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TO ANSWER OUR MOST FUNDAMENTAL QUESTIONS, SCIENCE NEEDS TO FIND A PLACE FOR THE ARTS.

The Future of Science...Is Art?

FOURTH CULTURE BY **JONAH LEHRER** / JANUARY 16, 2008

In the early 1920s, Niels Bohr was struggling to reimagine the structure of matter. Previous generations of physicists had thought the inner space of an atom looked like a miniature solar system with the atomic nucleus as the sun and the whirring electrons as planet in orbit. This was the classical model.

But Bohr had spent time analyzing the radiation emitted by electrons, and he realized that science needed a new metaphor. The behavior of electrons seemed to defy every conventional explanation. As Bohr said, "When it comes to atoms, language can be used onl as in poetry." Ordinary words couldn't capture the data.

Bohr had long been fascinated by cubist paintings. As the intellectual historian Arthur Miller notes, he later filled his study with abstra still lifes and enjoyed explaining his interpretation of the art to visitors. For Bohr, the allure of cubism was that it shattered the certaint of the object. The art revealed the fissures in everything, turning the solidity of matter into a surreal blur.

Bohr's discerning conviction was that the invisible world of the electron was essentially a cubist world. By 1923, de Broglie had already determined that electrons could exist as either particles or waves. What Bohr maintained was that the form they took depended on how you looked at them. Their very nature was a consequence of our observation. This meant that electrons weren't like little planets at all. Instead, they were like one of Picasso's deconstructed guitars, a blur of brushstrokes that only made sense once you stared at it. The art that looked so strange was actually telling the truth.

Black Peacock, 1950
ALEXANDER CALDER
This mobile is a powerful example of how an art form can be tailored to the physiology of a specific area in the brain. Calder's composition anticipated, artistically, the physiological properties of the cells of an area called V5, which are selectively responsive to motion and its direction. Viewed from a distance, the separate pieces of the mobile appear as static spots of varying sizes. But as the pieces move in different directions, each one stimulates only the category of cell that is selectively responsive to the direction in which the spot is moving. — *Semir Zeki, Neuroscientist, University College London* © Christie's Images/Corbis

It's hard to believe that a work of abstract art might have actually affected the history of science. Cubism seems to have nothing in common with modern physics. When we think about the scientific process, a specific vocabulary comes to mind: objectivity, experiments, facts. In the passive tense of the scientific paper, we imagine a perfect reflection of the real world. Paintings can be profound, but they are always pretend.

This view of science as the sole mediator of everything depends upon one unstated assumption: While art cycles with the fashions, scientific knowledge is a linear ascent. The history of science is supposed to obey a simple equation: Time plus data equals understanding. One day, we believe, science will solve everything.

But the trajectory of science has proven to be a little more complicated. The more we know about reality—about its quantum mechanic and neural origins—the more palpable its paradoxes become. As Vladimir Nabokov, the novelist and lepidopterist, once put it, "The greater one's science, the deeper the sense of mystery."

Consider, for example, the history of physics. Once upon a time, and more than once, physicists thought they had the universe solved. Some obscure details remained, but the basic structure of the cosmos was understood. Out of this naïveté, relativity theory emerged, fundamentally altering classical notions about the relationship of time and space. Then came Heisenberg's uncertainty principle and th surreal revelations of quantum physics. String theorists, in their attempts to reconcile ever widening theoretical gaps, started talking about eleven dimensions. Dark matter still makes no sense. Modern physics knows so much more about the universe, but there is still s much it doesn't understand. For the first time, some scientists are openly wondering if we, in fact, are incapable of figuring out the cosmos.

Or look at neuroscience. Only a few decades ago, scientists were putting forth confident conjectures about "the bridging principle," the neural event that would explain how the activity of our brain cells creates the subjective experience of consciousness. All sorts of bridges were proposed, from 40 Hz oscillations in the cerebral cortex to quantum coherence in microtubules. These were the biological processes that supposedly turned the water of the brain into the wine of the mind.

But scientists don't talk about these kinds of bridging principles these days. While neuroscience continues to make astonishing progress in learning about the details of the brain—we are a strange loop of kinase enzymes and synaptic chemistry—these details only highlight our enduring enigma, which is that we don't *experience* these cellular details. It is ironic, but true: The one reality science cannot reduce is the only reality we will ever know.

The fundamental point is that modern science has made little progress toward any unified understanding of everything. Our unknowns have not dramatically receded. In many instances, the opposite has happened, so that our most fundamental sciences are bracketed by utter mystery. It's not that we don't have all the answers. It's that we don't even know the question.

This is particularly true for our most fundamental sciences, like physics and neuroscience. Physicists study the fabric of reality, the invisible laws and particles that define the material world. Neuroscientists study our perceptions of this world; they dissect the brain in order to understand the human animal. Together, these two sciences seek to solve the most ancient and epic of unknowns: What is everything? And who are we?

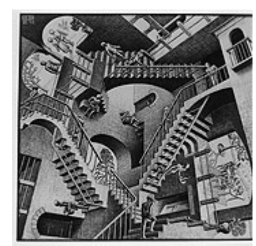
Symphony No. 7 in D Minor, Op. 70, 1885
ANTONÍN DVOŘÁK
A particular region in the prefrontal cortex of the human brain, Brodman Area 47, is engaged in trying to figure out what's going to happen next i a sequence of events manifested over time, in spoken language, signec language, music, etc. When expectations are met, these neural circuits are rewarded and reinforced. When expectations are violated, a differen part of our brain, the anterior cingulated, becomes activated, focusing our attention on the unexpected sequence. The end of Dvořák's 7th Symphony is a wonderful artistic exploration of the delicate orchestration of neural responses that allows us to feel both surprised and rewarded by clever permutations of what we're accustomed to. We retrieve these perceptions from episodic memory traces the next time we hear a similar piece of music.— *Daniel Levitin, Neuroscientist, McGi University*

But before we can unravel these mysteries, our sciences must get past their present limitations. How can we make this happen? My answer is simple: *Science needs the arts*. We need to find a place for the artist within the experimental process, to rediscover what Boh observed when he looked at those cubist paintings. The current constraints of science make it clear that the breach between our two cultures is not merely an academic problem that stifles conversation at cocktail parties. Rather, it is a practical problem, and it holds back science's theories. If we want answers to our most essential questions, then we will need to bridge our cultural divide. By heeding the wisdom of the arts, science can gain the kinds of new insights and perspectives that are the seeds of scientific progress.

Since its inception in the early 20th century, neuroscience has succeeded in becoming intimate with the brain. Scientists have reduced our sensations to a set of discrete circuits. They have imaged our cortex as it thinks about itself, and calculated the shape of ion channels, which are machined to subatomic specifications.

And yet, despite this vast material knowledge, we remain strangely ignorant of what our matter creates. We know the synapse, but don't know ourselves. In fact, the logic of reductionism implies that our self-consciousness is really an elaborate illusion, an epiphenomenon generated by some electrical shudder in the frontal cortex. There is no ghost in the machine; there is only the vibration of the machinery. Your head contains 100 billion electrical cells, but not one of them is you, or knows or cares about you. In fact, you don't even exist. The brain is nothing but an infinite regress of matter, reducible to the callous laws of physics.

The problem with this method is that it denies the very mystery it needs to solve. Neuroscience excels at unraveling the mind from the bottom up. But our self-consciousness seems to require a top-down approach. As the novelist Richard Powers wrote, "If we knew the world only through synapses, how could we know the synapse?" The paradox of neuroscience is that its astonishing progress has exposed the limitations of its paradigm, as reductionism has failed to solve our emergent mind. Much of our experiences remain outside its range.



Relativity, 1953
M.C. ESCHER
I believe that understanding the worlc is a lot like seeing the world, and the visual illusions to which the eye is prone provide exquisite metaphors fc the cognitive illusions to which the mind is prone. When you first look at drawing such as Escher's *Relativity*, everything seems fine. But as you inspect it you suddenly realize that what you're seeing is impossible—each section of the canvas is coherer but all these possible parts add up tc an impossible whole. Escher's work exposes the masterful fraud that our brains perpetrate upon us—the neura magic show that we call reality. — *Daniel Gilbert, Psychologist, Harvard University* © 2007 The M.C. Escher Company-Holland.

This world of human experience is the world of the arts. The novelist and the painter and the poet embrace those ephemeral aspects of the mind that cannot be reduced, or dissected, or translated into the activity of an acronym. They strive to capture life as it's lived. As Virginia Woolf put it, the task of the novelist is to "examine for a moment an ordinary mind on an ordinary day…[tracing] the pattern, however disconnected and incoherent in appearance, which each sight or incident scores upon the consciousness." She tried to describe the mind from the inside.

Neuroscience has yet to capture this first-person perspective. Its reductionist approach has no place for the "I" at the center of everything. It struggles with the question of qualia. Artists like Woolf, however, have been studying such emergent phenomena for centuries, and have amassed a large body of knowledge about such mysterious aspects of the mind. They have constructed elegant models of human consciousness that manage to express the texture of our experience, distilling the details of real life into prose and plot. That's why their novels have endured: because they *feel* true. And they feel true because they capture a layer of reality that reductionism cannot.

Study for an angel's face from The Virgin of the Rocks, ca. 1483
LEONARDO DA VINCI
This pencil study stunningly illustrates for me a key parallel between science and the arts: They strive for representation and expression, to capture some essential truth about a chosen subject with simplicity and economy. My equations and diagrams are no more the world I'm trying to describe than the artist's pencil strokes are the woman he drew. However, it shows what's possible, despite that limitation. The woman that emerges from the simple pencil strokes is so alive that she stares into your soul. In attempting to capture the universe, I mustn't confuse my equations with the real thing, but from them some essential truths about nature will spring forth, transcending the mathematics and coming to life.—*Clifford Johnson, Physicist, University of Southern California* © Alinari Archives/Corbis

By taking these artistic explorations seriously, neuroscientists can better understand the holistic properties they are trying to parse. Before you break something apart, it helps to know how it hangs together. In this sense, the arts are an incredibly rich data set, providing science with a glimpse into its blind spots. If neuroscience is ever going to discover the neural correlates of consciousness, or find the source of the self, or locate the cells of subjectivity—if it's ever going to get beyond a glossary of our cortical parts—then it has to develop an intimate understanding of these higher-order mental events. This is where the current methods of science reach their limit.

What neuroscience needs is a new method, one that's able to construct complex representations of the mind that aren't built from the bottom up. Sometimes, the whole is best understood in terms of the whole. William James, as usual, realized this first. The eight chapters that begin his epic 1890 textbook, *The Principles of Psychology*, describe the mind in the conventional third-person terms of the experimental psychologist. Everything changes, however, with chapter nine. James starts this section, "The Stream of Thought," with a warning: "We now begin our study of the mind from within."

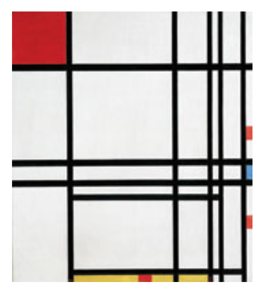
With that single sentence, as radical in sentiment as the modernist novel, James tried to shift the subjec of psychology. He disavowed any scientific method that tried to dissect the mind into a set of elemental units, be it sensations or synapses. Such a reductionist view is the *opposite* of science, James argued, since it ignores our actual reality.

Modern science didn't follow James' lead. In the years after his textbook was published, a "New Psychology" was born, and this rigorous science had no need for Jamesian vagueness. It wanted to purg itself of anything that couldn't be measured. The study of experience was banished from the laboratory.

But artists continued creating their complex simulations of consciousness. They never gave up on the ineffable, or detoured around experience because it was too difficult. They plunged straight into the pandemonium. No one demonstrates this better than James Joyce. In *Ulysses*, Joyce attempted to capture the mind's present tense. Everything in the novel is seen not from the omniscient perspective of the author, but through the concave lenses of his imaginary characters. We eavesdrop on their internal soliloquies, as Bloom, Stephen, and Molly think about beauty, and death, and eggs in bed, and the number eight. This, Joyce says, is the broth of thought, the mind before punctuation, the stream of consciousness rendered on the page. *Ulysses* begins where William James left off.

Similarly, Samuel Taylor Coleridge, enchanted with opium, was writing poetry about the "the mind's self-experience in the act of thinking" long before there was even a science of the mind. Or look at the world of visual art. As the neuroscientist Semir Zeki notes, "Artists [painters] are in some sense neurologists, studying the brain with techniques that are unique to them." Monet's haystacks appeal to us, in part, because he had a practical understanding of color perception. The drip paintings of Jackson Pollock resonate precisely because they excite some peculiar circuit of cells in the visual cortex. These painters reverse-engineered the brain, discovering the laws of seeing in order to captivate the eye.

Of course, the standard response of science is that such art is too incoherent and imprecise for the scientific process. Beauty isn't truth; Monet got lucky. The novel is just a work of fiction, which is the opposite of experimental fact. If it can't be plotted on a line graph or condensed into variables, then it's not worth taking into account. But isn't such incoherence an essential aspect of the human mind? Isn't our inner experience full of gaps and non-sequiturs and inexplicable feelings? In this sense, the messiness of the novel and the abstraction of the painting is actually a mirror. As the poetry critic Randall Jarrell put it, "It is the contradictions in works of art which make them able to represent us—as logical and methodical generalizations cannot—our world and our selves, which are also full of contradictions."



Composition No. 8, 1939-1942
PIET MONDRIAN
Mondrian, in search of "the constant truths concerning forms," settled on the straight line as the major feature o his compositions. He believed that straight lines are constituents of all forms. Many years later, physiologists discovered orientation-selective cells which respond selectively to straight lines, and are widely thought to be th physiological "building blocks" of for perception. Each cell responds increasingly more grudgingly when exposed to images that depart from the preferred orientation, until the response disappears altogether at th orthogonal orientation.—*Semir Zeki, Neuroscientist, University College London* © Kimbell Art Museum/Corbi

No scientific model of the mind will be wholly complete unless it includes what can't be reduced. Science rightfully adheres to a strict methodology, relying on experimental data and testability, but this method could benefit from an additional set of inputs. The cultural hypotheses of artists can inspire the questions that stimulate important new scientific answers. Until science sees the brain from a more holistic perspective—and such a perspective might require the artistic imagination—our scientific theories will be detached from the way we see ourselves.

Neuroscience, of course, believes that it has no inherent limitations. One day, a team of scientists may explain human consciousness. The bridging principle will be solved. The mystery of experience will turn out to be another trick of matter. Such scientific optimism might be right. Only time will tell. (It's worth noting that not every scientist is quite so optimistic. Noam Chomsky, for example, has declared that, "It is quite possible—overwhelmingly probable, one might guess—that we will always learn more about human life and personality from novels than from scientific psychology.") Regardless, it's clear that solving the deepest mysteries of the brain—what the philosopher David Chalmers calls "the hard questions of consciousness"—will require a new scientific approach, one that is able to incorporate the wisdom of the arts. We are such stuff as dreams are made on, but we are also just stuff. Neither truth, when seen alone, is our solution, for our reality exists in plural.

At first glance, physics seems particularly remote from the subjective sphere of the arts. Its theories are extracted from arcane equations and the subatomic debris of supercolliders. This science continually insists that our most basic intuitions about reality are actually illusions, a sad myth of the senses. Artists rely on the imagination, but modern physics *exceeds* the imagination. To paraphras Hamlet, there are more things in heaven and earth—dark matter, quarks, black holes—than could ever be dreamt up. A universe this strange could only be discovered.

But the surreal nature of physics is precisely why it needs the help of artists. The science has progressed beyond our ability to understand it, at least in any literal sense. As Richard Feynman put it, “Our imagination is stretched to the utmost, not, as in fiction, to imagine things which are not really there, but just to comprehend those things which *are* there.” It’s a brute fact of psychology that the human mind cannot comprehend the double-digit dimensions of string theory, or the possibility of parallel universes. Our mind evolve in a simplified world, where matter is certain, time flows forward and there are only three dimensions. When we venture beyond these innate intuitions, we are forced to resort to *metaphor*. This is the irony of modern physics: It seeks reality in its most fundamental forn and yet we are utterly incapable of comprehending these fundaments beyond the math we use to represent them. The only way to knov the universe is through analogy.

As a result, the history of physics is littered with metaphorical leaps. Einstein grasped relativity while thinking about moving trains. Arthur Eddington compared the expansion of the universe to an inflated balloon. James Clerk Maxwell thought of magnetic fields as little whirlpools in space, which he called vortices. The Big Bang was just a cosmic firecracker. Schrödinger’s cat, trapped in a cosmic purgatory, helped illustrate the paradoxes of quantum mechanics. It’s hard to imagine string theory without its garden hose.

These scientific similes might seem like quaint oversimplifications, but they actually perform a much more profound function. As the physicist and novelist Alan Lightman writes, “Metaphor in science serves not just as a pedagogical device, but also as an aid to scientifi discovery. In doing science, even though words and equations are used with the intention of having precise meaning, it is almost impossible not to reason by physical analogy, not to form mental pictures, not to imagine balls bouncing and pendulums swinging.” Th power of a metaphor is that it allows scientists imagine the abstract concept in concrete terms, so that they can grasp the implications o their mathematical equations. The world of our ideas is framed by the only world we know.

But relying on metaphor can also be dangerous, since every metaphor is necessarily imperfect. (As Thomas Pynchon put it, “The act of metaphor is a thrust at truth and a lie, depending on where you are.”) The strings of the universe might be *like* a garden hose, but they are *not* a garden hose. The cosmos isn’t a plastic balloon. When we chain our theories to ordinary language, we are trespassing on the purity of the equation. To think in terms of analogies is to walk a tightrope of accuracy.

A Couple in the Street, 1887
CHARLES ANGRAND
Human eyes are horizontally offset from each other, and the visual system uses that offset to calculate depth. When an object is fixated upon, images are cast on the same place on each retina. A view with many identical (or similar) objects casts multiple images on the eyes, which can either be correctly matched, giving a flat impression, or mismatched, so one image corresponds to the other, but at a different depth. I think that the artists from the impressionist and post-impressionist periods figured this out. They said they could paint air and managed to do so by creating false stereopsis cues, which manipulate depth perception. So Angrand’s painting actually looks more three-dimensional when you view the painting with both eyes instead of with a single eye.—*Margaret Livingstone, Neuroscientist, Harvard University* © The Bridgeman Art Library/Getty Images

This is why modern physics needs the arts. Once we accept the importance of metaphor to the scientific process, we can start thinking about how we can make those metaphors *better*. Poets, of course, are maste of metaphor: The power of their art depends on the compression of meaning into meter; vague feelings are translated into visceral images. It’s not a coincidence that many of the greatest physicists of the 20th century—eminent figures like Einstein, Feynman, and Bohr—were known for their distinctly romantic method of thinking. These eminent scientists depended on their ability to use metaphor to see what no one else had ever seen, so that the railroad became a metaphor for relativity, and a drop of liquid helped symbolize the atomic nucleus. Poets can speed this scientific process along, helping physicists to invent ne metaphors and improve their old ones. Perhaps we can do better than a garden hose. Maybe a simile will help unlock the secret of dark matter. As the string theorist Brian Greene recently wrote, the arts have the ability to “give a vigorous shake to our sense of what’s real,” jarring the scientific imagination into imagining new things.

But there’s another way that artists can bring something to the cosmic conversation: they can help make tl scientific metaphors *tangible*. When the metaphysical equation is turned into a physical object, physicists can explore the meaning of the mathematics from a different perspective. Look, for example, at a Richard Serra sculpture. His labyrinths of bent metal let us participate in the theoretical, so that we might imagine the strange curves of space-time in an entirely new way. The fragmented shapes of cubism, which engaged in such a fruitful dialogue with the avant-garde physics of its time, served a similar purpose. Picasso never understood the equations—he picked up non-Euclidian geometry via the zeitgeist—but he was determined to represent this new way of thinking about space in his paintings. A century later, physicists are still using his shattered still lifes as a potent symbol of their science. Abstract art lets us comprehend, at least a little bit, the incomprehensible.

It’s time for the dialogue between our two cultures to become a standard part of the scientific method. (Ou universities could begin by offering a “Poetry for Physicists” class.) But it’s also crucial to take our scientifi metaphors beyond the realm of the metaphorical, so we can better understand the consequences of our theories. Art galleries should be filled with disorienting evocations of string theory and the EPR paradox. Every theoretical physics department should support an artist-in-residence. Too often, modern physics seems remote and irrelevant, its suppositions so strange they’re meaningless. The arts can help us reattach physics to the world we experience.

The Tragedy, 1903
PABLO PICASSO
Artists have known for a very lon time that color and luminance ca be treated independently. Our perception of depth, three-dimensionality, movement (or the lack of it), and spatial organizatio are all carried by a subdivision of our visual system that is essentially color-blind, and sees the world in shades of gray. This an evolutionarily older part of our visual system. One cannot see depth or motion in the absence c luminance contrast. In Picasso's *The Tragedy*, one can appreciate the three-dimensionality of the scene because, despite the peculiar choice of colors, the luminance is just right.—*Margare Livingstone, Neuroscientist, Harvard University* © Francis G. Mayer/Corbis

Neuroscience can also benefit from the reactions of artists. Novelists can simulate the latest theory of consciousness in their fiction. If a theory can't inspire characters that feel true, then it probably isn't true itself. (Woolf, for example, was an early critic of Freudian theory, dismissing the way it turned all of her "characters into cases.") Painters can explore new theories about the visual cortex. Dancers can help untangle the mysterious connection between the body and emotion. By heeding the wisdom of the arts, science extends to art the invitation to participate in its conversation and the opportunity to add science to its repertoire. And by, in turn, interpreting scientific ideas and theories, the arts offers science a new lens through which to see itself.

C.P. Snow, the essayist who coined the "two culture" cliché, proposed a simple solution to the problem of divided cultures. He argued that we needed a "third culture," which would close the "communications gap" between scientists and artists. Each side, Snow said, would benefit from an understanding of the other, as writers learned about the second law of thermodynamics and scientists read Shakespeare.

There is currently a nascent third culture, but it strays from Snow's conception. While his third culture was based upon dialogue, our current third culture consists, almost entirely, of scientists talking directly to the general public. As John Brockman, the founder of this new third culture, wrote: "What traditionally has been called 'science' has today become 'public culture'...Science is the only news." There is, of course, much to be said for scientists cutting out "the middleman" and translating their data for the masses. Many of the scientists that make up this third culture have greatly increased the public's understanding of the scientific avant-garde. From Richard Dawkins to Brian Greene, from Steven Pinker to E.O. Wilson, these figures not only do important scientific research, they write in elegant prose. In doing so, they are teaching us much.

But what of the collaboration between science and the arts? Are we really prepared to live with a permanent cultural schism? If we are serious about unifying human knowledge, then we'll need to create a new movement that coexists with the third culture but that deliberately trespasses on our cultural boundaries and seeks to create relationships between the arts and the sciences. The premise of this movement—perhaps a *fourth* culture—is that neither culture can exist by itself. Its goal will be to cultivate a positive feedback loop, in which works of art lead to new scientific experiments, which lead to new works of art and so on. Instead of ignoring each other, or competing, or co-opting each other in naïve or superficial ways, science and the arts will truly impact each other. The old intellectual boundaries will disappear. Neuroscience will gain new tools with which to confront the mystery of consciousness and modern physics will improve its metaphors. Art will become a crucial source of scientific ideas.

This will ultimately lead us to take a broader view of truth. Right now, science is widely considered our sole source of Truth, with a capital "T." Everything that can't be stated in the language of acronyms and equations risks being disregarded as a pretty fiction, which is the opposite of scientific fact.

But the epic questions that modern science must answer cannot be solved by science alone. Bringing our two cultures together will allo us to judge our knowledge not by its origins, but in terms of its usefulness. What does this novel or experiment or poem teach us about ourselves? How does it help us understand who we are, or what the universe is made of? What long-standing problem has it engaged, perhaps even solved? If we are open-minded in our answers to these questions, we will discover that poems and paintings can help advance our experiments and theories. Art can make science better.

But before any of this can happen, our two existing cultures must modify their habits. First of all, the humanities must sincerely engag with the sciences. Henry James defined the writer as someone on whom nothing is lost; artists must heed his call, and not ignore science's inspiring descriptions of reality.

At the same time, the sciences must recognize that their truths are not the only truths. No single area of knowledge has a monopoly on knowledge. As Karl Popper, an eminent defender of science wrote, "It is imperative that we give up the idea of ultimate sources of knowledge, and admit that all knowledge is human; that it is mixed with our errors, our prejudices, our dreams, and our hopes; that all we can do is to grope for truth even though it is beyond our reach." The struggle for scientific truth is long and hard and never ending. we want to get an answer to our deepest questions—the questions of who we are and what everything is—we will need to draw from bot science and art, so that each completes the other.