under physicist and Nobel laureate William Henry Bragg, studying small molecules such as tartaric acid. Moving to the University of Leeds, UK, in 1928, Astbury probed the structure of biological fibres such as hair. His colleague Florence Bell took the first X-ray diffraction photographs of DNA, leading to the "pile of pennies" model (W. T. Astbury and F. O. Bell *Nature* **141**, 747–748; 1938). Her photos, plagued by technical limitations, were fuzzy. But in 1951, Astbury's lab produced a gem, by the rarely mentioned Elwyn Beighton. Using wet DNA fibres, he took images revealing the black-cross diffraction pattern characteristic of helical molecules. They were never published, and Astbury did not follow up on them; if he had, the story of DNA might have been very different.

Many other "lost heroes" emerge in Williams's telling. Martin Henry Dawson and James Lionel Alloway made important contributions to Oswald Avery's demonstration that DNA probably made up genes. H. F. W. Taylor, C. J. Threlfall and Michael Creeth crucially participated in J. Masson Gulland's work showing that DNA solutions changed viscosity owing to the rupture of hydrogen bonds between nucleotides. All is scrupulously documented in more than 50 pages of notes.

Although there is little Williams can add to the intensely scrutinized narrative on the double helix itself, he clarifies key issues. He points out that the infamous conflict between Wilkins and chemist Rosalind Franklin arose from actions of John Randall, head of the biophysics unit at King's College London. He implied to Franklin that she would take over Wilkins' work on DNA, yet gave Wilkins the impression she would be his assistant. Wilkins conceded the DNA work to Franklin, and PhD student Raymond Gosling became her assistant. It was Gosling who, under Franklin's supervision, took the iconic X-ray diffraction 'Photograph 51'. Williams debunks the myth that Wilkins "stole" it; he clarifies how, before moving on to Birkbeck, University of London, Franklin gave her materials and data on DNA to Gosling, to pass on to Wilkins to use as he wished. It was after this that Wilkins showed Photograph 51 to James Watson, who, with Crick, used it to uncover the double helix.

There are a few errors — inevitable in a book of such scope. Williams writes, for instance, that biochemist Linus Pauling took a "surprisingly long time" to recognize that his proposed three-strand structure of DNA was wrong. In fact, at a meeting before the publication of the true, two-strand structure (J. D. Watson and F. H. C. Crick *Nature* **171**, 737–738; 1953), Pauling remarked that the discovery "may turn out to be the greatest development in the field of molecular genetics in recent years". And, on occasion, the scope is too broad. The tragic figure of Nikolai Vavilov, the great Soviet plant geneticist of the early twentieth century who perished in the Gulag, features prominently, but I am not sure how relevant his research is here. Yet pulling such figures into the limelight is partly what distinguishes Williams's book from others.

What of those others? Franklin Portugal and Jack Cohen covered much the same ground in the 1977 *A Century of DNA*, but that now seems dated. James Schwartz's *In Pursuit of the Gene* (2008) hardly touches on biochemistry, whereas Siddhartha Mukherjee's 2016 *The Gene* devotes little space to the backstory of the double helix.

Isaac Newton wrote to natural philosopher Robert Hooke that he had seen further than others only by standing on the shoulders of giants. *Unravelling the Double Helix* looks beyond giants to the many researchers, now half-forgotten, whose contributions paved the way for an icon of science. ■

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PARTICLE PHYSICS

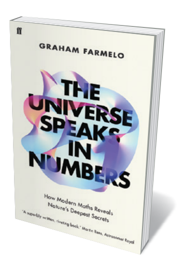
A singing, dancing Universe

Jon Butterworth enjoys a celebration of mathematics-led theoretical physics.

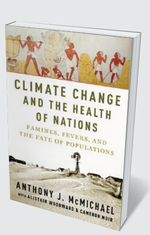
Mathematics is an immensely powerful tool for understanding the laws of the Universe. That was demonstrated dramatically, for instance, by the 2012 discovery of the Higgs boson, predicted in the 1960s. Yet an ongoing, often fervid debate over the direction of theoretical physics pivots on the relationship between physics and maths — specifically, whether maths has become too dominant.

The worry — expressed by a number of theorists and writers over several decades — is that theoretical physics has become a monoculture too focused on a small clutch of concepts and approaches. Those include string theory, overstated predictions of new discoveries, over-reliance on mathematical elegance as a guide and a general drift into what physicist and writer Jim Baggott, in *Farewell to Reality* (2013), called "fairy-tale physics", divorced from its empirical base. Notable critiques have come from theoretical physicists including Peter Woit, Lee Smolin and, more recently, Sabine Hossenfelder (see A. Ananthaswamy *Nature* **558**, 186–187; 2018). Science writer Graham Farmelo clearly intends *The Universe Speaks in Numbers* as a riposte.

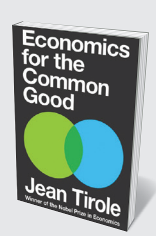
Farmelo takes us on a tour through the ▶



The Universe Speaks in Numbers: How Modern Maths Reveals Nature's Deepest Secrets
GRAHAM FARMELO
Faber & Faber (2019)



Climate Change and the Health of Nations
Anthony J. McMichael OXFORD UNIV. PRESS *(2019)*
In this posthumously published volume, epidemiologist Anthony McMichael journeys through the deep history of Earth's changing climate and its human implications — such as agricultural collapse resulting from shifts in temperature. A book with echoes for today.



Economics for the Common Good
Jean Tirole PRINCETON UNIV. PRESS *(2019)*
French economist Jean Tirole's deft study (translated by Steven Rendell) questions his discipline's role in society. Researchers, he argues, should become socially responsible, probing issues beyond the euro's stability, such as climate change and resource distribution.

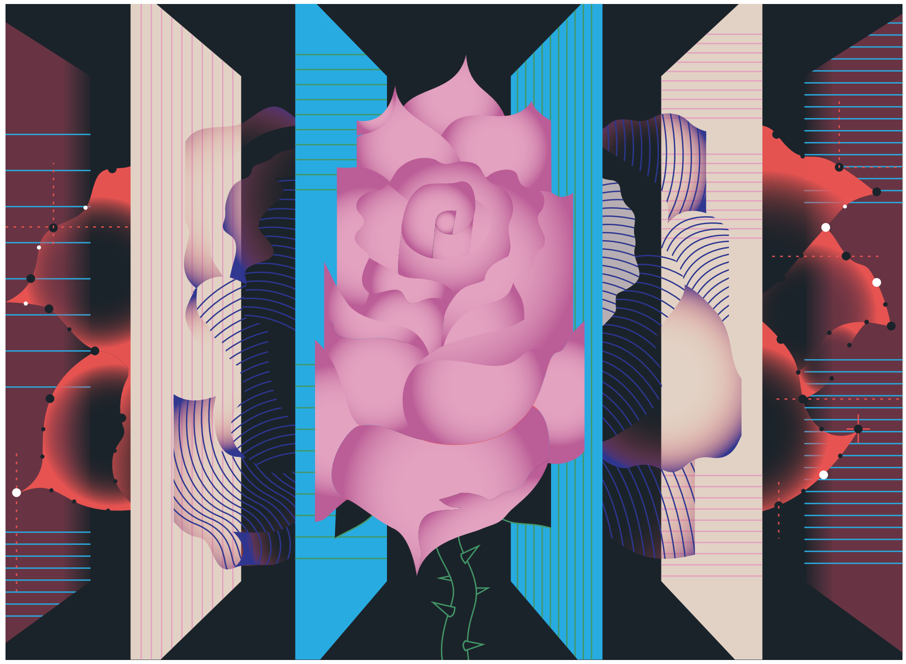
history of the field. His main protagonists are James Clerk Maxwell, Albert Einstein and Paul Dirac (subject of Farmelo's outstanding 2009 biography, *The Strangest Man*). The unification of electricity, magnetism and light in Maxwell's equations is a highlight of any good physics degree. I suspect most physicists can remember the moment when, after a few algebraic tricks with currents and voltages, the speed of light appeared, as if by magic. The Universe isn't just speaking in numbers: it's singing and dancing.

That constant value of the speed of light led to Einstein's special theory of relativity in 1905. From this, in an amazing conceptual (and mathematically abetted) leap, Einstein conjured up general relativity in 1915 (see page 306), then the curvature of space-time, and eventually the gravitational waves discovered by the Laser Interferometer Gravitational-Wave Observatory (LIGO) 100 years later. And in 1928, Dirac, demanding mathematical consistency between quantum mechanics and special relativity, gave us both an understanding of the spin of the electron — without which the periodic table of the elements makes no sense — and predicted the existence of antimatter, discovered experimentally a few years later.

These are brilliant successes of the mathematical approach, and Farmelo leads us through them adeptly, with a mixture of contemporary accounts and scientific insight. He also casts a sceptical eye on the stories the players tell about themselves — and here the tensions start to be felt. Take Einstein's warning to those who want to learn about theoretical physicists' methods: "Don't listen to their words, fix your attention on their deeds." As Farmelo recounts, this is given interesting context by studies of Einstein's notebooks, showing how he later overstated the role of mathematics, and underplayed that of physical insight, in his own breakthrough.

A PRODUCTIVE UNION

Farmelo's argument is that mathematics and physics work effectively together, to the benefit of both. Dirac and Einstein were evangelists for mathematically led physics, but their pleas were more or less ignored by their younger colleagues, such as Richard Feynman and Steven Weinberg, who were developing the standard model of particle physics. During what Farmelo calls "the long divorce" between mathematics and theoretical physics from the 1930s to the 1970s, our current understanding of fundamental physics was assembled. Dirac and Einstein were hardly involved in those developments.

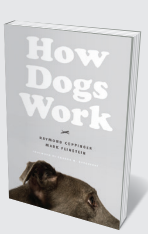


That the most fruitful period in the development of particle physics coincided with its estrangement from pure mathematics could be seen as undermining Farmelo's case. However, the pace of progress probably had more to do with the rapid experimental advances of the time than with any intrinsic issue in the relationship between the two subjects.

This was a fertile patch for experimentation, and theorists were continually buffeted by new and startling results, from the appearance of the muon to the observation of structure inside the proton; these demanded explanation. Although the few mathematical physicists engaged in the field, notably Freeman Dyson, made important contributions, most physicists didn't need to go beyond well-established mathematical techniques to progress. Dyson himself (quoted by Farmelo) says that "we needed no help from mathematicians. We thought we were very smart and could do better on our own." And, as Farmelo puts it, the feeling was mutual: physicists "rarely generated ideas that were of the slightest interest to mathematical researchers". Many on both sides of the divorce were content with the situation.

MATHEMATICS AND PHYSICS WORK EFFECTIVELY TOGETHER, TO THE BENEFIT OF BOTH.

There has been a re-engagement since the 1980s. In the mainstream of particle physics, theorists and experimentalists were calculating and confirming multiple results that established the standard model as, at the very least, a remarkably precise 'effective theory'. But others, led by luminaries such as Michael Atiyah, Edward Witten and pioneers of



How Dogs Work
Raymond Coppinger & Mark Feinstein
Univ. Chicago Press *(2019)*
Cognitive scientists Raymond Coppinger and Mark Feinstein explore the biological basis of canine behaviour and its interplay with the environment, examining everything from dogs' wildly varying morphologies to why they bark.

Listening In: Cybersecurity in an Insecure Age
Susan Landau Yale Univ. Press *(2019)*
Digitization, notes mathematician Susan Landau, offers amazing potential and convenience — at the cost of privacy and a need to ramp up security. She issues both a warning to protect data, and a call to modify how much control we relinquish in our cyber-reliance.

string theory including Michael Green and John Schwarz, were probing its mathematical boundaries.

Whether the mathematical approach eventually became too dominant, taking over in terms of academic recognition and funding, is the crux of much of today's debate. Farmelo gives a lively description of the back-and-forth of contributions typical of any thriving interdisciplinary area, with physical problems stimulating mathematical breakthroughs and mathematics throwing up new insights and techniques in physics. He steers clear of discussing the infeasibly large 'string landscape' of possible physical theories to which the mathematical approach seems to have led — contrary to hopes of a unique 'theory of everything'. Instead, he concentrates on developments more directly useful and testable in physics, where some of this mathematical sophistication begins to feed back into an understanding of the standard model.

The standard model is a complex, subtle and immensely successful theoretical structure that leaves significant questions unanswered. Farmelo makes a convincing case that, in attempting to answer those questions, mathematics has a crucial role. Yet whether theoretical physics has become too enamoured of beautiful mathematics will, I suspect, remain a topic of hot debate.

The long experimental search for the Higgs was motivated by the fact that, before we accepted the existence of a quantum energy field that fills the whole Universe — part of the theory that predicted the particle — we demanded more evidence than 'it makes the maths come out right'. The need for evidence is even stronger if the argument is 'it makes the maths look beautiful'. The Universe might speak in numbers, but it uses empirical data to do so. ■

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HISTORY

England's Galileo

Georgina Ferry relishes a biography of the formidable Moon-mapping Tudor scientist Thomas Harriot.

Thomas Harriot: A Life in Science
ROBYN ARIANRHOD
Oxford University Press (2019)

The phrase 'publish or perish' came into use in the twentieth century to encapsulate academic pressures. It is also a lesson from the life of Thomas Harriot, who lived when there were no academic journals, and who never taught at a university.

A contemporary of William Shakespeare, Harriot was an English mathematician, astronomer and natural philosopher whose original work bears comparison with that of Johannes Kepler and Galileo Galilei. Yet, outside the enthusiastic circle of historians of early modern science who call themselves Harrioteers, his name is almost unknown: he never published his mathematical work. In *Thomas Harriot: A Life in Science*, mathematician Robyn Arianrhod sets out to explain how historians have nevertheless been able to place him, almost four centuries after his death in 1621, among the founders of modern science.

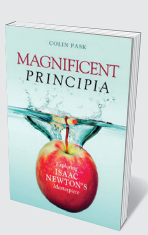
Harriot is elusive. The earliest known document concerning him lists him as a "plebeian" scholar registering to study at the University of Oxford in 1577. He never married and left no children. By 1583, he was employed by Walter Raleigh, naval commander, explorer and favourite of Queen Elizabeth I, to teach astronomy and navigation — a field he greatly improved — to sea captains. He was celebrated in his lifetime by the writer Gabriel Harvey as among the "profound mathematicians", alongside Thomas Digges and John Dee. Afterwards, he was largely forgotten.

He has a higher profile in the United States, thanks to the one work he did publish. *A Brief and True Report of the New Found Land of Virginia* is a first-person account of a 1585–86 voyage sent by Raleigh to survey what is now part of North Carolina. The party landed on Roanoke Island and surveyed it and the nearby mainland; almost all its members returned to England in June 1586. Harriot was "employed in discovering". His report, published in 1588, includes the first detailed English description of the language and customs of the Algonquian people, and of the region's natural resources and climate. Arianrhod shows that his interest in local people was far from typical: he learnt their language, admired how they interplanted beans, squashes and maize (corn), and respected their religion. Meanwhile, the military expedition leaders fatally soured relations by overreacting to perceived wrongdoing and making unreasonable demands.

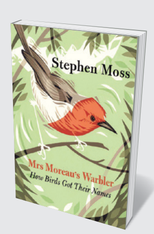
Previous biographers — the US authors Henry Stevens in 1900 and John Shirley in 1983 — were prompted by the *Brief and True Report*. Neither fully addressed Harriot's scientific contributions, as Arianrhod tries to do. Harriot's will mentioned a trunk full of mathematical papers. A few were circulated and partly published by friends such as the mathematician Walter Warner after his death, but what became of the collection was unknown until 1784, when it turned up in some disorder at Petworth House, home to heirs of the ninth Earl of Northumberland, Harriot's patron after Raleigh. Only since the mid-twentieth century have scholars made sense of the thousands of manuscript sheets.

What they reveal is astonishing. To mention only a portion of Harriot's work, he discovered Snell's law of refraction two decades before mathematician Willebrord Snell; formulated laws of motion and falling bodies independently of Galileo and decades before Isaac Newton; produced the first drawing of the Moon through a telescope and made important observations of sunspots, again independently of Galileo; played with binary arithmetic nearly a century before Gottfried Wilhelm Leibniz; and was the first to develop fully symbolic algebra. There are well-grounded suspicions that René Descartes saw some of Harriot's papers before publishing *The Geometry* in 1637.

Where Harriot falls down, say some ▶



Magnificent *Principia*
Colin Pask PROMETHEUS *(2019)*
Isaac Newton remains a giant of physics, as his 1687 *Principia* confirms. Maths historian Colin Pask presents an easily digestible guide to the work, enlivened with passages from Newton's life. An invitation to wonder at what some see as the greatest single scientific book ever published.



Mrs Moreau's Warbler
Stephen Moss FABER *(2019)*
Names make sense of the world; they also reveal something about us. Stephen Moss unveils the often surprising roots of avian etymology and offers insight into fierce, long-standing debates such as that over *Prunella modularis,* variously known as the dunnock and hedge sparrow.