especially in astronomy and Earth sciences. The cornerstone of science is good, careful, repeatable observation, not theory, but that fact is often not made clear.

A colleague told me about a comment from a creationist who complained that we scientists keep changing our theories. That theories do change is a crucial and often glossed-over point. We accept those theories that explain the majority of our observations and reject those that do not. At some point in the future, all of our current operational theories will be either rejected or modified, because they will no longer explain the majority of our observations. Every successful theory contains certain essential elements from previously successful ones; for example, Einstein's theories of relativity, in the appropriate limit, reduce to Newton's theory of motion. We should expect that every theory will, at some point, be supplanted. The ascendant theory of the moment must incorporate the most recent observations we have made.

Furthermore, we must avoid tangling science and religion. They are different worldviews–one physical, one spiritual. Too many scientists are willing to write philosophical and metaphysical treatises from their positions as scientists. We need to step back from such activities unless we make it clear that they are done outside our scientific expertise.

Just as we wish to discourage those with strong religious views from telling us what and how to teach in our sciences, we should tread lightly in crossing over and commenting on religious matters, except as private citizens. We all have the right to express our individual views of spirituality; we just need to do it without reference to our sciences.

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Examination of humans and other life forms clearly shows that the designs in nature, although marvelous, are not intelligent. They show evidence of random mutation and harsh selection—the best evidence against intelligent design and its supporters.[1] The evolution and ID theories predict very different attributes for the design of life forms. We should test those two theories as we test any others.

Intelligent designs contain no extraneous and nonfunctional components and the components are connected in a logical fashion. To expand on William Paley's example,[2] anyone examining the design of a fine mechanical watch could see that each part served some definite purpose and that the parts were logically connected. Paley's argument was forceful in 1802 because no one then could examine the human life form in much detail and most people found it hard to believe that random events could lead to such a marvelous organism.

Today we have both the tools to examine life forms down to their DNA code and a much higher appreciation of random variation as a design process. A significant fraction of human DNA has been found to be nonfunctional "junk DNA." Researchers have found no logical order for the distribution of the functional DNA among the chromosomes or along a given chromosome. Such a lack of order is what random variation followed slowly by selection would produce. It can also be argued that larger structures, like the human appendix or our organs of metabolism that consume muscle rather than fat when we try to diet, are not intelligent design choices.

Humans design the most complex and marvelous products—for example, integrated circuits—using "simulated annealing"[3] processes of computer-generated random variation and selection. The simulated annealing process mimics the thermodynamic process by which crystals evolve randomly toward perfection. So the absence of intelligent design does not prove the absence of an intelligent designer: God may have elected to use evolution to design His creations.

The theory of evolution implies that the design of humans, and all other life forms, will continue to change (evolve), as do simulated annealing designs (as long as the designer lets the computer run). ID theory, in contrast, implies that the design of humans should not change. However, there is abundant evidence that humans continue to evolve.

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I enjoyed the articles about intelligent design and the efforts of its creationist supporters to sneak it into the public schools.

One of the sneakiest features of ID is that its advocates avoid stating their hypothesis clearly. If ID means that the universe does not contain "designs" inferior to what we would expect of a competent human engineer, then ID is factually wrong. There are many, many examples of inefficient, unnecessarily complicated, even tragically bungled "design" in nature. What intelligent being would use deadly genetic diseases (thalassemia and sickle cell anemia) as "solutions" to the problem of malaria? Any sensible person would find the optimal solution for vision and then implement that solution in every animal that needs to see. There are around 40 different types of eyes in nature, so the hypothesis of an "intelligent" designer radically disagrees with the facts.

If ID means God, which is what its advocates want us to think, then it becomes untestable even in principle. An omnipotent being can do anything; therefore, the hypothesis that "God did it" makes no predictions about how "it" was done. Checking the theory against the facts is impossible because it can fit any facts. Furthermore, since a theory with an omnipotent being allows one to entertain *any* hypothesis, the theory is worse than untestable—it actually undermines everything we think we know. Will the Sun rise in the south tomorrow? It will if God wants it to! Is the Sun we see today the same Sun we saw yesterday? Maybe God made a new one overnight!

Advocates argue that we cannot know whether ID is true if science refuses to consider it. Mano Singham says that, "to be valid, science does not have to be true." This assertion just begs for the creationist response: "So let's test ID to see if it is valid!" The claim that theories can sometimes be useful even if untrue has some obvious merit and is a favorite of the antirealist school of philosophy of science. Antirealism holds that entities such as atoms or electric fields don't actually exist (that is, they are not "true"), they are just useful ("valid") fictions. The great weakness of antirealism is that it fails to explain the predictive power of scientific theories. If X doesn't exist, then the success of theories that postulate X must be nothing more than curve fitting. But how can curve fitting successfully

predict neutron stars or electromagnetic waves? Antirealism is weak enough as academic philosophy; it is hopeless as a public response to creationists.

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**Melott replies:** Science and religion can validly interact in some ways. Science can comment usefully on such issues as the age of the Shroud of Turin, the parting of the Red Sea, or genetic studies of alleged lost tribes of Israel. These are all related to religion. In turn, religious (or antireligious) interpretations of science may add meaning or provide the values needed to judge technological possibilities. Problems arise when either sphere, science or religion, pretends to constrain the other, because miracles and empiricism don't mix well.

Beware of using the presence of junk DNA to judge intelligent design. In fact, much so-called junk DNA has been found to have a biological function; ID proponents call this support for their position.

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**Singham replies:** Ted Lawry argues that the predictive power of theories is indicative of their truth. But dominant scientific theories have always made successful predictions; that is how they gained their ascendancy in the first place. The geocentric model of the Solar System, for example, had enormous predictive power. So did the phlogiston theory of combustion. But that did not prevent those theories from being supplanted by other theories that, in key respects, directly contradicted their predecessors.

One way to sustain the position that, if a scientific theory works well and is predictive, it must be true is to add the supposition that we are currently living at the end of science, that is, that our current scientific theories are the final word. That position is more or less the one taken by science writer John Horgan.[1] But if we follow historical precedent and allow for the fallibility of even current highly successful theories, as David C. Nobes argues, then we are faced with the problem of how we would ever know when we have achieved "truth."

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# Can GPS Test Gravity's Speed of Propagation?

Neil Ashby's article (Physics Today, May 2002, page 41) about the satellite network that was installed for the global positioning system is very impressive; the precision to which the orbits of the individual satellites are known is fantastic. Relativistic corrections of the order of $10^{-10}$ and smaller are relevant and need to be applied; that level of precision is a real challenge and allows researchers to test the predictions of special and general relativity with comparable precision.

I wonder if the system's achieved precision is sufficient for determining the fundamental constant of the gravitational action's propagation speed, and if it has been determined yet. One possible way to do that would be to analyze the eccentricity effect on the satellites' orbits from the tidal force of the Moon. On a geostationary satellite at a height of 36 000 km, the effect is ±2 km, and the axis of eccentricity precesses around Earth following the Moon's 28-day journey. The phase of that precession follows the Moon's orbit with a delay of 1 second, if one assumes a gravitational propagation speed equal to the speed of the electromagnetic interaction. Within 14 days, the eccentricity has rotated by 180 degrees. The challenge for researchers is to determine the precession to better than 1 second, the time the gravitational field needs to travel from the Moon to the satellite. Determining the 4-km eccentricity in 14 days to better than 1 second calls for a precision of 1 part in $10^{10}$.

Perhaps this analysis has already been done. Physicists may think it is trivial, because all predictions of special and general relativity have proven to be correct so far. However, I think this investigation would be a fundamental one, since the expansion speed of two different interactions, gravitational and electromagnetic, need not be identical.

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