Science's 20 Greatest Hits Take Their Lumps

Readers applaud the goals of science literacy but tell Hazen and Trefil to watch their language and put process before facts

EARLIER THIS YEAR, SCIENCE LITERACY MAVENS Robert Hazen and James Trefil stuck out their necks by daring to publish a list of the Top 20 Great Ideas of Science in this publication. They were particularly brave because they knew that we were going to offer our readers an ax with which to whack at them. Actually, the ax was a fax: readers were invited to fax their opinions on the list and its shortcomings and to suggest additions (*Science*, 18 January, p. 266). And 199 of you couldn't resist the temptation. Hazen and Trefil kept their heads, but each got quite a crew cut.

Hazen, a geophysicist, and Trefil, a physicist, had first published their candidates for the 20 most important ideas of science in a new book, "Science Matters: Achieving Scientific Literacy," which also serves as curriculum guide for their undergraduate general science course at George Mason University. When *Science* offered up a digest, many readers were quick to applaud Hazen and Trefil's efforts even as they criticized details of their list. For example, many respondents gave a qualified thumbs up for the notion of giving students—and the public—a course on the ABCs of science. Faxers called the idea "worthwhile" and "great"; after rewriting 5 or 10 of the ideas, a typical fax ended with a note of appreciation. And most respondents took the burden of peer review seriously, as scientists should: Many of you sent single-spaced missives on the importance of scientific literacy, the beauty of science, and the difference between science and religion; two expressed their feelings in verse.

Parasites Paramount

An especially provocative Top 20 contender from Hugh Hixon, Riverside, California:

"Successful systems accumulate parasites."

Hixon's rationale: "This is a fundamental observation, rooted in the thermodynamic observation that it is easier to move (or steal) something than it is to make it. It accounts successfully for predation, crime, war, noncontributing authors on publications, taxation, lawyers, unproductive business practices and government programs, immune systems, a lot of ecology, and probably scientific illiteracy."

But then you got down to business: Not one of the Top 20 was left unscathed by your critiques. "Hits" hit hardest included Number 1: "The universe is regular and predictable." Hazen and Trefil intended this phrase to assert that the cosmos is amenable to scientific study—but many of you weren't buying. Nor were you buying Hit Number 16: "Everything on the earth operates in cycles." In fact, many who objected to Number 1 also hated Number 16. Take Edward Epstein, principal scientist at the Climate Analysis Center:

"I've taken an informal poll among my colleagues in the National Meteorological Center. To a person, two items in the list caught their attention, if not their wrath—items #1 and #16. Among people whose jobs are prediction and/or research related to prediction, there is very little sympathy for the suggested *truth* that the universe is *predictable* or that 'everything on the earth operates in cycles'" (emphasis theirs). Snapped David Henderson, chairman of the chemistry department at Trinity College, criticizing Number 1, "Determinism is dead, but you would not know it from the Top 20."

Indeed, nearly 40 faxers attacked Number 1 and another 30 slammed Number 16. Unperturbed, Hazen and Trefil told *Science* that they do spend time in their book on such unpredictable topics as chaos. And they say Number 1 should be read as a general statement about how natural laws govern the universe, not as a defense of determinism.

Hit Number 12, "Stars live and die like everything else," was also high on the reader hit list, drawing many complaints for its breezy lingo. "Like everything else? Do they have sex?" wondered physicist Wendell Holladay of Vanderbilt University, who was perhaps guilty himself of forgetting the world's asexual reproducers. But Trefil isn't moved: "On this one I won't budge," he declared, saying that the colloquial use of "live" and "die" is okay for nonbiological entities.

Hazen and Trefil are both physical scientists, so perhaps it's no surprise that they're willing to co-opt the language of biology to describe stars. But many respondents cried foul at what they perceived to be the slighting of some disciplines—especially math and biology—in the list. "It is not too surprising that of the 20 great ideas of science picked by a physicist and a geophysicist, 16 are rooted in physics and geophysics," wrote Clifford Saper, professor of neuroscience at the University of Chicago. "Their biases are showing," sniffed Samuel Scheiner, biologist at Northern Illinois University in DeKalb. "As demonstrated by the list, Dr. Trefil is still 'unfamiliar with large areas of biology.' " (Scheiner was quoting Trefil's own admission that he had to learn some biology in order to teach the Top 20.)

Predictably, suggested additions sorted out by discipline: Chemists wanted more chemistry, and physicists added even more physics.

The Universe in Verse

Jonathan Post and Christine Carmichael, scientists and poets with Emerald City Publishing in Altadena, California, turned the Top 20 into verse. It may not scan well enough to get into the Humanities Top 20, but readers may enjoy a few stanzas:

By means of Mathematics
the cosmos is depictable.
That is to say, "The universe
is regular and predictable."

From Thermodynamics' first law
the world has never swerved.
It's always been observed
that energy is conserved.

The oceans dry,
the iceberg melts.
"Stars live and die
like everything else."

No man is an island,
connections are expected.
Ecologically speaking,
"All life is connected."

Biologists' favorite inserts included:

Living beings follow the laws of physics and chemistry; there is no "vital" force.

No two organisms are alike

Enzymes control the work of cells

Life is based on carbon

Water is essential for life

The sun provides the energy used by almost all life on earth

The concept of homeostasis.

Hazen is quick to point out that most of these ideas are included in the course and the book, though they are not given Top 20 status. He says that biology is fairly represented because the basic ideas of physics apply to everything, including life. But most biologists seemed to agree with philosopher of biology Elliot Sober of the University of Wisconsin, who protested to *Science* that Newton's laws aren't part of the biological canon.

Mathematicians had good cause to complain of disciplinary discrimination, since math was completely absent from the Top 20. Faxers suggested several additions, including the idea that equations can describe the universe, the concept of mathematical proofs, and some elements of probability and statistics. "Remember all that nasty theoretical mathematics you had to take in college? Well, that's the way the universe actually works," wrote Richard Landau of Nashua, New Hampshire. "Touché," respond Hazen and Trefil, implying that they

do remember all those equations. But they beg off teaching math, pleading the well-worn excuse of short semesters. Squeezing math into an already abreviated course on science is just too rough, they say. "Communicating the role of mathematics is one point that I'm very sympathetic to, but I don't know quite what to do about it," says Hazen.

Though many faxers complained about missing hits, even more were outraged by the vague language used to describe the items that Hazen and Trefil did include. "Catchy drivel," "facile sloganeering," "a parlor game," and "just plain wrong," were among the more choice descriptions of the hit list. Much of the ire seemed to be chiefly aimed at the informal style, since many of the summary statements lacked the precise language most scientists expect when reading about science. Ambiguous words like "everything" and "useful" infuriated faxers.

▲ *Hazen* *Trefil* ▼

Top 20: Hits or Duds?

Here's Hazen and Trefil's original Top 20 Great Ideas of Science. No ideas were left unchanged by Science *readers, although Numbers 2 and 9 earned but a few complaints.*

1. The universe is regular and predictable.
2. One set of laws describes all motion.
3. Energy is conserved.
4. Energy always goes from more useful to less useful forms.
5. Electricity and magnetism are aspects of the same force.
6. Everything is made of atoms.
7. Everything—particles, energy, the rate of electron spin—comes in discrete units and you can't measure anything without changing it.
8. Atoms are bound together by electron "glue."
9. The way a material behaves depends on how its atoms are arranged.
10. Nuclear energy comes from the conversion of mass.
11. Everything is really made of quarks and leptons.
12. Stars live and die like everything else.
13. The universe was born at a specific time in the past and has been expanding ever since.
14. Every observer sees the same laws of nature.
15. The surface of the earth is constantly changing and no feature on the earth is permanent.
16. Everything on the earth operates in cycles.
17. All living things are made from cells, the chemical factories of life.
18. All life is based on the same genetic code.
19. All forms of life evolved by natural selection.
20. All life is connected.

"While I would agree that many of the ideas that are in the list are indeed the most important ones, I would object to the absolute and simple-minded terms in which they are expressed....In one place the list says 'everything' is made of atoms, then 'everything' is really made of quarks and leptons. Your compilation of their list is baby-talk that reduces Science with a capital 'S' into Saturday morning cartoons," grumped Elwyh Loh, assistant professor of medicine at the University of Pennsylvania.

"They're right. What can I say?" admits Trefil to some of these complaints. "Some of the wording could have been better. We spent more time on what was in the chapters themselves than on the slogans."

Then came the philosophical faxers. While some considered their own disciplines underrepresented in the Top 20, many more argued that Trefil and Hazen had left out the essence of science itself: the scientific method. Any course that purports to teach scientific literacy should at least introduce students to the process of discovery, they said.

"I am aghast at the efforts of Trefil and Hazen to present their '20 Great Ideas' as anything calculated to motivate scientific literacy. 'Twenty Rigid Dogmas' would be more accurate," wrote William Dilworth of Beloit, Wisconsin. "A literal reading of the list effectively conceals science as method, which is probably the only aspect of science of use and value to the nonspecialist." Wrote Thomas Fasy of Mt. Sinai School of Medicine, "It was the scientific method (shared by all scientists) that makes these 'hits' possible."

Hazen says he agrees whole-heartedly with such sentiments. "How I start the course the first day isn't, 'Here are 20 ideas to explain everything in the universe.' The first thing I tell 'em is there's no such thing as truth in science," he says.

A Vote for Protein

Scott C. Mohr, associate professor of chemistry at Boston University, quoted novelist Kurt Vonnegut to sing the praises of proteins:

'What is the secret of life?' I asked.
'Protein,' the bartender declared.
'They found out something about protein.'
—*Cat's Cradle*

The book does spend more time on the process of science than the hit list alone implies. Science is defined as a way of knowing, and a few ideas are developed historically in order to illustrate the scientific method. Also, a lab for the course is under development and should fill the methodological gaps.

But in the scheme of the Top 20, facts are clearly primary. The book spends relatively little time on concepts such as falsifiability or the importance of publishing data, ideas that many respondents thought nonscientists should thoroughly understand in order to distinguish science from pseudoscience. "If science is presented as a collection of ideas, however important, which students are expected to believe merely because we say so, then we reduce science to the level of astrology or numerology. We must also try to give them the ability to question skeptically what they are told and to find their own answers through experimentation and research," wrote Jim Mahoney, professor of physics at Marlboro College, Vermont.

Among the philosophical faxers, many suggested some convention within the Top 20 to illustrate that science evolves, and even that its greatest hits are always open to scrutiny. Several clever scientists and one lawyer suggested that Hit Number 1 strike a subversive note, thus casting a tinge of uncertainty over all the rest and presumably encouraging the proper skepticism in students. T. J. Murphy, cardiologist at Emory University School of Medicine suggested simply: "Nothing is sacred."

Indeed, Hazen and Trefil take that idea to heart: Their Top 20 list is far from sacred. In fact, many of the comments—all of which *Science* has passed along to the daring duo—will be incorporated into the next version of the book, and Hazen says he appreciates the free advice. "I've learned a tremendous amount. If I were to rewrite the whole thing, it would be a slightly and in parts substantially different book." In the next edition, for example, Number 6 will be "All matter is made of atoms." Number 16 will become "Earth operates in many cycles." And Number 3 will be refined into some version of "Mass plus energy is conserved."

"We're gratified," says Trefil. "Part of our purpose is to get people thinking about these things." ■ ELIZABETH CULOTTA

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