MATHEMATICS

Modern math meets fairy-tale physics

No longer seen as a simple tool, today's math is a font for new ideas in theoretical physics

By **Andrew Robinson**

When Charles Darwin published his theory of evolution by natural selection, he used only words—no mathematics. The same was true of Alfred Wegener's first description of his theory of continental drift. Even Dmitri Mendeleev's first publication of the periodic table used no mathematics, merely a simple numbering system for the chemical elements.

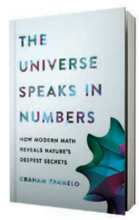
In physics, by contrast, sophisticated mathematics played an integral part in the publication of Isaac Newton's laws of motion; James Clerk Maxwell's analysis of electromagnetism; Albert Einstein's theory of relativity; and the quantum mechanics of Paul Dirac, Werner Heisenberg, and Erwin Schrödinger.

The proper—and hence, productive—relationship between physics and mathematics is a decades-old preoccupation of theoretical physicist Graham Farmelo, as captured in his new book, *The Universe Speaks in Numbers*. He is the author of *The Strangest Man*, a widely admired biography of Dirac, a physicist with an unusual college education—first as an undergraduate in engineering, then as an undergraduate in mathematics—who revolutionized quantum physics in the 1920s. Noting the common theme that runs across his own body of work, Farmelo writes of his most recent project, "I feel I've been working on this book all my life, or at least since I was about eleven years old."

The physics-mathematics relationship is complex and controversial, as evidenced by the ongoing debates between physicists about string theory, which Farmelo dramatizes in the second part of the book, assisted by his personal familiarity with many of the participants. This highly mathematical, extradimensional framework has yet to receive experimental support because of the high energies required to test it. Nevertheless, string theory impresses the majority of today's leading theoretical physicists, many of whom work with mathematicians.

Yet, as Farmelo confesses, "Ashamed though I am to admit it," when in 1976 he first heard a mathematician (Michael Atiyah) address a gathering of physicists, "I believed—and even hoped—that this overlap between mathematics and physics was of only academic interest, destined to be a footnote in the history of both subjects."

Einstein changed his mind about the ranking of mathematics in physics over three or four decades, as Farmelo reveals in an excellent historical section covering Newton to the 1970s. While developing his 1905 special theory of relativity and his quantum theory, Einstein regarded mathematics as a tool, not as a source of ideas. But later, while struggling with his general theory of relativity, mathematical concepts such as Bernhard Riemann's geometry of curved space provided Einstein with crucial new ideas. Even so, his loyalty remained with physics. In 1921, he wittily remarked: "As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality."



The Universe Speaks in Numbers
Graham Farmelo
Basic Books, 2019.
332 pp.

However, from the late 1920s until his death, while Einstein was searching for a unified field theory of gravity and electromagnetism, mathematics alone struck him as capable of explaining the structure of the universe. In 1933, he provocatively told an Oxford audience in a lecture, "On the method of theoretical physics"—note his use of "the"—"It is my conviction that pure mathematical construction enables us to discover the concepts and the laws connecting them which give us the key to the understanding of the phenomena of nature."

During this period, Einstein was generally criticized for his lack of interest in new experimental data from nuclear physics, his lack of sympathy for quantum mechanics, and his obsession with mathematics. Farmelo sympathizes with Einstein's controversial 1933 claim, while adding that pure mathematical construction must be consistent with relativity and quantum mechanics. But honesty compels him to admit that the dearth of new experimental data in recent years, including that from the Large Hadron Collider at CERN, is dispiriting. As Steven Weinberg tells him gloomily, "There are first-rate theoretical physicists today who have never had the experience of comparing one of their predictions with an experimental observation."

But this dearth should not trigger theoreticians to downgrade experiments, Farmelo concludes. "If theories in physics, or in any other branch of science, ever become mere social constructs, their merits decided by people alone, the discipline will be doomed to return to the dark ages of pure metaphysics." ■

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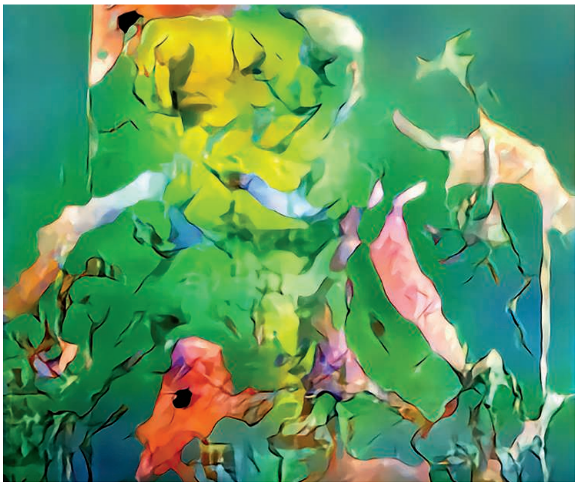

Green Genesis was created in 2018 by "AICAN," an "artificial intelligence artist" developed at Rutgers University.

PODCAST

The Creativity Code
Art and Innovation in the Age of AI
Marcus du Sautoy
Belknap Press, 2019. 320 pp.

When asked about the origins of an evocative piece of music, a composer is likely to focus on structure and pattern, asserts mathematician Marcus du Sautoy. So why not enlist the help of an algorithm? This week on the *Science* podcast, du Sautoy explores the concept of creativity, comparing human and artificial intelligence to reveal how we can make the most of machine learning. sciencemag.org/podcasts

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