A Beautiful Question: Finding Nature's Deep Design

Does the universe embody beautiful ideas?

Artists as well as scientists throughout human history have pondered this "beautiful question." With Nobel laureate Frank Wilczek as your guide, embark on a voyage of related discoveries, from Plato and Pythagoras up to the present. Wilczek's groundbreaking work in quantum physics was inspired by his intuition to look for a deeper order of beauty in nature. In fact, every major advance in his career came from this intuition: to assume that the universe embodies beautiful forms, forms whose hallmarks are symmetry-harmony, balance, proportion-and economy. There are other meanings of "beauty," but this is the deep logic of the universe-and it is no accident that it is also at the heart of what we find aesthetically pleasing and inspiring.

Wilczek is hardly alone among great scientists in charting his course using beauty as his compass. As he reveals in A Beautiful Question, this has been the heart of scientific pursuit from Pythagoras, the ancient Greek who was the first to argue that "all things are number," to Galileo, Newton, Maxwell, Einstein, and into the deep waters of twentiethcentury physics. Though the ancients weren't right about everything, their ardent belief in the music of the spheres has proved true down to the quantum level. Indeed, Wilczek explores just how intertwined our ideas about beauty and art are with our scientific understanding of the cosmos.

Wilczek brings us right to the edge of knowledge today, where the core insights of even the craziest quantum ideas apply principles we all understand. The equations for atoms and light are almost literally the same equations that govern musical instruments and sound; the subatomic particles that are responsible for most of our mass are determined by simple geometric symmetries. The universe itself, suggests Wilczek, seems to want to embody beautiful and elegant forms. Perhaps this force is the pure elegance of numbers, perhaps the work of a higher being, or somewhere between. Either way, we don't depart from the infinite and infinitesimal after all; we're profoundly connected to them, and we connect them. When we find that our sense of beauty is realized in the physical world, we are discovering something about the world, but also something about ourselves.

Gorgeously illustrated, A Beautiful Question is a mind-shifting book that braids the age-old quest for beauty and the age-old quest for truth into a thrilling synthesis. It is a dazzling and important work from one of our best thinkers, whose humor and infectious sense of wonder animate every page. Yes: The world is a work of art, and its deepest truths are ones we already feel, as if they were somehow written in our souls.
Frank Wilczek won the Nobel Prize in Physics in 2004 for work he did as a graduate student. His 1989 book, Longing for the Harmonies, was a New York Times notable book of the year. Wilczek is a regular contributor to Nature and Physics Today and his work has also been anthologized in Best American Science Writing and the Norton Anthology of Light Verse. He lives in Cambridge, Massachusetts, where he is the Herman Feshbach Professor of Physics at the Massachusetts Institute of Technology.

This work was prepared especially for A Beautiful Question by He Shuifa,a modern master of traditional Chinese art and calligraphy. He is renownedfor the vigor and subtlety of his brushwork and for the spiritual depth of hisdepictions of flowers, birds, and nature. A simple translation of the inscriptionis this: "Taiji double fish is the essence of Chinese culture. This imagewas painted by He Shuifa on a lake in early winter." The playful "doublefish" aspect of Taiji comes to life in He Shuifa's image. The yin and yangresemble two carp playing together, and there are hints of their eyes and fins.In Henan, on the Yellow River, there is a waterfall called Dragon's Gate.Yulong carp attempt to jump the cataract, although it is very difficult forthem. Those that succeed transform into lucky dragons. With a sense ofhumor, we may associate this event with the transformation of virtual intoreal particles, an essential quantum process that is now thought to underliethe origin of structure in the Universe (see plates XX and AAA). Alternativelywe may identify ourselves with the carp, and their strivings with ourquest for understanding.

USER'S MANUAL

- The "Timelines" are mainly focused on events mentioned or alluded to in the book. They do what timelines do. They are not intended to be complete histories of anything, and they aren't.
- The "Terms of Art" section contains explanatory definitions and discussions of key terms and concepts that occur in the main text. As you can infer from its length, it is rather more than a standard glossary. It contains alternative perspectives on many ideas in the text, and develops a few in new directions.
- The "Notes" section contains material that might, in an academic setting, have gone into footnotes. It both qualifies the text and provides some more technical references on particular points. You'll also find a pair of poems in there.
- The brief "Recommended Reading" section is not a routine list of popularizations, nor of

textbooks, but a carefully considered set of recommendations for further exploration in the spirit of the text, emphasizing primary sources.

I hope you've already enjoyed the cover art and the frontispiece, which set the tone for our meditation beautifully.

There's also a "User's Manual"-but you knew that.

THE QUESTION

This book is a long meditation on a single question:

Does the world embody beautiful ideas?

Our Question may seem like a strange thing to ask. Ideas are one thing, physical bodies are quite another. What does it mean to "embody" an "idea"?

Embodying ideas is what artists do. Starting from visionary conceptions, artists produce physical objects (or quasi-physical products, like musical scores that unfold into sound). Our Beautiful Question, then, is close to this one:

Is the world a work of art?

Posed this way, our Question leads us to others. If it makes sense to consider the world as a work of art, is it a successful work of art? Is the physical world, considered as a work of art, beautiful? For knowledge of the physical world we call on the work of scientists, but to do justice to our questions we must also bring in the insights and contributions of sympathetic artists.

SPIRITUAL COSMOLOGY

Our Question is a most natural one, in the context of spiritual cosmology. If an energetic and powerful Creator made the world, it could be that what moved Him-or Her, or Them, or It-to create was precisely an impulse to make something beautiful. Natural though it may be, this is assuredly not an orthodox idea, according to most religious traditions. Many motivations have been ascribed to the Creator, but artistic ambition is rarely prominent among them.

In Abrahamic religions, conventional doctrine holds that the Creator set out to embody some combination of goodness and righteousness, and to create a monument to His glory. Animistic and polytheistic religions have envisaged beings and gods who create and govern different parts of the world with many kinds of motives, running the gamut from

benevolence to lust to carefree exuberance.

On a higher theological plane, the Creator's motivations are sometimes said to be so awesome that finite human intellects can't hope to comprehend them. Instead we are given partial revelations, which are to be believed, not analyzed. Or, alternatively, God is Love. None of those contradictory orthodoxies offers compelling reasons to expect that the world embodies beautiful ideas; nor do they suggest that we should strive to find such ideas. Beauty can form part of their cosmic story, but it is generally regarded as a side issue, not the heart of the matter.

Yet many creative spirits have found inspiration in the idea that the Creator might be, among other things, an artist whose esthetic motivations we can appreciate and share-or even, in daring speculation, that the Creator is primarily a creative artist. Such spirits have engaged our Question, in varied and evolving forms, across many centuries. Thus inspired, they have produced deep philosophy, great science, compelling literature, and striking imagery. Some have produced works that combine several, or all, of those features. These works are a vein of gold running back through our civilization.

Galileo Galilei made the beauty of the physical world central to his own deep faith, and recommended it to all:

The greatness and the glory of God shine forth marvelously in all His works, and is to be read above all in the open book of the heavens.

. . . as did Johannes Kepler, Isaac Newton, and James Clerk Maxwell. For all these searchers, finding beauty embodied in the physical world, reflecting God's glory, was the goal of their search. It inspired their work, and sanctified their curiosity. And with their discoveries, their faith was rewarded.

While our Question finds support in spiritual cosmology, it can also stand on its own. And though its positive answer may inspire a spiritual interpretation, it does not require one.

We will return to these thoughts toward the end of our meditation, by which point we will be much better prepared to appraise them. Between now and then, the world can speak for itself.

HEROIC VENTURES

Just as art has a history, with developing standards, so does the concept of the world as a work of art. In art history, we are accustomed to the idea that old styles are not simply obsolete, but can continue to be enjoyed on their own terms, and also offer important context for later developments. Though that idea is much less familiar in science, and in science it is subject to important limitations, the historical approach to our Question offers many advantages. It allows us-indeed, forces us-to proceed from simpler to more complex ideas. At the same time, by exploring how great thinkers struggled and often went astray, we gain perspective on the initial strangeness of ideas that have become, through

familiarity, too "obvious" and comfortable. Last but by no means least, we humans are especially adapted to think in story and narrative, to associate ideas with names and faces, and to find tales of conflicts and their resolution compelling, even when they are conflicts of ideas, and no blood gets spilled. (Actually, a little does . . .)

For these reasons we will sing, to begin, songs of heroes: Pythagoras, Plato, Filippo Brunelleschi, Newton, Maxwell. (Later a major heroine, Emmy Noether, will enter too.) Real people went by those names-very interesting ones! But for us they are not merely people, but also legends and symbols. I've portrayed them, as I think of them, in that style, emphasizing clarity and simplicity over scholarly nuance. Here biography is a means, not an end. Each hero advances our meditation several steps:

 Pythagoras discovered, in his famous theorem about right-angled triangles, a most fundamental relationship between numbers, on the one hand, and sizes and shapes, on the other. Because Number is the purest product of Mind, while Size is a primary characteristic of Matter, that discovery revealed a hidden unity between Mind and Matter.

Pythagoras also discovered, in the laws of stringed instruments, simple and surprising relationships between numbers and musical harmony. That discovery completes a trinity, Mind-Matter-Beauty, with Number as the linking thread. Heady stuff! It led Pythagoras to surmise that All Things Are Number. With these discoveries and speculations, our Question comes to life.

 Plato thought big. He proposed a geometric theory of atoms and the Universe, based on five symmetrical shapes, which we now call the Platonic solids. In this audacious model of physical reality, Plato valued beauty over accuracy. The details of his theory are hopelessly wrong. Yet it provided such a dazzling vision of what a positive answer to our Question might look like that it inspired Euclid, Kepler, and many others to brilliant work centuries later. Indeed, our modern, astoundingly successful theories of elementary particles, codified in our Core Theory (see page 8), are rooted in heightened ideas of symmetry that would surely make Plato smile. And when trying to guess what will come next, I often follow Plato's strategy, proposing objects of mathematical beauty as models for Nature.

Plato was also a great literary artist. His metaphor of the Cave captures important emotional and philosophical aspects of our relationship, as human inquirers, with reality. At its core is the belief that everyday life offers us a mere shadow of reality, but that through adventures of mind, and sensory expansion, we can get to its essence-and that the essence is clearer and more beautiful than its shadow. He imagined a mediating demiurge, which can be translated as Artisan, who rendered the realm of perfect, eternal Ideas into its imperfect copy, the world we experience. Here the concept of the world as a work of art is explicit.

 Brunelleschi brought new ideas to geometry from the needs of art and engineering. His projective geometry, in dealing with the actual appearance of things, brought in ideas-relativity, invariance, symmetry-not only beautiful in themselves, but pregnant with potential.

- Newton brought the mathematical understanding of Nature to entirely new levels of ambition and precision.

A common theme pervades Newton's titanic work on light, the mathematics of calculus, motion, and mechanics. It is the method he called Analysis and Synthesis. The method of Analysis and Synthesis suggests a two-stage strategy to achieve understanding. In the analysis stage, we consider the smallest parts of what we are studying their "atoms," using the word figuratively. In a successful analysis, we identify small parts that have simple properties that we can summarize in precise laws. For example:

- In the study of light, the atoms are beams of pure spectral colors.
- In the study of calculus, the atoms are infinitesimals and their ratios.
- In the study of motion, the atoms are velocity and acceleration.
- In the study of mechanics, the atoms are forces.

(We'll discuss these in more depth later.) In the synthesis stage we build up, by logical and mathematical reasoning, from the behavior of individual atoms to the description of systems that contain many atoms.

When thus stated broadly, Analysis and Synthesis may not seem terribly impressive. It is, after all, closely related to common rules of thumb, e.g., "to solve a complex problem, divide and conquer"-hardly an electrifying revelation. But Newton demanded precision and completeness of understanding, saying,

'Tis much better to do a little with certainty & leave the rest for others that come after than to explain all things by conjecture without making sure of any thing.

And in these impressive examples, he achieved his ambitions. Newton showed, convincingly, that Nature herself proceeds by Analysis and Synthesis. There really is simplicity in the "atoms," and Nature really does operate by letting them do their thing.

Newton also, in his work on motion and mechanics, enriched our concept of what physical laws are. His laws of motion and of gravity are dynamical laws. In other words, they are laws of change. Laws of this kind embody a different concept of beauty than the static perfection beloved of Pythagoras and (especially) Plato.

Dynamical beauty transcends specific objects and phenomena, and invites us to imagine the expanse of possibilities. For example, the sizes and shapes of actual planetary orbits are not simple. They are neither the (compounded) circles of Aristotle, Ptolemy, and Nicolaus Copernicus, nor even the more nearly accurate ellipses of Kepler, but rather curves that must be calculated numerically, as functions of time, evolving in complicated ways that depend on the positions and masses of the Sun and the other planets. There is great beauty and simplicity here, but it is only fully evident when we understand the deep design. The appearance of particular objects does not exhaust the beauty of the laws.

- Maxwell was the first truly modern physicist. His work on electromagnetism ushered in

both a new concept of reality and a new method in physics. The new concept, which Maxwell developed from the intuitions of Michael Faraday, is that the primary ingredients of physical reality are not point-like particles, but rather space-filling fields. The new method is inspired guesswork. In 1864 Maxwell codified the known laws of electricity and magnetism into a system of equations, but discovered the resulting system was inconsistent. Like Plato, who shoehorned five perfect solids into four elements plus the Universe, Maxwell did not give up. He saw that by adding a new term he could both make the equations appear more symmetric and make them mathematically consistent. The resulting system, known as the Maxwell equations, not only unified electricity and magnetism, but derived light as a consequence, and survives to this day as the secure foundation of those subjects.

By what is the physicist's "inspired guesswork" inspired? Logical consistency is necessary, but hardly sufficient. Rather it was beauty and symmetry that guided Maxwell and his followers-that is, all modern physicists-closer to truth, as we shall see.

Maxwell also, in his work on color perception, discovered that Plato's metaphorical Cave reflects something quite real and specific: the paltriness of our sensory experience, relative to available reality. And his work, by clarifying the limits of perception, allows us to transcend those limits. For the ultimate sense-enhancing device is a searching mind.

QUANTUM FULFILLMENT

The definitive answer "yes" to our Question came only in the twentieth century, with the development of quantum theory.
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Other Books
Mind, Value, and Cosmos, Mind, Value, and Cosmos: On the Relational Nature of Ultimacy is an investigation into the nature of ultimacy and explanation, particularly as it relates to the status of, and relationship among Mind, Value, and the Cosmos. It draws its stimulus from longstanding "axianoetic" convictions as to the ultimate status of Mind and Value in the western tradition of philosophical theology, and chiefly from the influential modern proposals of A.N. Whitehead, Keith Ward, and John Leslie. What emerges is a relational theory of ultimacy wherein Mind and Value, Possibility and Actuality, God and the World are revealed as "ultimate" only in virtue of their relationality. The ultimacy of relationality–what Whitehead calls "mutual immanence"–uniquely illuminates enduring mysteries surrounding: any and all existence, necessary divine existence, the nature of the possible, and the world as actual. As such, it casts fresh light upon the whence and why of God, the World, and their ultimate presuppositions.
□ □ □ □ □ . But we do not take the beauty of a theory as convincing evidence of its truth." For a discussion of the evidential nature of the aesthetic, see S. M. Thomas Dubay , The Evidential Power of Beauty : Science and Theology Meet (San ..."