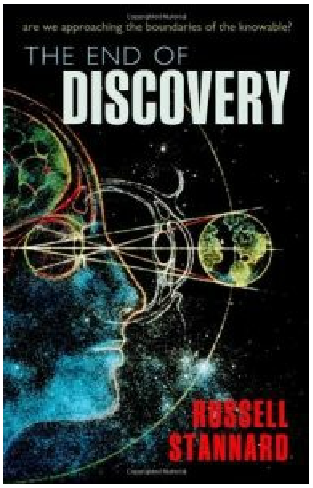

Book The End of Discovery

Are We Approaching the Boundaries of the Knowable?

Russell Stannard
Oxford UP, 2010
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Recommendation

This is an ambitious yet accessible book that spans the universe from its creation to yesterday and includes pretty much everything in it. Physicist and professor Russell Stannard, a confident guide through this complex and, at times, contradictory territory, proves skilled at analogies and visualizations, and sympathetic over the difficulty of the questions he raises. These are mind-shattering inquiries: thoughts about thoughts and observations about observations. The author presents this confusion as the status quo and illuminates how all the contradictions of physics still come together to define a universe. Stannard also reminds the reader that everything he describes could be obsolete tomorrow. He provides perspective for – and *BooksInShort* recommends this book to – all those interested in science, predictions of the future, philosophy and human nature.

Take-Aways

- Science won't reach its limits soon, but it will stop making fundamental discoveries.
- People's internal experiences with their minds and thoughts differ fundamentally from objective or scientific descriptions of thinking.
- The universe began with the Big Bang. Before that, neither space nor time existed.
- It is roughly 13.7 billion years old; no one knows how big it is, or if space is infinite.
- Because the universe formed perfectly to support human life, according to the "anthropic principle," some thinkers conclude it has a creator.
- Spacetime is static, but human consciousness perceives time as continually flowing.
- The vastness of space is not an empty nothingness; it is curved by mass and something has to be there if space is going to curve.
- Matter is made up of hundreds of small particles with many different qualities.
- Einstein's work led to the discovery that light can act like a wave or like particles.
- Quantum theory and relativity – two incompatible theories – are physicists' primary tools for explaining the world.

Summary

Limits to Scientific Discovery

Science has advanced rapidly throughout recent history, but don't assume this progression will continue – ¬it can't. Science won't reach its limits anytime soon, but it will stop making fundamental discoveries. This won't be because humanity knows everything; rather, the human brain evolved for certain functions, and human intelligence has its limits. For example, confirming string theory would require a "particle accelerator the size of a galaxy." Certain profound questions have long resisted resolution, perhaps because they have no answers.

What Is the Relationship Between the Brain and the Mind?

Scientists cannot explain the relationship between brain activity and people's "mental experience." This leads to an even larger question: Why should you "have mental experiences at all?" You know you're conscious, and you assume other people are, since they act like you, but you can't know that directly. The "problem of consciousness" has been around for thousands of years, sitting at the intersection of two different ways of discussing things. One "language" talks about what you feel and think; the other addresses scientific and mathematical observable phenomena. The two do not align.

> "What actually is space – space itself?"

Free will poses a challenge. If your brain chemistry follows physical laws, then as science masters those laws, it should be able to predict your decisions based on your biological makeup. So, if your brain generates your thoughts, are you choosing freely? Some thinkers argue that the universe has enough randomness to allow free will. Others take a "dualistic approach," arguing that the brain and the mind influence one another, but are distinct. Some look to the unconscious as the source of choices.

Humanity in the Universe

The best scientific explanation for the origins of the universe is that 13.7 billion years ago, everything in existence compressed into a single point. The Big Bang followed. How and why did it happen? To answer those questions, science peers backward in time. Astronomers can't see the light an object emits now; they see the light it generated 10,000 or 10 million years ago, but not all the way back to the Big Bang. "Radiation fog" blocks anything that happened prior to 300,000 years after the Big Bang. Scientists try to get a sense of what happened before by tracking elusive particles called neutrinos. Physicists know that the Big Bang happened, but they don't fully understand its nature. It was an explosion different from explosions that occur now. Today, if something explodes, energy moves outward through space. At the time of the Big Bang, space didn't exist. Space itself exploded, moving outward like a balloon expanding. Determining what caused the Big Bang is "an insuperable problem" – a question about cause and effect. For cause and effect to exist, time has to exist. But before the Big Bang, there was no time.

> "We take it for granted that science...progressively advances. But it was not always so. And, more importantly, it will not continue to be so – not indefinitely."

Once extant, the universe follows certain "laws of nature," which are best expressed algebraically. These rules are true everywhere, like the idea that parallel lines never meet. Scientists use different "mathematical systems" to describe various aspects of the universe. No one now knows which system is correct. Kurt Gödel's "incompleteness theorem" argues that you can't prove that some statements are true, even when they are. "Fundamental incompleteness" limits human understanding. The quest to comprehend natural laws is complicated by the possibility that they can change.

"The Anthropic Principle"

The universe formed perfectly to support human life. If the Big Bang had been more violent, created matter wouldn't have coalesced into stars. If it had been less violent, everything would have been pulled back together into a "Big Crunch." Gravity had to be the right strength to draw together gases created by the Big Bang, to jump-start nuclear fusion and to keep the sun burning long enough for life to evolve. The stars had to burn in just the right way to create heavier elements – such as carbon, a foundation of life – via "nuclear resonance." These weightier atoms had to be "blasted out" of stars through neutrinos. The resulting clouds of matter combined to make planets. Once life began, the "copying process" that transmits genetic material had to permit just the right degree of error: exact enough to create new creatures similar to their parents, but containing sufficient variations for different life forms to emerge. This collection of coincidences that make the "universe...hospitable to life" describes the anthropic principle. It is impossible to compute how unlikely it is that these factors occurred randomly. Thus, some thinkers conclude that the universe has a creator.

> "It is a very strange world that we inhabit. It had to be strange for us, and for other forms of life, to be able to live in it."

To know the size of the universe requires distinguishing between "the observable universe" and the universe per se. No one knows if space has limits; some experts argue that it is curved; a spaceship could blast through space and eventually find itself back where it started. The density of space determines whether the universe is closed or not. If the matter in the universe adds up to a "critical density," it will curve space around itself. However, adding up the visible mass proves that it comprises no more than "5% of the critical value." The stars rotating around the galactic core and the galaxies in the cluster containing Earth's solar system are both moving too fast for that to be the correct total. Thus science posits the existence of "dark matter" which "emits no light."

> "Four-dimensional spacetime is sometimes called the block universe. It encompasses all of space and all of time."

Each discovered planet feeds the question about whether humanity is alone in the universe. Scientists can discern if conditions are right for life to evolve elsewhere, but not if it has. If life exists somewhere else, it might come into being, flourish and become extinct without humans on Earth ever knowing. Even life that achieves intelligence might suffer extinction. The universe could follow a pattern in which intelligent life reaches a sufficient stage of technological development to produce atomic weapons and then blows itself up. Since it might take "100,000 years to reach even the nearest star," humanity can only scan the heavens for signs and signals.

Space and Time

Space is not empty nothing. Einstein's theory of relativity indicates that space is curved by mass and something has to be there if space is going to curve. Quantum theory suggests that "empty space is not empty at all." Instead, "a seething crowd of subatomic particles" continually blink in and out of being, converting matter into energy. Scientists cannot observe these "virtual particles" because they come and go too quickly, but experts can see the proof of their existence: The particles generate enough energy to drive galaxies apart. They also produce an "overall energy" used to calculate the "dark energy" contributing to the universe's makeup. The English theoretical physicist Paul Dirac argued that these particles generate "antiparticles" that exist everywhere in an energy continuum. If so, why do observations show more matter than antimatter?

> "When thinking about the universe, one cannot help wondering whether there is life out there."

A final question about space involves measuring it. As science has come to perceive smaller and smaller units, scientist ask whether – as instruments grow ever more sophisticated – there will ever be a stopping point? Quantum pioneer Max Planck argued for a unit known as the "Planck length," which is "10-20 times the size of the proton." The smallest unit of time is "Planck time": the span required for light to travel the length of one Planck. "The trouble with the Planck length and Planck time, of course, is that both are almost inconceivably small compared to any spatial distance or time interval that has ever been measured, or is ever likely to be measured."

> "A combined theory of quantum gravity...is the physicists' Holy Grail. It was a theory that Einstein sought in his latter years – but failed to find."

"Spacetime" is static and unchanging, but human consciousness perceives time as continually flowing. Your consciousness is like "a searchlight beam" sent out along the universe's time axis. What you light up is the current instant. Beyond this is the "physical time" of spacetime, the time measured by clocks and your internal perception of time. The sequence of your experiences and thoughts defines this "mental time." Physical and mental time are similar.

Physics, Quantum Physics and String Theory

An atom has a nucleus made up of neutrons and protons; electrons surround that core at a distance. Atoms can combine into molecules when the negatively charged electrons in one atom feel the attraction of the positively charged protons in another atom. The protons in the nucleus repel one another due to their positive charge, but the "strong nuclear force" holds them together. Breaking atoms down to smaller particles led physicists to wonder if they could be further broken down. Testing discovered more than 200 other particles. These new particles have a quality called "strangeness," in that you can produce positively charged particles only if you simultaneously produce negatively charged ones. Studying electric charges raises the philosophical question: Can you know "things-in-themselves," or can you know only their observed properties?

> "Though we never actually see the virtual activity that is causing the dark energy, the dark energy is expected to be there."

One theory defining contemporary physics is quantum physics, which has a paradox at its core concerning the nature of light. Ancient Greek observers argued that "light was made up of particles," while 17th-century thinkers Christian Huygens and Robert Hooker thought that light was a wave. Their contemporary, Isaac Newton, endorsed particles. Decades later, Thomas Young showed that light definitely displayed wave properties. Young shone light through two thin openings. The light produced brighter and darker areas due to waves of illumination interfering with one another. Particle theory suffers a troubling contradiction: When light hits metal, electrons are emitted, as if light were "a stream of particles."

> "The idea that all we can talk about are probabilities is not very satisfactory."

Albert Einstein's work on the "photoelectric effect" led to the "wave-particle duality." Light sometimes behaves like a wave and sometimes like a particle. When light moves through an opening, you can't predict where individual photons will strike; you only know the most probable locations. Nor can you know where an individual electron is, because observing the electron interferes with it. So, you can know either its location or its momentum, but not both. This is "Heisenberg's uncertainty principle." Physicists understand how to apply quantum theory to solve scientific problems, but the actual relationship of quantum theory to the real world is problematic.

A Theory of Everything?

Quantum theory forces a shift in the accepted definition of science. Formerly, you could understand science as analyzing the world as it is. Scientific truths described reality. Now, they're what scientists observe when they look at reality. "Schrödinger's cat experiment" gives this shift vivid form. Imagine that you've sealed a cat in a chamber with a radioactive substance. You can't see into the chamber, but you've rigged it so that if one atom of the radioactive substance decays, emitting an alpha particle, it will kill the cat. Under quantum theory, you can't know if the cat is alive or dead; all you have are probabilities. So you can treat the cat as a shifting mix of alive and dead. This makes mathematical sense, but you know that in the "real" world the cat is either alive or dead. Speaking in terms of "partial life" does not compute in everyday experience.

> "What we write down in the textbooks is not a description of the world...but a description of us looking at the world – interacting with the world."

Physicists use two master theories to explain the physical world. They use quantum theory to describe very small items ("subatomic particles"), and they use relativity to discuss "the large and massive." But the two theories may not be compatible. To make them fit together, you'd need "a combined theory of quantum gravity." At present, the nearest theory to that is "string theory," which argues that rather than being composed of particles, matter is made up of "tiny infinitesimally thin one-dimensional strings." These strings are "under tension" and vibrate at different frequencies depending on that tension.

> "When it comes to understanding things-in-themselves – whether it be space, time or properties of matter – we [are] up against a barrier of the knowable."

String theory argues that the qualities scientists observe in any specific particle are not generated by it being a new or different particle, but by the observing of strings under different circumstances. These strings would be around a Planck length long – small, but large enough to "smear out the quantum fluctuations" and provide a "bridge between quantum theory and general relativity." However, using string theory generates "imaginary mass" for some particles and thus posits extra spatial dimensions to account for all the observed qualities of mass. Another theory, also speculative, is "M-theory" ("M" stands for "membrane" or "meta"), which argues that rather than strings, you should imagine "two-dimensional membranes." M-theory also requires multiple dimensions (11 spatial dimensions, plus time). The goal in all this speculation is to produce a "Theory of Everything": one unified theory that explains everything and fits it all together fully.

About the Author

Russell Stannard is an emeritus professor of physics at the United Kingdom's Open University.