with lower carbon emissions and to move away from our almost exclusive dependence on crude-oil–derived transportation fuels would encourage adoption of advanced internal combustion engine vehicles in the near term and, eventually, of hydrogen vehicles.

Ramesh Gopalan makes a good point about carbon sequestration. However, removing CO_2 from small sources (such as small engines), collecting it, transporting it, and sequestering it are daunting tasks. Building a CO_2 disposal infrastructure for small-scale carbon capture and collection could be as difficult and costly as implementing a hydrogen infrastructure. Carbon sequestration is better suited to large energy complexes that produce decarbonized energy carriers (electricity or hydrogen).

Vladislav Bevc questions whether large-scale use of hydrogen would be feasible, given that large-scale conversion of primary energy resources would be required. Studies have found that sufficient hydrogen to supply foreseeable demands for fluid fuels could be produced from a variety of primary resources including fossil resources (possibly with carbon sequestration), renewables (wind, biomass, or solar), and perhaps nuclear.

To illustrate this point, consider energy use for US automobiles. An efficient, four- to five-passenger hydrogen car is projected to have a fuel economy equivalent to about 60–80 miles per gallon of gasoline. If such a car were driven 11 000 miles per year (the US average), and if one assumes that gasoline has a lower heating value of 122 megajoules per gallon, such a vehicle would use 17–22 gigajoules of energy per year. If all 132 million US passenger cars used hydrogen, the total energy use would be perhaps 2.2–3.0 exajoules per year. If the hydrogen is made from fossil fuels or biomass at 60–80% efficiency (depending on the feedstock), the primary energy use would be 3–5 EJ per year. This contrasts with current primary energy use of about 10 EJ for US automotive transportation.[1]

Reference

1. For a discussion of primary energy resources for hydrogen production, see J. Ogden, *Annu. Rev. Energy Environ.* **24**, 227 (1999).

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Intelligent Design Tangles Science and Religion

I found the Opinion articles by Adrian Melott and Mano Singham (PHYSICS TODAY, June 2002, page 48) particularly interesting and deserving of comment. Although I agree with much of what the authors say, I think some of their statements need to be taken further. What is it that we as scientists do, and how do we communicate it to the general public? What is the place of theory in science?

We scientists have not, in general, been very good at communicating to the wider community what we do, and many of us fall into the trap of "hypothesis testing." My daughters' high-school science teachers expect every experiment to test a hypothesis, and science fair judges will often give a project a poor grade if there is no hypothesis.

Certainly it is important that we have theories and hypotheses that attempt to explain our observations and to predict future observations. Hypotheses, however, do not exist without first having some observations on which to base them. We are often making new observations,

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.

References

1. K. M. Ashman, *Physics and Society* **29**(3), 2 (2000).
2. W. Paley, *Natural Theology*, R. Faulder, London (1802).
3. S. Kirkpatric, C. D. Gelatt Jr, M. P. Vecchi, *Science* **220**, 671 (1983).

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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