away (Knodlseder 2000). Therefore, radioactive decay rates were not significantly different 169,000 years ago. Similar evidence exists for supernovae millions of light years away.

A.5 Old-Earth Creationists

Old-Earth creationists accept the evidence that the Earth is billions of years old but also believe that life was an act of creation by God. An old-Earth creationist can at least partially reconcile this view with modern scientific knowledge. A student with this belief may have a discussion with an Astro 101 instructor about what happened to living creatures after life first appeared, whether it was "sparked" by an astronomical, chemical, or other physical phenomenon, or by God. Or, the challenge may involve the actual origin of life:

> **Student question:** A major problem with evolution is that it doesn’t adequately explain the origin of life, does it?
> **Possible response:** Evolution does not purport to explain the origin of life. Evolution deals only with what happened to life after it already formed.

A.6 Gap Creationism

Gap creationism provides a way of reconciling the Bible with an ancient Earth. The idea is that there was a long period of time, a long gap, between the first two verses of Genesis. Thus, there was time for the universe and Earth to have been created even before the biblical six days of creation.

A.7 Day-Age Creationism

Day-age creationists assume that each of the biblical six days of creation actually represents extremely long periods of time. Thus, they can accept an old age for the Earth and the universe while still maintaining the order of events described in Genesis 1.

Both Gap and Day-Age creationism have a common theme in that they allow for extremely long time periods for the creation of the Earth. However, they would be unlikely to accept the nebular model of the formation of the Solar System because it is not described in Genesis.

> **Student question:** How do you know that the Earth formed in a swirling cloud of dust and gas?
> **Possible response:** For one thing, we can see planetary systems in various stages of formation around many stars. So we know that this process occurs. Also, formation by this process makes a number of predictions about the resulting planetary system, which are consistent with what we observe in our Solar System. For example, the nebular model would be expected to result in planets with roughly coplanar orbits, and in fact, that's what we see!

A.8 Progressive Creationism

Progressive creationists accept most modern scientific conclusions but view the Big Bang as an act of creation by God; however, they do not accept much of modern biology. They believe that God created "kinds" of organisms sequentially in the order seen in the fossil record, but they also believe that the more recent kinds were simply recently created by God and not genetically related to older kinds. Note that the term *progressive* is used not because these creationists are progressive, but because of their belief in progressive acts of creation that produced the sequence of species seen in the fossil record. Progressive creationism is one of the more common old-Earth creationism views today and can be illustrated in an exchange regarding the evolution of humans:

> **Student question:** If man descended from apes, why are there still apes around?
> **Possible response:** First, this question contains the misconception that man descended from apes when, in fact, both man and apes descended from a common ancestor. But, you're really asking how it is possible for an ancestral species to still exist. A useful analogy for this question is something like the following: Some Americans immigrated to this country from Germany. Does that mean that there shouldn't be any more Germans? No. Similarly, that some apes evolved into different creatures doesn't mean that there shouldn't still be apes around. The point is that mutations can cause a small number of individuals to give rise to a new species without affecting the rest of the population, just as a small number of Germans can immigrate to this country while all the other Germans remain in their country.

A.9 Intelligent Design Creationism

Intelligent design creationists take the view that life is so complex that it could have only resulted from the work of God. Intelligent design ideas are now very technical, involving a large amount of microbiology. This is state-of-the-art creationism and is used as a way of getting these ideas into public school science classes even though it is illegal to teach creationism. (The U.S. Supreme Court concluded that teaching creationism in public schools is an illegal promotion of a particular religion; Edwards v. Aguillard, 1987).

> **Student question:** Some aspects of life are so complicated that they couldn't have occurred just by chance. Doesn't that show that evolution can't explain everything about life?
> **Possible response:** Complexity clearly doesn't require an "intelligent designer" because it can be explained by the laws of physics in a number of natural phenomena. For example, clouds and ice crystals are complex arrangements of water molecules that respond in certain ways to different temperatures and other variables. No intervention is needed. In addition, the evolution of many such complex phenomena can actually be observed in real time, allowing us to see the creation of complexity ourselves. In life, evolution accounts for complex systems arising via much more gradual variations and selection. For example, Darwin (1872) explained how, based on evolution by natural selection, an organism's photosensitive cells could evolve gradually into human eyes.

A.10 Evolutionary Creationists

Evolutionary creationists argue that God guides evolutionary (and all other natural) processes at every step. Evolutionary creationists can therefore accept modern science; they just take the view that it is all the work of God.

Students who fall into this or any of the following three categories will probably not pose evolutionary or long time scale challenges to the Astro 101 instructor.

A.11 Theistic Evolutionists

Theistic evolution is the view that evolution is the process by which God decided to have life develop. Theistic evolutionists basically accept modern science, assuming that God intervenes only occasionally for certain supernatural acts, such as the creation of the human soul. Pope John Paul II maintained this view, which is also found in some Protestant teachings.

A.12 Methodological Materialistic Evolutionists

Materialistic evolutionists accept modern science and can believe in God, but they maintain that God does not actively interfere with evolution or other natural processes.

A.13 Philosophical Materialistic Evolutionists

Philosophical materialists take the position that the supernatural does not exist. In their view, evolution and all other aspects of nature exist without the interference, or even the presence, of God.

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