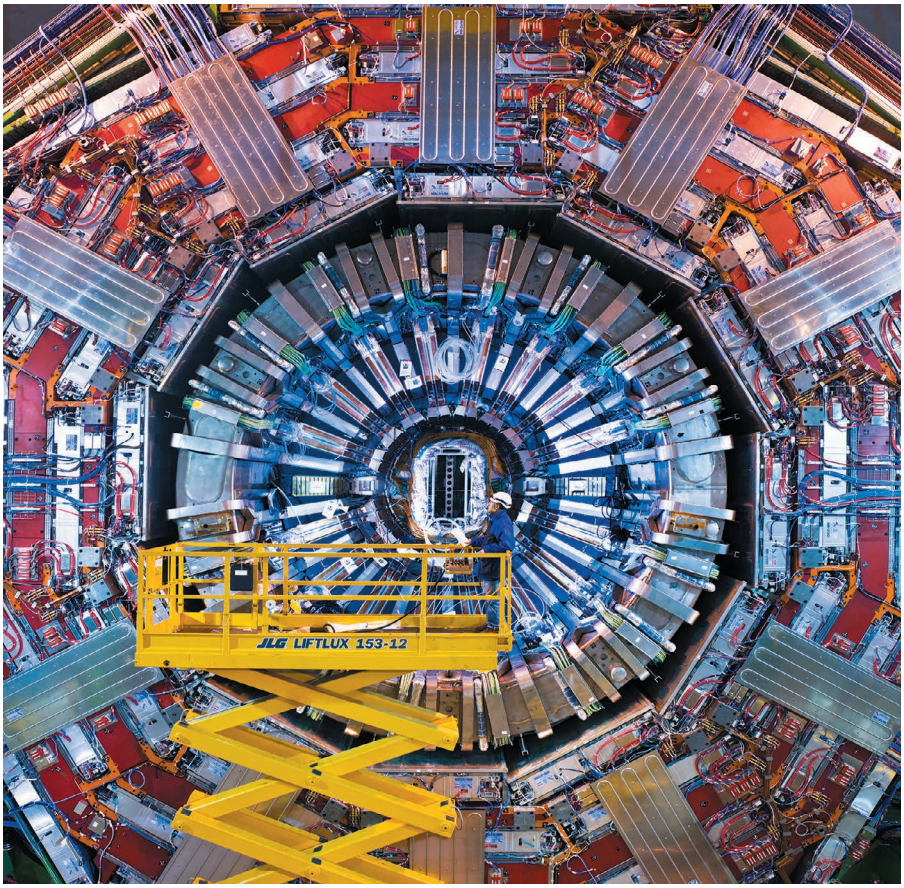


MAXIMILIEN BRICE/CERN

The Large Hadron Collider at CERN has ruled out many elegant physics theories.

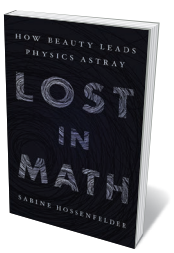
THEORY

Beauty, proof and the crisis in physics

Anil Ananthaswamy parses Sabine Hossenfelder's analysis of why the field is at an impasse.

"Why should the laws of nature care about what I find beautiful?" With that statement, theoretical physicist and prolific blogger Sabine Hossenfelder sets out to tell a tale both professional and personal in her new book, *Lost in Math*. It explores the morass in which modern physics finds itself, thanks to the proliferation of theories devised using aesthetic criteria, rather than guidance from experiments. It also charts Hossenfelder's own struggles with this approach.

Hossenfelder — a research fellow specializing in quantum gravity and modifications to the general theory of relativity at the Frankfurt Institute for Advanced Studies in Germany — brings a trenchant new voice to concerns that have been rumbling in physics for at least two decades. In 2006, Lee Smolin's *The Trouble with Physics* and Peter Woit's *Not Even Wrong* fired the first salvos at the trend of valuing mathematical elegance over empirical evidence. Both books took on string theory, a 'theory of everything' in which the fundamental constituents of nature are strings vibrating in many more spatial dimensions than the familiar three. Since its entry into mainstream physics in the mid-1980s, the theory has failed to make predictions that would unambiguously verify or falsify it.



Lost in Math: How Beauty Leads Physics Astray
SABINE HOSSENFELDER
Basic (2018)

Hossenfelder, too, tackles string theory, but her broadsides are more basic. She points to the paucity of experimental data, exacerbated as the machines needed to probe ever higher energies and smaller distances become more costly to build. Given that, she is worried that too many theorists are using mathematical arguments and subjective aesthetics to judge a theory's validity.

For example, Hossenfelder questions the desire for naturalness — the idea that a theory should not be contrived or have parameters that have to be fine-tuned to fit observations. The standard model of particle physics feels like such a contrivance to many physicists, despite its spectacular success in predicting particles such as the Higgs boson, discovered at the Large Hadron Collider (LHC) at CERN, Europe's particle-physics laboratory near Geneva, Switzerland. In the theory, to prevent the mass of the Higgs from ballooning beyond reasonable bounds, certain parameters have to be set just so, rather than be derived from first principles. This smacks of unnaturalness.

To get rid of this ugliness, physicists developed supersymmetry — an elegant theory in which every known particle has a hypothetical partner particle. Supersymmetry made the Higgs mass natural. It also showed how three of the four fundamental forces of nature would have been one at energies that existed shortly after the Big Bang (an aesthetically pleasing scenario). It even unexpectedly provided a particle, the neutralino, that could explain dark matter — matter that is unseen, yet thought to exist because of its observed gravitational effect on galaxies and galactic clusters. Hossenfelder explains that in combining everything that theoretical physicists value (symmetry, naturalness, unification and unexpected insights), supersymmetry has become "what biologists fittingly call a 'superstimulus' — an artificial yet irresistible trigger".

But despite decades of theorizing by hundreds of top-notch physicists, everyone agrees that supersymmetry is in trouble. The most natural version of it, which requires no fine-tuning, has been ruled out by the LHC data. Hossenfelder quotes theorist Nima Arkani-Hamed as saying that the "best people" were aware of this problem well before the LHC went online. Hossenfelder then chides those very "best people" — no names are given — for not calling "bullshit" on widespread claims that the LHC would discover supersymmetry or dark matter.

Hossenfelder often wears a journalist's hat. Interviews with highly respected physicists (such as theorist Garrett Lisi and Nobel laureates Steven Weinberg and Frank Wilczek) form a significant chunk of *Lost in Math*, as Hossenfelder strives to make sense of the field and her own dissatisfaction with it. We are introduced to myriad problems that plague physics, such as the fine-tuning of the standard model, the lack of a theory of quantum gravity, and

worries about what quantum mechanics is really saying about the nature of reality. (Full disclosure: the latter is the topic of my forthcoming book *Through Two Doors at Once*, which Hossenfelder has endorsed). Hossenfelder also worries about the lack of empirical evidence to sift through in checking the solutions (see N. Wolchover *Nature* **555**, 440–441; 2018).

She reproduces many of her discussions with physicists at length, so the material can get a tad repetitive. She could have used her own strong voice to synthesize some of the arguments. Still, there are moments when Hossenfelder's journalistic forays stand out. For example, her account of meeting the intimidating Weinberg, who "talks like a book, almost print-ready", is self-deprecatingly funny and spot-on (I speak from personal experience).

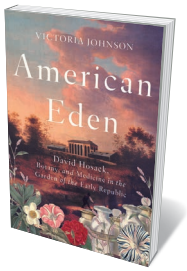
"Despite decades of theorizing, everyone agrees that supersymmetry is in trouble."

Lost in Math is self-aware and dosed with acerbic wit, and it asks bold questions. Hossenfelder's Twitter followers and readers of her blog, 'Backreaction', will recognize her no-holds-barred style. But not all physicists will agree with her. Theorizing in the absence of empirical data is not new, and has paid dividends. For instance, in the early 1960s, the physicist Murray Gell-Mann used symmetry to tidy up the standard model and predict the existence of particles he called quarks. The mathematics turned out to be correct, and he won the 1969 physics Nobel prize for the work. As he noted at the Nobel banquet: "The beauty of the basic laws of natural science, as revealed in the study of particles and of the cosmos, is allied to the litheness of a merganser diving in a pure Swedish lake."

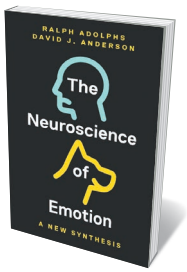
Hossenfelder acknowledges all this, but she also challenges those who seek to break the current impasse in physics by insisting that nature must be forever beautiful. Admitting that "complaining about aesthetic biases" won't make the daunting problems in physics go away, she argues for a few ground rules. These include making sure that there is a real problem, which emerges from existing conflicts in theory and data; being clear about one's assumptions (such as the desire for naturalness or simplicity); and using empirical evidence to choose the right maths for the physics at hand. They are her compass points to prevent us from losing our way in a mathematical jungle, however beautiful. ■

Anil Ananthaswamy's *next book,* Through Two Doors at Once, *tells the story of quantum mechanics from the perspective of the double-slit experiment.*
e-mail: anil@nasw.org

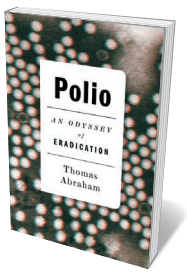
Books in brief



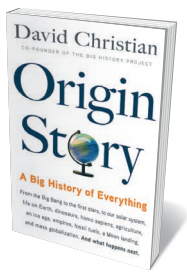
American Eden
Victoria Johnson LIVERIGHT *(2018)*
In the 1760s, colonial America was ravaged by yellow fever, typhus and tuberculosis. David Hosack, born into that world, became a titan of medical research in the fledgling nation. He published on tetanus and breast cancer, pioneered smallpox vaccination and, as Victoria Johnson's fine science biography reveals, contributed vastly to medicinal botany. Hosack's famed, now lost, Elgin Botanic Garden in New York City became a key training centre for scientists and surgeons, who peered "into the globe-spanning, dizzying complexity of the natural world" through plants. A rich and compelling read.



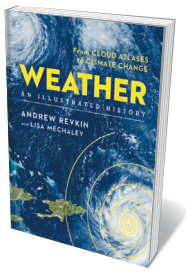
The Neuroscience of Emotion
Ralph Adolphs and David J. Anderson PRINCETON UNIVERSITY PRESS *(2018)*
Anger, fear, joy: what are emotions, and what are they for? The sparsity of clear or robust answers spurred neuroscientists Ralph Adolphs and David Anderson to frame an integrated science of emotion. The result is scholarly, lucid and pertinent to both neurobiology and psychology. Mining research from the molecular level to the cognitive, they examine emotions as biological and reflective of evolved adaptations in species as varied as rodents, the fruit fly *Drosophila melanogaster* and *Homo sapiens*. They usefully conclude with open questions for future research.



Polio: The Odyssey of Eradication
Thomas Abraham HURST *(2018)*
Despite the 99% reduction in polio cases since 1988 under the Global Polio Eradication Initiative (GPEI), the disease lingers on in a handful of countries. Meanwhile, vaccine-derived polioviruses have triggered outbreaks elsewhere. Science journalist Thomas Abraham travelled from slum to boardroom to research the GPEI's premise and practice, as well as the broader trajectory of the disease and the efforts to tackle it. The result is a trenchant, well-argued analysis, isolating problems such as the initiative's strategic focus on single vaccinations in regions also riddled with malaria and diarrhoea.



Origin Story: A Big History of Everything
David Christian LITTLE, BROWN *(2018)*
Historian David Christian is, with Bill Gates, co-founder of the Big History Project, an online syllabus stretching from the beginnings of the cosmos to human hegemony. Here, Christian distils that 13.8-billion-year chronicle by simplifying the mapping. Each threshold, such as the Big Bang or the lunar landings, is beautifully captured. Heat energy becomes a "drunken traffic cop"; gravity the "virtuoso chain-saw sculptor" of the early Universe; humans uniquely "cultivate and domesticate" information, like farmers. Long-haul science with wit and oomph.



Weather: An Illustrated History
Andrew Revkin and Lisa Mechaley STERLING *(2018)*
This fascinating chronicle of humanity's complex relationship with weather by environmental journalist Andrew Revkin and science educator Lisa Mechaley is told through 100 milestones, each paired with a stunning archival image. A potted history of windscreen wipers sits next to a 1903 schematic of Mary Anderson's invention; an image of eleventh-century Chinese scientist Shen Kuo faces his prescient observation of climate change; and a dramatic illustration of a waterspout accompanies Benjamin Franklin's bizarre account of chasing and whipping a whirlwind in 1755. **Barbara Kiser**