The End of Science
by John Horgan
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I'm delighted to be here at McGill tonight. I've been rather fond of Canada lately, because it has given my book The End of Science such a warm reception. Last summer my book made the McClean's bestseller list for a couple of weeks. And Canadian reviewers have given me some hearty pats on the back. But even those who praised the book usually took pains to point out that they did not agree with its central premise. A review in the Toronto Globe and Mail last summer ended with this line: "What higher praise can you give to a book than to say that you loved it, even though you thought it was totally wrong?"

Just this month another Canadian reviewer suggested that I concocted this end-of-science schtick as a way to package a lot of material about famous scientists I'd gathered over the years. Let me assure you that's not so. Anyone who doubts my sincerity can ask my wife or friends or colleagues at Scientific American about my true intentions. They will tell you horror stories about having to endure years of interminable harangues from me on the limits of science.

Now it's your turn. What I'd like to do tonight is summarize my end-of-science argument and then rebut, one by one, the most common counter-arguments. If I'm successful, none of you will have any questions for me at the end of my speech, because you'll all find my thesis so convincing. But since that's never happened before, I'll try to leave plenty of time for questions.

My claim is that science is a bounded enterprise, limited by social, economic, physical and cognitive factors. Science is being threatened, literally, in some cases, by technophobes like the Unabomber, by animal-rights activists, by creationists and other religious fundamentalists, by post-modern philosophers and, most important of all, by stingy politicians.

Also, as science advances, it keeps imposing limits on its own power. Einstein's theory of special relativity prohibits the transmission of matter or even information at speeds faster than that of light. Quantum mechanics dictates that our knowledge of the microrealm will always be slightly blurred. Chaos theory confirms that even without quantum indeterminacy many phenomena would be impossible to predict. And evolutionary biology keeps reminding us that we are animals, designed by natural selection not for discovering deep truths of nature but for breeding.

All these limits are important. But in my view, by far the greatest barrier to future progress in science--and especially pure science--is its past success. Researchers have already created a map of physical reality, ranging from the microrealm of quarks and electrons to the macrorealm of planets, stars and galaxies. Physicists have shown that all matter consists of a few basic particles ruled by a few basic forces.

Scientists have also stitched their knowledge into an impressive, if not terribly detailed, narrative of how we came to be. The universe exploded into existence roughly 15 billion years ago and is still expanding outwards. About 4.5 billion years ago, the debris from an exploding star condensed into our solar system.

Sometime during the next few hundred million years, single-celled organisms emerged on the earth. Prodded by natural selection, these microbes evolved into an amazingly diverse array of more complex creatures, including Homo sapiens.

I believe that this map of reality that scientists have constructed, and this narrative of creation, from the big bang through the present, is essentially true. It will thus be as viable 100 or even 1,000 years from now as it is today. I also believe that, given how far science has already come, and given the limits constraining further research, science will be hard-pressed to make any truly profound additions to the knowledge it has already generated. Further research may yield no more great revelations or revolutions but only incremental returns.

The vast majority of scientists are content to fill in details of the great paradigms laid down by their predecessors or to apply that knowledge for practical purposes. They try to show how a new high-temperature superconductor can be understood in quantum terms, or how a mutation in a particular stretch of DNA triggers breast cancer. These are certainly worthy goals.

But some scientists are much too ambitious and creative to settle for filling in details or developing practical applications. They want to transcend the received wisdom, to precipitate revolutions in knowledge analogous to those triggered by Darwin's theory of evolution or by quantum mechanics.

For the most part these over-reachers have only one option: to pursue science in a speculative, non-empirical mode that I call ironic science. Ironic science resembles literature or philosophy or theology in that it offers points of view, opinions, which are, at best, "interesting," which provoke further comment. But it does not converge on the truth.

One of the most spectacular examples of ironic science is superstring theory, which for more than a decade has been the leading contender for a unified theory of physics. Often called a "theory of everything," it posits that all the matter and energy in the universe and even space and time stem from infinitesimal, string-like particles wriggling in a hyperspace consisting of 10 (or more) dimensions. Unfortunately, the microrealm that superstrings allegedly inhabit is completely inaccessible to human experimenters. A superstring is supposedly as small in comparison to a proton as a proton is in comparison to the solar system. Probing this realm directly would require an accelerator 1,000 light years around. Our entire solar system is only one light day around. It is this problem that led the Nobel laureate Sheldon Glashow to compare superstring theorists to "medieval theologians." How many superstrings can dance on the head of a pin?

There are many other examples of ironic science that you have probably heard of, in part because science journalists like myself enjoy writing about them so much. Cosmology, for example, has given rise to all kinds of theories involving parallel universes, which are supposedly connected to our universe by aneurisms in spacetime called wormholes. In biology, we have the Gaia hypothesis of Lynn Margulis and James Lovelock, which suggests that all organisms somehow cooperate to ensure their self-perpetuation. Then there are the anti-Darwinian ideas of Brian Goodwin and Stuart Kauffman, who think life stems not primarily from natural selection but from some mysterious "laws of complexity" that they have glimpsed in their computer simulations.

Psychology and the social sciences, of course, consist of little BUT ironic science, such as Freudian psychoanalysis, Marxism, structuralism and the more ambitious forms of sociobiology. Some observers say all these untestable, far-fetched theories are signs of science's vitality and boundless possibilities. I see them as signs of science's desperation and terminal illness. So that's my argument, in a nutshell. Now let me go through the most common objections.

1. That's What They Thought 100 Years Ago.

Nine times out of 10, when I give my end of science spiel--whether to a Nobel laureate in physics or to some poor soul that I'm trapped at a cocktail party--the response is some variation of, "Oh, come on, that's what they thought 100 years ago." The reasoning behind this response goes like this: As the 19th century wound down, scientists thought they knew everything. But then Einstein and other physicists discovered relativity and quantum mechanics, opening up vast new vistas for modern physics and other branches of science. The moral is that anyone who predicts science is ending will surely turn out to be as short-sighted as those 19th-century physicists were. Another popular anecdote involves the U.S. patent commissioner who, sometime in the 19th century, supposedly quit his job because he thought everything had been invented.

First of all, both of these tales are simply not true. No American patent official ever quit his job because he thought everything had been invented. And physicists at the end of the last century were engaged in debating all sorts of profound issues, such as whether atoms really exist.

What people are really implying when they say "that's what they thought 100 years ago" is that, because science has advanced so rapidly over the past century or so, it can and will continue to do so, possibly forever. This is an inductive argument, and as an inductive argument it is deeply flawed. Science in the modern sense has only existed for a few hundred years, and its most spectacular achievements have occurred within the last century. Because we were all born and raised in this era of exponential progress, we simply assume that it is an intrinsic, permanent feature of reality.

But viewed from an historical perspective, the modern era of rapid scientific and technological progress appears to be not a permanent feature of reality but an aberration, a fluke, a product of a singular convergence of social, intellectual and political factors. Ask yourself this: Is it really more reasonable to assume that this period of extremely rapid progress will continue forever rather than reaching its natural limits and coming to an end?

2. Answers always raise new questions.

This is probably the second most common response to my argument. It is quite true that answers always raise new questions. But most of the answerable questions raised by our current theories tend to involve details. For example, when, exactly, did our ancestors begin walking upright? Was it three million years ago, or four million? On which chromosome does the gene for cystic fibrosis reside? The

answers to such questions may be fascinating, or have enormous practical value, but they merely extend the prevailing paradigm rather than yielding profound new insights into nature

Other questions are profound but unanswerable. The big bang theory, for example, poses a very obvious and deep question: Why did the big bang happen in the first place, and what, if anything, preceded it? The answer is that we don't know, and we will never know, because the origin of the universe is too distant from us in space and time. That is an absolute limit of science, one forced on us by our physical limitations. There are lots of other unanswerable questions. Are there other dimensions in space and time in addition to our own? Are there other universes?

Then there is a whole class of what I call inevitability questions. Just how inevitable was the universe, or the laws of physics, or life, or life intelligent enough to wonder how inevitable it was? Underlying all these questions is the biggest question of all: Why is there something rather than nothing? None of these inevitability questions are answerable. You can't determine the probability of the universe or of life on earth when you have only one universe and one history of life to contemplate. Statistics require more than one data point. So, again, it is true that answers always raise new questions. But that does not mean that science will never end. It only means that science can never answer all possible questions, it can never quench our curiosity, it can never be complete.

Unanswerable questions, by the way, are what give rise to superstring theory, Gaia, psychoanalysis and other example of ironic science, as well as all of philosophy.

3. What About Life on Mars?

The day the life on Mars story broke last August, I walked into my office at Scientific American, and several colleagues immediately came up to me with big smirks and said, "So, what does Mr. No More Big Discoveries say now?" It took me a while to come up with a response, but here it is:

The discovery of extraterrestrial life would represent one of the most thrilling findings in the history of science. I hope to live long enough to witness such an event. But the so-called evidence presented last summer doesn't even come close. It consists of some organic chemicals and globule-shaped particles that vaguely resemble terrestrial microbes but which are subject to many alternative interpretations. Those scientists who are most knowledgeable about very old microfossils--those who are the real experts in the origin of terrestrial life--are also the most skeptical of the life-on-Mars interpretation. That's a very bad sign.

There is only one way we are going to know if there is life on Mars, and that is if we send a mission there to conduct a thorough search for it. Our best hope is to have a human crew drill deep below the surface, where there is thought to be enough liquid water and heat to sustain microbial life as we know it. It will be decades, at least, before we can muster the resources and money for such a project, even if society is willing to pay for it.

Let's say that we do eventually determine that microbial life existed or still exists on Mars. That would be fantastic, an enormous boost for origin-of-life studies

and biology in general. But would it mean that science is suddenly liberated from all the limits that I have described? Hardly. If we find life on Mars, we will know that life arose in this solar system, and perhaps not even more than once. It may be that life originated on Mars and then spread to the earth, or vice versa.

More importantly, we will be just as ignorant about whether life exists elsewhere in the universe, and we will still be facing huge obstacles to answering that question. Let's say that engineers come up with a space transport method that boosts the velocity of spaceships by a factor of more than 10, to one million miles an hour. That spaceship would still require 3,000 years to reach the nearest star, Alpha Centauri.

Now it's possible that one of these days the radio receivers employed in our Search for Extraterrestrial Intelligence program, called SETI, will pick up electromagnetic signals--the alien equivalent of Seinfeld--coming from another star. But it's worth noting that most of the SETI proponents are physicists, who have an extremely deterministic view of reality. Physicists think that the existence of a highly technological civilization here on earth makes the existence of similar civilizations elsewhere highly probable.

The real experts on life, biologists, find this view ludicrous, because they know how much contingency--just plain luck--is involved in evolution. Stephen Jay Gould, the Harvard paleontologist, has said that if the great experiment of life were re-run a million times over, chances are it would never again give rise to mammals, let alone mammals intelligent enough to invent television.

For similar reasons Gould's colleague Ernst Mayr, who may be this century's most eminent evolutionary biologist, has called the search for extra-terrestrial life a waste of time and money. The U.S. Congress apparently agrees with Mayr, because they terminated the funding for the SETI program three years ago. It's now just getting by on private funds.

4. The paradigm shift argument.

It is amazing to me how many otherwise hard-nosed scientists, when confronted with the argument that science might be ending, start sounding like philosophical relativists, or social constructivists, or other doubters of scientific truth. They begin to sound, in other words, like the people who write for the postmodern journal Social Text, which last June was the victim of a hoax that was perpetrated by the New York University physicist Alan Sokal and subsequently made the front page of The New York Times.

According to these skeptics, science is a process not of discovery but of invention, like art or music or literature. We just think science can't go any further because we can't see beyond our current paradigms. In the future, we will submit to new paradigms that cause the scales to fall from our eyes and open up vast new realms of inquiry. This kind of thinking can be traced back to the philosopher Thomas Kuhn, who wrote the extremely influential book Structure of Scientific Revolutions, and who died last June.

But modern science has been much less revolutionary--much less susceptible to dramatic shifts in perspective--than Thomas Kuhn suggested. Particle physics

rests on the firm foundation of quantum mechanics, and modern genetics, far from undermining the fundamental paradigm of Darwinian evolution, has bolstered it.

If you view atoms and elements and the double helix and viruses and stars and galaxies as inventions, projections of our culture, which future cultures may replace with other convenient illusions, then you are unlikely to agree with me that science is finite. If science is as ephemeral as art, of course it can continue forever. But if you think that science is a process of discovery rather than merely of invention, if you believe that science is capable of achieving genuine truth, then you must take seriously the possibility that all the great, genuine paradigm shifts are behind us.

5. The Chaoplexity Gambit

Many modern scientists--including, no doubt, some right here at McGill--hope that advances in computers and mathematics will enable them to transcend their current knowledge and create a powerful new science. This is the faith that sustains the trendy fields of chaos and complexity. In my book I lump chaos and complexity together under a single term, chaoplexity, because after reading dozens of books about chaos and complexity and talking to scores of people in both fields, I realized that there is no significant difference between them. Also, I just wanted to irritate the chaoplexologists.

Chaoplexologists have argued that with more powerful computers and mathematics they can answer age-old questions about the inevitability, or lack thereof, of life, or even of the entire universe. They can find new laws of nature analogous to gravity or the second law of thermodynamics. They can make economics and other social sciences as rigorous as physics. They can find a cure for AIDS. These are all claims that have been made by researchers at the Santa Fe Institute, which is a leading center of chaoplexity.

These claims stem from an overly optimistic interpretation of certain developments in computer science. Over the past few decades, researchers have found that various simple rules, when followed by a computer, can generate patterns that appear to vary randomly as a function of time or scale. Let's call this illusory randomness "pseudo-noise." A paradigmatic example of a pseudo-noisy system is the mother of all fractals, the Mandelbrot set, which is an icon of the chaoplexity movement.

The fields of both chaos and complexity have held out the hope that much of the noise that seems to pervade nature is actually pseudo-noise, the result of some underlying, deterministic algorithm. But the noise that makes it so difficult to predict earthquakes, the stock market, the weather and other phenomena is not apparent but very real. This kind of noisiness will never be reduced to any simple set of rules, in my view.

Of course, faster computers and advanced mathematical techniques will improve our ability to predict certain complicated phenomena. Popular impressions notwithstanding, weather forecasting has become more accurate over the last few decades, in part because of improvements in computer modeling. But an even more important factor is improvements in data-gathering--notably satellite imaging.

Meteorologists have a larger, more accurate database upon which to build their models and against which to test them. Forecasts improve through this dialectic between simulation and data-gathering.

At some point, we are drifting over the line from science per se toward engineering. The model either works or doesn't work according to some standard of effectiveness; "truth" is irrelevant. Moreover, chaos theory tells us that there is a fundamental limit to forecasting related to the butterfly effect. One has to know the initial conditions of a system with infinite precision to be able to predict its course. This is something that has always puzzled me about chaoplexologists: according to one of their fundamental tenets, the butterfly effect, many of their goals may be impossible to achieve.

6. What about the human mind?

The human mind is by far the most wide open frontier for science, mainly because it is still so profoundly mysterious, in spite of all the advances of modern neuroscience. In his bestseller Listening to Prozac the psychiatrist Peter Kramer portrayed us as marching inexorably toward a Brave New World in which we can fine-tune our moods and personalities with drugs. This vision is a fantasy. What the scientific literature actually says is that Prozac and other so-called wonder drugs are no more effective for treating depression and other common emotional disorders, statistically speaking, than the more primitive antidepressants, such as imipramine, which themselves are no more effective, statistically speaking, than talk therapy.

Kramer was on firmer ground when he said, at the end of his book, that our understanding of our own minds is still "laughably primitive." The question is, when, if ever, will that situation change? Last June I attended the annual meeting of the American Psychiatric Association at the Javits Center in New York City, along with almost 20,000 other people. There were therapists there who still admit to being Freudians. And why not? No theory or treatment for the mind has been shown to be significantly better than psychoanalysis. Cheaper, maybe, but that's not a scientific criterion. The hot, up-and-coming treatment for depression, and even schizophrenia and other disorders, is electroshock therapy, which can cause severe memory loss and other side effects. That does not seem like a sign of progress to me. Incidentally, I made some of these same arguments and observations in an article in the December issue of Scientific American, called "Why Freud Isn't Dead."

The science of mind has--in certain respects--become much more empirical and less speculative since the days of Freud. We have acquired an amazing ability to probe the brain, with microelectrodes, magnetic resonance imaging, positron-emission tomography and the like. Maybe all this work will culminate in a great new unified theory of and treatment for the mind. But I suspect it won't. What I think neuroscience can and will accomplish is correlating specific physiological processes in the brain to specific mental functions--such as memory, perception and so forth--in ever-finer detail. This kind of nitty-gritty, empirical research should have profound practical consequences, such as providing better ways to diagnose and treat mental illness.

But neuroscience will not deliver what so many philosophers and scientists yearn for. It will not solve all the ancient philosophical mysteries relating to the mind--the mind-body problem, the problem of free will, the solipsism paradox, and so on. Nor will neuroscience demonstrate that consciousness is somehow a necessary component of existence, which is an idea that is alluring not only to New Agers but also to scientists and philosophers who should know better. This is a material world. We have all seen bodies without minds, but only psychics and psychotics have seen minds without bodies. The universe existed for billions of years before we came along, and it will continue to exist for eons after we and our minds are gone.

7. What about applied science?

In my book I don't really deal with applied science as carefully as I should have, since my focus was primarily on pure science. Also, I think it is much harder to predict the course of technology and medicine, since they have a larger component of invention than pure science does. But I believe that the limits of applied science are also coming into sight. Let me give you two examples, one from physics and one from biology.

It once seemed inevitable that physicists' knowledge of nuclear fusion--which gave us the hydrogen bomb--would culminate in a cheap, clean, boundless source of energy. But after 50 years and billions of dollars of research, that dream has now become vanishingly faint. Fusion researchers always said, keep the money coming, and in 20 years we will give you energy too cheap to meter. In the last few years, the U.S. has drastically cut back on its fusion budget, and plans for next-generation reactors have been delayed. Now even the most optimistic researchers predict that it will take at least 50 years before we have economically viable fusion reactors. Realists acknowledge that fusion energy is a dream that may never be fulfilled: the technical, economic and political obstacles are simply too great to overcome.

Turning to applied biology, the most dramatic achievement that I can imagine is immortality. Many scientists are now attempting to identify the precise causes of aging. It is conceivable that if they succeed in pinpointing the mechanisms that make us age, researchers might then learn how to block the aging process and to design versions of Homo sapiens that can live indefinitely. But evolutionary biologists suggest that immortality may be impossible to achieve. Natural selection designed us to live long enough to breed and raise our children. As a result, senescence does not stem from any single cause or even a suite of causes; it is woven inextricably into the fabric of our being.

The implications of this fact were explored in the December 1995 issue of the magazine Technology Review. The writer, Harvey Sapolsky, a professor of social policy at MIT, noted that the major justification for the funding of science since the Second World War was national security--or, more specifically, the Cold War. Now that scientists no longer have the Evil Empire to justify their huge budgets, Sapolsky asked, what other goal can serve as a substitute? The answer he came up with was immortality. Most people think living longer, and possibly even forever, is desirable,

he pointed out. But the best thing about making immortality the primary goal of science, Sapolsky said, is that it is almost certainly unattainable, so scientists can keep getting funds for more research forever.

8. The End of Science is an unprovable and therefore ironic hypothesis

I admit that, as a journalist, I'm overly fond of playing gotcha games. In my book, for example, I describe an interview with the great philosopher Karl Popper, who argued that scientists can never prove a theory is true; they can only falsify it, or prove it is false. Naturally I had to ask Popper, Is your falsifiability hypothesis falsifiable? Popper was 90 then, but still intellectually armed and very dangerous. He put his hand on my hand, looked deep into my eyes, and said, very gently, "I don't want to hurt you, but it is a silly question."

Given my style of journalism, I guess it's only fair that some critics have tried to give me a taste of my own medicine, pointing out triumphantly that my own end-of-science thesis is an example of ironic theorizing, since it is ultimately untestable and unprovable. This argument was put forth in the review of my book in The Economist, American Scientist and elsewhere.

But to quote Karl Popper again, "It is one of the most idiotic criticisms one can imagine!" Compared to atoms, or stars, or galaxies, or genes or other objects of genuine scientific investigation, human culture is ephemeral; an asteroid could destroy us at any moment and that would bring about the end not only of science but also of history, politics, art--you name it. So obviously any prediction about the future of human culture is an educated guess, at best, at least compared to nuclear physics, or astronomy, or other disciplines that prove certain facts beyond a reasonable doubt.

But just because we cannot know with certainty what our future is does not mean that we cannot make cogent arguments in favor of one scenario over another. I think my end-of-science scenario is much more plausible than the ones that I am trying to displace, in which we keep discovering profound new truths about the universe forever, or arrive at an end point in which we achieve perfect wisdom and mastery over nature.

9. The Lack-of-Imagination Argument

Of all the criticisms of my thesis, the one that really gets under my skin is that it reflects a failure of imagination. Actually, it is all too easy to imagine great discoveries just over the horizon. Our culture does it for us, with TV shows like Star Trek and movies like Star Wars and ads and political rhetoric that promise us tomorrow will be very different from--and almost certainly better than--today. Scientists, and science journalists, too, are forever claiming that a huge revelation or breakthrough or Holy Grail awaits us just over the horizon. I have to admit, I've written my share of such stories for Scientific American.

What I want readers of my book to imagine is this: What if there is no big thing over the horizon? What if what we have is basically what we are going to have? We are not going to invent warp-drive spaceships that can take us to other

galaxies or even other universes. We are not going to become infinitely wise or immortal through genetic engineering. We are not going to discover the mind of God, as the British physicist Stephen Hawking once put it. We are not going to know why there is something rather than nothing. We'll be stuck in a permanent state of wonder before the mystery of existence--which may not be such a terrible thing. After all, our sense of wonder is the wellspring not only of science but also of art, and literature, and philosophy, and religion.

Some interviewers have asked me: If science ends, what will happen to humanity? What will be our fate? The honest answer is: How the hell should I know? But let me offer a couple of prophecies from people I interviewed for my book.

One is Gunther Stent, one of the pioneers of modern genetics. Almost 30 years ago Stent wrote a brilliant book, unfortunately long out of print, called The Coming of the Golden Age. In it Stent predicted that the very success of science will be its own undoing. As science helps us achieve universal affluence, we will have less incentive to acquire new knowledge. We will end up in a state that Stent called "the new Polynesia," in which most of us pursue pleasure for its own sake through drugs or virtual reality or direct electronic stimulation of our brain's pleasure center.

A rather different scenario was set forth by Francis Fukuyama in his 1992 book The End of History. Fukuyama argued that the triumph of capitalist liberal democracy over socialism has ended humanity's struggle to find the least noxious, most just political system. But Fukuyama, who is an acolyte of the German philosopher Frederick Nietzsche, suspected that our insatiable will to power, our need for constant self-overcoming, will prevent us from being satisfied with the affluence and comfort provided by this best of all possible worlds. We will start inventing wars, basically just to give ourselves something to do.

Well, Fukuyama, I think, was showing signs of severe Nietzsche intoxication. I can recognize this disorder in others, because I went through it a few decades ago. Gunther Stent, for his part, was a bit too influenced by the hippie era; he wrote his book, after all, in Berkeley in the late 1960's.

I don't think our fate will be either mindless battle, as Francis Fukuyama feared, or mindless hedonism, as Gunther Stent feared, but some combination of the two. We will continue to muddle along as we have been, oscillating between pleasure and misery, enlightenment and befuddlement, kindness and cruelty. It won't be heaven, but it won't be hell, either. In other words, the post-science world won't be all that different from our world. And the sad truth is, most people won't miss science. They'd rather watch the O.J. trial than a Nova program on the big bang.

One final note, and then I'll take questions. I've been accused by some critics of having a hidden anti-science agenda. That's ridiculous. I became a science writer because I love science. I think science is the most miraculous and noble and meaningful of all human creations. My conviction that science is ending is deeply disturbing to me, because I can't imagine anything better for humanity to do than to try to figure out what we are, where we came from and where we are going. I sincerely hope that some future scientist--maybe even someone in this room--will discover something as important as natural selection or quantum mechanics or the

expansion of the universe, something that spawns a whole new era in pure science and proves me wrong. But I also sincerely believe that isn't going to happen.

Thank you.