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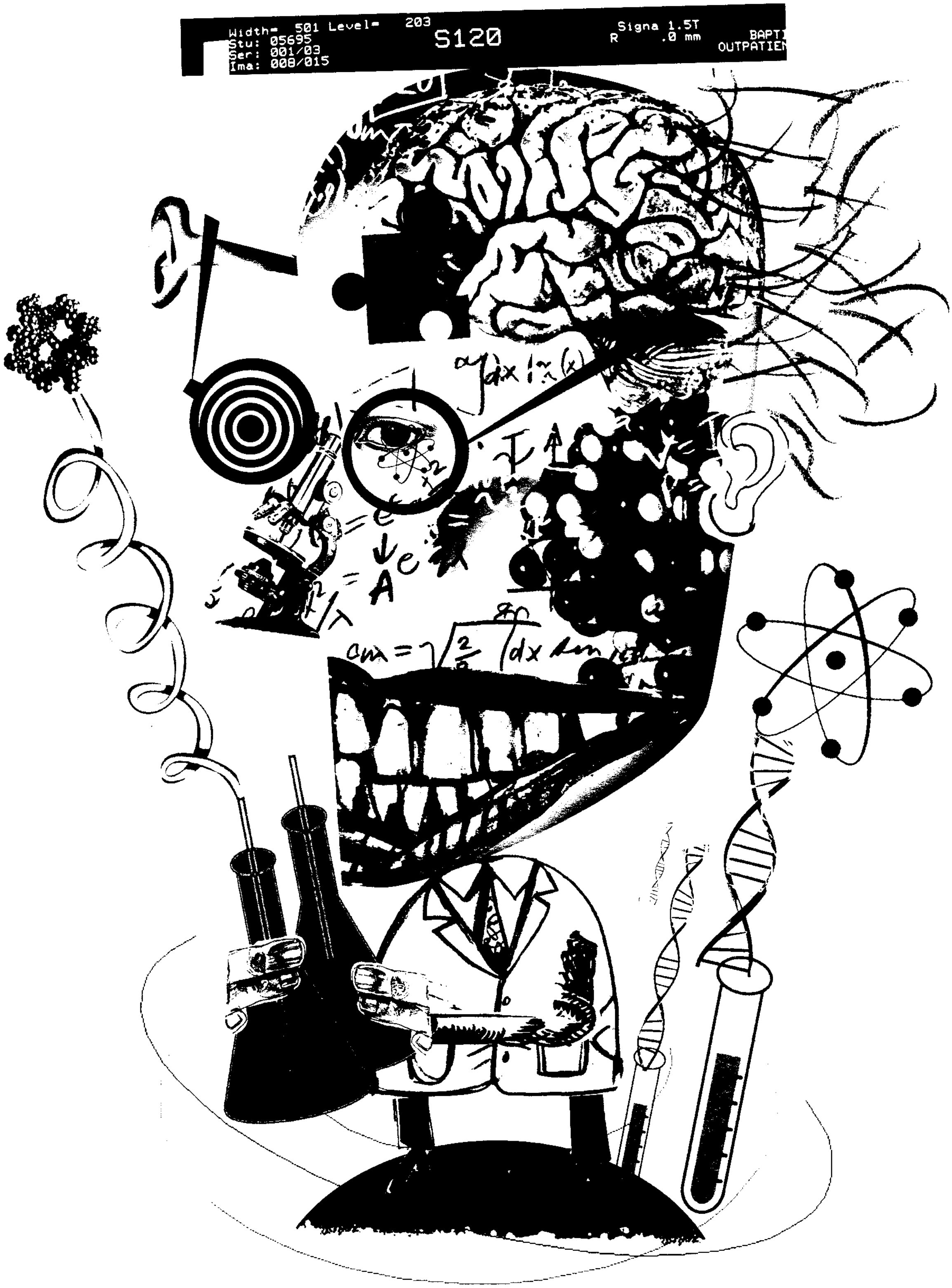

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Creation Myths

What scientists don't – and can't – know about the world

by Robert M. Hazen

What's the first thing that comes to mind when you hear the word "scientist"? Chances are it isn't "modesty or "humility." A simple experiment underscores this conclusion. Type "modest scientist" or "humble scientist" into the Internet search engine Google and you'll be lucky if you get more than a couple of hits. Try the same thing with "arrogant scientist" and the number of hits increases by an order of magnitude.

When asked to free-associate with the word "scientist," my students often respond with superficially flattering adjectives such as "brilliant," "genius," "really smart," and the like. But one senses a degree of alienation in these clichés. Like members of some secret priesthood, scientists seem to possess powerful knowledge that is at once admired and feared. No one fully likes or trusts what he doesn't understand.

Consequently, pervasive stereotypes in popular culture often paint a darker image of the scientist. The plots of countless novels, comic books, and movies reinforce the myth of the mad, power-hungry scientist – the unethical human experiments of *Frankenstein* and *Dr. Jekyll and Mr. Hyde*, the prideful genetic engineers of *Jurassic Park* and *Gattaca*, the callous environmental exploiters of *The Fly* and *The Core*. Brilliant individuals, to be sure, but you wouldn't want to trust your world to such arrogance.

Most scientists view their profession differently. Trying to understand the natural world is an inherently humbling experience. Two metaphors of the scientific enterprise underscore this point: the scientist as builder and the scientist as explorer.

Many researchers relate to an evocative 1945 essay, "The Builders," in which Vannevar Bush compared the scientific enterprise to the erection of a massive stone edifice. Bush had spent much of the previous half-decade coordinating America's scientific efforts during World War II (including the Manhattan Project that produced the atomic bomb), and he continued to play an active political role by advocating a new National Science Foundation to support a broad range of nonmilitary research. He crafted his essay to inspire support for such research.

Bush's elaborate building metaphor emphasizes that the process of constructing the magnificent structure of science is done piece by piece by many individual workers. Some gifted scientists contribute soaring new towers that offer breathtaking vistas, while others work in obscure corners. Some building blocks, like keystones and cornerstones, turn out to be more important than others. "There are those men of rare vision," Bush writes, "who can grasp well in advance just the block that is needed for rapid advance on a section of the edifice .... These are the master workmen." On the other hand, "Some spend all their days trying to pull down a block or two that a rival has put in place." Once in a while, these builders find that a portion of the building is flawed and has to be redesigned or even torn down.

In this picture of the scientific world, where each scientist contributes a small part of a mighty edifice, pride and humility surely go hand in hand. Like a stonemason working on a cathedral, each scientist can boast, "That's my lintel! That's my gargoyle!" Yet the entire structure is so magnificent and overwhelming that the individual is dwarfed and awed by the whole.

Vannevar Bush's vision is inspiring, and it may well have helped garner support for scientific research. But I believe it is also flawed. To my mind, scientists are more like explorers than builders. Most of us in science reject the notion that we construct knowledge of the natural world. Rather, we discover what's already there. In this metaphor of science, the physical universe is like a vast network of caves with countless interconnecting chambers and crawlways. For centuries, scientists have explored these caverns. Some portions are well-traveled and meticulously described. Other passageways have been identified and crudely mapped but await more detailed investigation. But the vast extent of the cavern system remains unknown, beyond the reach of present technologies. **From time to time, when we catch glimpses of the unknown, we feel a sense of pride and satisfaction in learning something that no human has ever known before — but we are equally humbled by how much we don't know.**

In this metaphorical context, scientific discovery differs significantly from invention in the arts. In science every discovery carries with it a sense of the inevitable. Even if Newton had died in infancy

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(as physicians thought the two-pound premature Isaac surely would), someone else would have codified the laws of motion and gravity. If Charles Darwin had declined to spend five cramped years aboard the HMS *Beagle*, the theory of evolution would have been proposed by Alfred Russell Wallace instead. Indeed, Wallace's independent discovery of natural selection goaded Darwin into publishing his theory.

The nature of stars, the catalog of the chemical elements, the genetic code, plate tectonics, nuclear fusion, electrons, DNA – at one time or another all awaited discovery. Such research requires skill, dedication, and often luck, to be sure, but the discoveries were inevitable nonetheless. Over and over again in the history of science, two or more researchers have made the same discovery within weeks or days of each other. In this way scientists' work differs from that of creative geniuses in the arts. The fugues of Johann Sebastian Bach, the novels of Jane Austen, the self-portraits of Rembrandt, and the poems of Emily Dickinson – these works are creations founded on unique personal visions. Scientists, by contrast, don't create; they merely report on what has already been created.

The image of the arrogant scientist is fueled by the misperception that science is close to knowing everything of importance about the natural world. Science journalist John Horgan, whose book *The End of Science* made a splash in 1996, is only the most recent author to hawk this silly claim. Horgan suggests that previous generations have learned just about everything of importance about the natural world, leaving us poor surviving scientists to sweep up the crumbs. Horgan implies that our task is something like filling in the few remaining spaces in a postage-stamp collection.

Rubbish! Dozens of perplexing scientific questions about the natural world remain unanswered. Consider just four of these "Big Questions":

• *What kind of matter makes up most of the universe?* In the 1970s, astronomer Vera Rubin measured the rotation speed of nearby galaxies and discovered an astonishing anomaly. The galaxies were spinning up to three times faster than expected, as measured by the mass of all visible stars. The implication – most of the mass of galaxies (and hence of the universe) is invisible and completely undetectable by normal means. The familiar atoms of the periodic table constitute only a small fraction of the universe, and no one knows what makes up the rest.

• *How did life on Earth emerge?* Today we observe a sharp distinction between living cells and nonliving objects. Yet somehow life emerged from chemical reactions among water, air, and rocks. How did the transition from geochemistry to biochemistry occur? Was life's emergence on Earth a unique event in the history of our universe, or is life a cosmic imperative, likely to arise on any habitable planet or moon? Great strides have been made in the experimental pursuit of prelife chemistry, as well as in planetary exploration, but we are still a long way from convincing answers.

• *How do we develop from a single cell?* One of the greatest mysteries of life is the process by which each of us grows from a single cell – the fertilized egg – to a unique individual possessing something on the order of 100 trillion interconnected cells. Every cell in your body contains the complete set

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of genetic instructions necessary to make your clone, but these cells learn to regulate genes, turning them on and off in exquisitely controlled sequences. Thus, cells serve as brains, muscles, blood, and in numerous other specialized functions. Can we learn the secrets of development? And, if so, can we engineer cells to replace damaged tissues and organs?

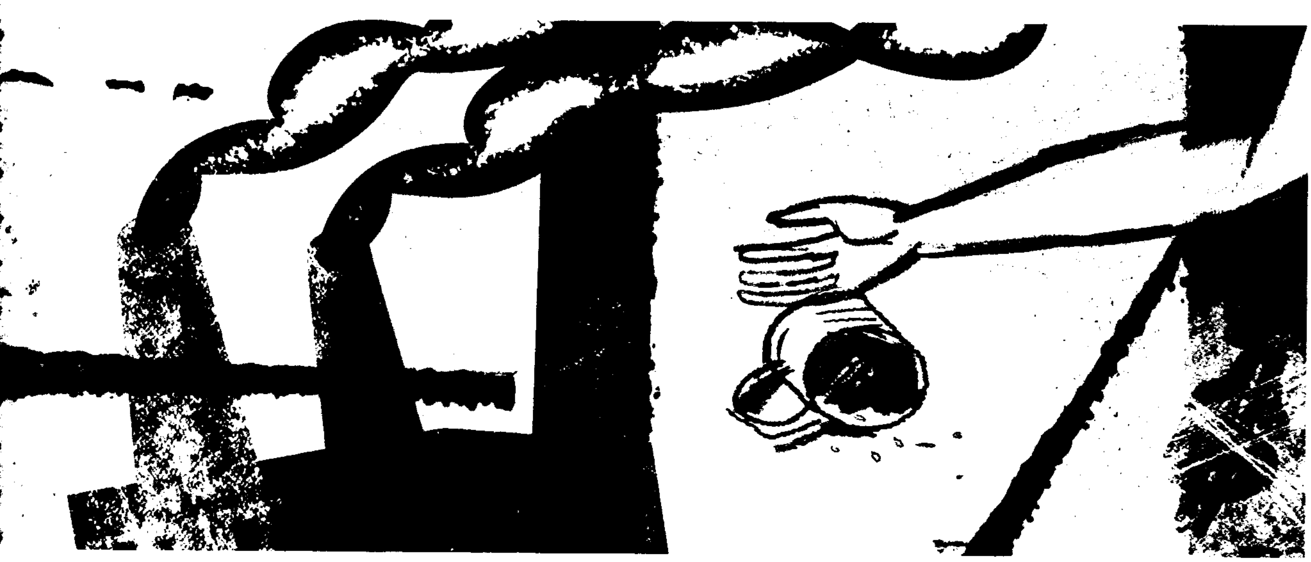
• *What is consciousness?* The human brain, the most complex object we know of, has trillions of interconnected neurons. Employing a variety of sophisticated analytical techniques, scientists can map certain features of this intricate network, such as the areas involved in emotions, reasoning, language, and memories. But no one has the vaguest idea of how the brain creates and sustains the mental state that we experience as self-awareness.

As if such daunting unanswered questions aren't humbling enough, think of the many urgent unsolved problems related to human health and well-being. We still have no cure for cancer, heart disease, Alzheimer's, and many other lethal ailments. In spite of our best efforts at scientific agriculture and resource management, much of the world is hungry and thirsty. **Humans have yet to come to terms with climate change, global pollution, war, and poverty.**

These mysteries represent a few of the questions we've realized we should ask – the things that we *know* we don't know. But what about all the things we don't know we don't know? In the past few decades we have discovered numerous phenomena that no one anticipated – quasars, dark matter, prions, lasers, buckeyballs, the ozone hole, tectonic plates, new domains of life, new planets, to name a few. The extent of our ignorance is incalculably vast. In such a world, it is modesty, not arrogance, that should inform the work of the scientist.

Perhaps the most humbling aspect of the natural universe is that so much of what is out there is not merely unknown – it is unknowable. There are six reasons why we cannot obtain complete answers to these questions:

• *The Speed of Light:* Light travels at a measly 186,000 miles per second; to the best of our knowledge, this is an absolute cosmic speed limit. Nothing we can build can ever travel faster than that. The speed of light may sound pretty fast, but in a known universe that is about 1,000,000,000,000,000,000 (a billion-billion) miles across, it would take many billions of years to travel from one side to the other. Consequently, the human species has absolutely no way of ever reaching



anything but the tiniest fraction of the inconceivable volume that is the known universe. We are trapped by space-time. The speed of light absolutely prevents us from knowing anything about distant stars and galaxies in the present, while the inexorable forward direction of time prevents us from ever visiting the past.

• *Experimental Errors:* Most scientists make their livings measuring things: the mass of molecules, the temperature of Earth's core, the distance to stars, the wavelengths of light. But all measurements, no matter how accurate, contain some experimental error. There are always more decimal places to determine. (This is one reason why scientists are constantly trying to develop and fund new and better apparatus – faster computers, more sensitive chemical analyzers, more powerful lasers, and bigger telescopes.)

• *Chaos:* The concept of a clockwork universe of natural laws, including Newton's laws of motion, the law of gravity, the equations governing electricity and magnetism, and so forth, provides a false sense of order and predictability. In fact, many natural systems, such as turbulent rivers, weather, and solar systems, are "chaotic" and thus inherently unpredictable. These systems are governed by natural laws, to be sure, but the slightest alteration in their initial state can lead to wildly different outcomes. Since every measurement carries with it some error, the future behavior of chaotic systems cannot be calculated.

• *The Uncertainty Principle:* A central idea of quantum mechanics, which was formulated early in the twentieth century, is that at the scale of atoms and electrons all physical parameters are quantized. Energy, magnetism, electric charge, and other properties exist as discrete units, or quanta, as opposed to existing on the illusory continuum we experience at everyday scales of distance. German physicist Werner Heisenberg realized a startling consequence of quantum mechanics: at the scale of an atom or electron, you can't measure anything without changing the quantum state of the object you're measuring. Shine a flashlight in your closet and you can see what's there without having your clothes jump around. But the very act of shining a light on an electron will cause the electron's state to change. That's a sobering reality for particle physicists, who must deal with probabilities rather than absolute measurements.

• *The Law of Unintended Consequences:* The uncertainty principle has an intriguing parallel in the large-scale, complex systems composed of numerous interdependent living and nonliving parts – ecosystems are the prime examples. We've learned the hard way that you can't investigate or change one part of such a system without affecting the other parts, often in unpredictable ways. Africa's largest freshwater lake, Lake Victoria, was changed forever by the introduction of a single predatory fish species that radically altered the entire ecosystem. Overuse of antibiotics has resulted in the evolution of new, more virulent bacterial strains. By the same token, no one can be absolutely certain of the consequences of introducing genetically modified organisms – plants with built-in pesticides, or freeze-resistant strawberries, for example – into the natural environment. You can't change one thing in a complex system without running the risk of disrupting the whole system.

• *Combinatorics:* Even if we could visit every corner of the universe and perform any measurement with absolute accuracy, we would still be stymied by the overwhelming immensity of universal possibilities. There are far more species of living things on earth than scientists to study them, and every species contains vast numbers of genetic variants. Chemists, who have about one hundred chemical elements to play with, are faced with an incalculable number of combinations of elements. One recent estimate suggests that there are on the order of ten to the sixtieth power "simple" carbon-based molecules, which means that there are more possible molecules than there are carbon atoms in the entire universe.

For all of these reasons, **scientists' attempts to know the universe are stymied.** Everything that we might someday know is minuscule in comparison to the things we will never know. It's clear, then, that scientists have many reasons to be mod-

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est. We are faced with daunting unanswered questions; the more we learn the more we find we don't know; and much of what's unknown is inherently unknowable. You simply can't immerse yourself in studying the natural universe without also being humbled by it.

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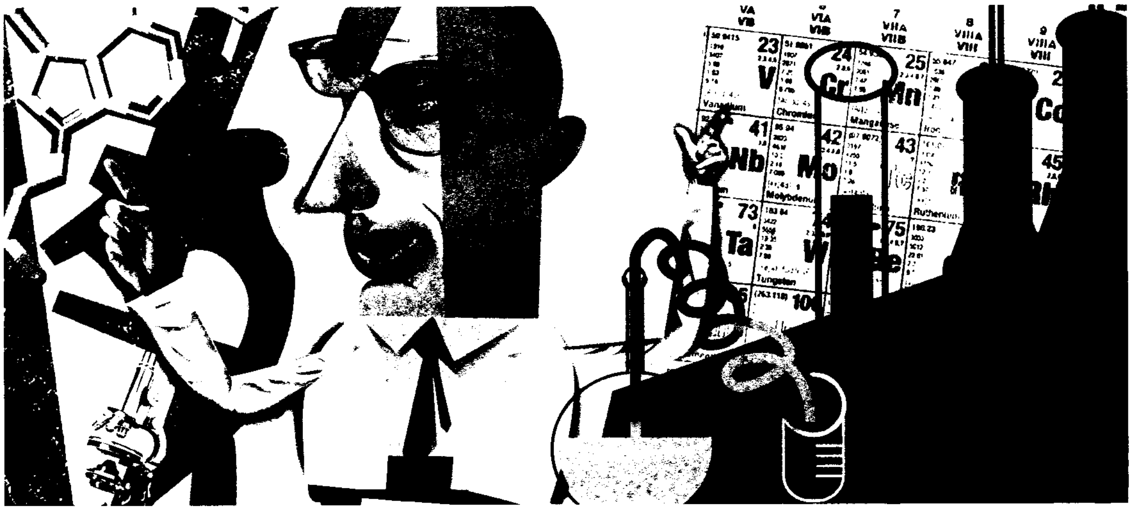
But scientists need not – indeed, must not – be timid when defending their intellectual turf. **Scientists may debate and argue, advocating this hypothesis or that one, but ultimately scientific truth is not a matter of opinion.** It must rest on observable facts. Scientists accept the premise that the universe can be characterized by a process of observation, experiment, and theoretical analysis. If I make a discovery and properly document the observations leading to that conclusion, then anyone else with proper training and adequate equipment should be able to reproduce that result.

This premise is at the heart of scientists' exploration of the origins of the universe. Nothing in the underlying paradigm of science precludes belief in a Creator. Indeed, I know many scientists who are devout in their religious faith and believe that science brings them closer to an understanding of Creation. But science has come under repeated attack from religious fundamentalists who seem to confuse the epistemologies of science and of faith. The central, immutable assumption of science is that our senses don't lie. We believe that what we see, or touch, or hear – if confirmed by the observations of others – represents some truth about the natural world. If I measure the properties of an electron or a rock or a bird, and you can confirm those measurements with independent observations of your own, then we have discovered something that is true. This belief in the power of our senses is central to the scientific enterprise. In this fundamental way, the epistemology of science differs from that of religion, in which truth is based on unalterable faith in sacred texts and revelation.

The most egregious recent attacks on the integrity of science have come from supporters of young Earth creationism – a religious doctrine based on a literal interpretation of the first chapters of the Old Testament. The four central precepts of young Earth creationism are (1) the Earth and heavens were created in more or less their present form approximately 10,000 years ago; (2) major geological features on Earth are the result of a catastrophic flood – the Noachian deluge; (3) all living things were formed by God as the result of a miraculous Creation; (4) subsequent changes to life by evolution have been minor and no new species have arisen.

Consider just the first of these precepts, the supposed 10,000-year age of Creation, from the standpoint of science. The following reproducible observations – measurements confirmed time and time again – point to a universe vastly older. For example:

• Lake-bottom deposits in Scandinavia reveal more than 200,000 layers of sediment that result



from annual spring thawing (using a microscope, you can count such layers like the annual growth rings of trees). These deposits lie on top of much thicker layers of sediment.

• Cave deposits in New Mexico reveal 500,000 years of annual deposits. These deposits occur on thick limestone formations that represent millions of years of coral reef growth.

• Ice cores from Antarctica reveal more than 1,000,000 years of annual ice layers, and the ice rests on thick layers of rocks that contain a variety of fossils representing tropical species of plants and animals.

• Radiometric dating based independently on the decay rates of radioactive isotopes of uranium, potassium, and rubidium all point to an age of 4.5 billion years for the Earth and Moon.

• Distance measurements reveal countless individual stars that are many millions of light-years away and individual galaxies many billions of light-years away. The light from these objects has been traveling through space for those immense lengths of time.

• The expansion of the universe points to an origin event (the "Big Bang") approximately 14 billion years ago.

• Numerous calculations of the time required for geological changes, including the rearrangement of tectonic plates, the growth of mountain chains, the formation of canyons and other erosion features, the cooling of Earth's deep interior, and the composition of the atmosphere point to time-spans in the hundreds of millions of years.

• The fossil record demonstrates a continuous, sequential change in the diversity of life over billions of years.

You can confirm these observations yourself, as countless researchers have done. These observations and many others absolutely disprove, at least from a scientific basis, the notion that the Earth and heavens are only 10,000 years old. There is no justification whatsoever for teaching young Earth creationism in a science classroom.

Almost a century-and-a-half ago the American naturalist and young Earth creationist Phillip Goss recognized this seemingly unresolvable conflict. He concluded that the only way to reconcile his observations with his faith was to invoke the "doctrine of created antiquity." According to this idea, the universe was created 10,000 years ago to look as if it were much older, perhaps as God's test of our faith in the Bible. So, if we observe stars that are more than 10,000 light-years away, then the universe was created with light from those stars already in transit to the Earth. If we measure rocks that appear to be hundreds of millions of years old, then the universe was created with just the right mixtures of radioactive isotopes to make the rocks appear much older than they really are. In 1857, Goss detailed his version of this idea in a book called *Omphalos*. (The word "omphalos" means "navel" in Greek; Goss argued that Adam was created with a navel, even though he had never been inside a womb.)

Created antiquity may seem a clever solution. It's absolutely impossible for a scientist to conceive of any experiment or observation that could prove the doctrine of created antiquity wrong. Any result can be explained away by proclaiming, "The universe was just created that way." Indeed, this characteristic of young Earth creationism is its ultimate weakness. Every scientific theory must be testable by observation or experiment. In principle, it must be possible to falsify the theory.

The history of the conflict between science and young Earth creationism is fascinating and informative, and it reveals a lot about different ways of knowing and the assumptions that underlie various epistemological approaches. In fact, I see no reason why both the science of age-dating and the theological doctrine of created antiquity shouldn't be taught side by side in a class on the history of ideas, or comparative religion, or current events for that matter. But to propose a 10,000-year old Earth as a valid alternative hypothesis in a science classroom is just plain wrong. That's why the courts have repeatedly rejected attempts to include creationism in science curricula.

One shouldn't confuse scientists' legitimate opposition to teaching creationism in a science classroom with closed-mindedness or arrogance. Sadly, however, in recent years we have seen more than enough arrogance and scorn from misguided zealots on both sides of this volatile issue. All too often, unthinking members of the scientific community have ridiculed the sincere beliefs of fundamentalist Christians, rather than focusing on the underlying epistemological differences. And several outspoken creationists have repeatedly returned the favor by misrepresenting and then mocking valid scientific discoveries. Such disrespect accomplishes nothing but continued polarization of the debate.

Those people on both sides who have perpetrated willful deceptions and hoaxes demonstrate the height of immodesty and arrogance, however. **Scientists and creationists alike should reject absolutely those who have fraudulently carved human footprints into rocks from the age of dinosaurs (to support the tenets of creationism), and those who have willfully misrepresented the developmental stages of embryos or the discovery of hominid fossils (to support the theory of evolution).** Such lies thwart our mutual search to understand Creator and Creation.

Scientists may have won the battle over teaching creationism in the science classroom, but we haven't won the war. The latest creationist challenge to the science curriculum comes from the intellectually flaccid doctrine of "Intelligent Design," or simply ID. According to its proponents, cellular life is so much more complex than any nonliving system that it could not possibly have emerged through a natural process. Indeed, they say, life on Earth is "irreducibly complex."

ID is not a new idea. Decades before Darwin, the British philosopher William Paley argued that the exquisite adaptations of plants and animals could not have arisen by chance. He resorted to a compelling analogy: If you were to walk down a path and find a wristwatch lying on the ground, you would know by inspection that an unseen maker had designed the watch. The timepiece's various interlocking components could not possibly have emerged spontaneously through any natural process. Similarly, according to ID proponents, one need only look at life on Earth to realize that no natural process could have led to its evolution. Look at the intricacies of the flagellum that moves a bacterium, or the flowering of a rose, or the structure of the human eye, and ID is obvious, they say. ID advocates usually avoid the subject of God's role in public discourse, but the question of who designed the designer (who must also be irreducibly complex) is always lurking in the background.

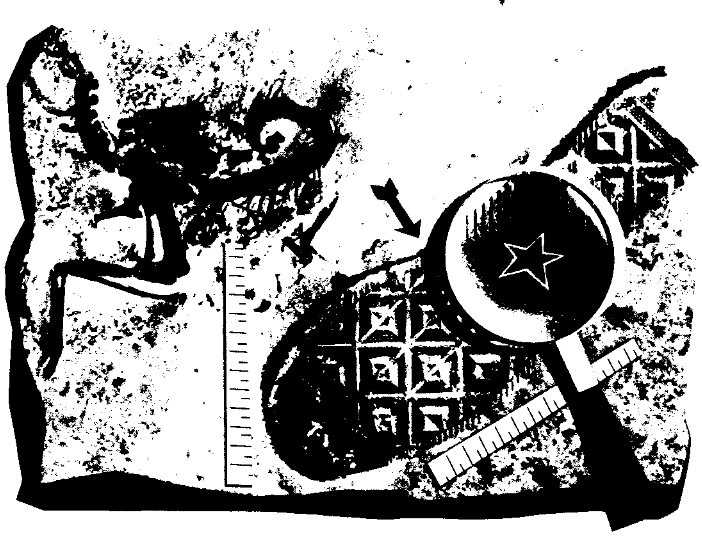
But Intelligent Design isn't the only plausible explanation for life's intricacies. The relatively new scientific study of emergent complexity challenges the basic assumptions of ID. We now realize that numerous natural systems of interacting "agents" – systems as diverse as sand dunes, ant colonies, slime mold, and the conscious mind – display new and surprising behaviors not associated with the individual agents. Even if we don't yet know all the details of the process, the origin of cellular life fits the pattern of emergent complexity. Many of us in the field of origins research are reasonably confident that the problem can be solved without invoking some external intervention.

What is the alternative? To resort to some unknowable super-intelligence is hardly an intellectually satisfying option – it's a kind of false modesty, if you will. Do we really want to throw up our hands and claim the problem is just too tough to solve? Indeed, ID is just another example of the tired old God-in-the-gaps reasoning. It implies that we have to resort to the supernatural every time we encounter some aspect of nature we don't fully understand.

Twenty years ago creationists used this strategy to attack the theory of evolution by natural selection. "Darwinists rarely mention the whale because it presents them with one of their most insoluble problems," claimed the noted creationist author Alan Haywood in a 1985 book. He pointed to the lack of intermediate forms between land animals and modern whales as an embarrassment to the theory of the evolutionists. But science thrives on such challenges. Subsequent concerted paleontological work on promising rock formations around the world has revealed a near-continuous sequence of dozens of fossil whales over the past 50 million years – a dramatic confirmation of Darwinian predictions. And, as the gap between cows and whales is filled in, God's presumed creative role is squeezed into the production of ever-more-trivial variations.

Many scientists prefer to believe in a God who created the whole universe from the outset – a God of natural laws. In the beginning God set the entire magnificent machinery of the universe in motion. Atoms and stars and cells and consciousness emerged inexorably – as did man's intellect, endowed with the capacity to discover the laws of nature through a natural process of self-awareness and discovery. In such a universe, scientific study provides a glimpse of Creator as well as Creation.

In spite of the power inherent in their knowledge of the physical universe, scientists can and should be modest about the current imperfect state of scientific understanding. To be sure, we've caught breathtaking glimpses of a universe of profound order enriched by emergent complexity, but all that we've learned is dwarfed by our ignorance. Nevertheless, we soldier on, knowing that science, however limited it may be, remains our best hope for curing disease, feeding the hungry, preserving our planet, and revealing the majesty of a Creation that is learning to know itself.



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