


Isaac Newton (left) and Gottfried Wilhelm Leibniz each independently invented calculus.

MATHEMATICS

The calculus chronicles

Anil Ananthaswamy savours a history of the field tracking change in everything from DNA to AI.

Midway through *Infinite Powers*, Steven Strogatz writes that Isaac Newton and Gottfried Wilhelm Leibniz both "died in excruciating pain while suffering from calculi — a bladder stone for Newton, a kidney stone for Leibniz". It was a cruelly ironic end for the scientists who independently invented calculus: the word comes from the Latin for 'small stone', in reference to pebbles once used for counting.

Such fascinating anecdotes abound in *Infinite Powers*. Strogatz, a mathematician working in nonlinear dynamics and complex systems, has written a romp through the history of calculus — the study of how things change. Starting with the ancient Greeks, the book ends with connections between the field and artificial intelligence and machine learning. Calculus was key to working with Newton's laws of motion, which stimulated the Industrial Revolution. It is also central to quantum mechanics, which underpins the modern revolution in computers and communications. The book is a roll call of luminaries, including Galileo Galilei, Johannes Kepler, René Descartes and Pierre de Fermat.

Strogatz's telling is very much that of an applied mathematician: he acknowledges that a historian or pure mathematician might disagree with it. He anchors the story in how the evolution of calculus was intertwined with attempts to understand nature. That is, the geometry of curved lines and surfaces; the study of the planets, accelerating and decelerating in their orbits; and the laws of change (concerning, for example, the flow of fluids).

Infinite Powers: How Calculus Reveals the Secrets of the Universe
STEVEN STROGATZ
Houghton Mifflin Harcourt (2019)

The book's pace varies, slowing down to focus on early groundwork and speeding up to discuss modern applications. It devotes a chapter to classical mathematician Archimedes, including his "heroic" calculations of π, the ratio of a circle's circumference to its diameter. There's an exquisite discussion of his method for expressing the area of a segment of a parabola in terms of the area of a simpler shape made up of straight lines. He broke the problem into smaller and smaller parts — flirting with infinity — and added it all back up to arrive at an answer. This presaged integral calculus. Strogatz then zips through the modern use of such principles in facial surgery and computer animation in films such as *Toy Story* (1995), where surfaces are modelled as composed of smaller and smaller triangles, and volumes as composed of tiny tetrahedrons.

The early-seventeenth-century rivalry between Descartes and Fermat is illuminating. We see them vying to combine geometry and algebra to give us analytical geometry — essential for present-day calculus. We now take for granted graphs that have one variable on the x-axis and the other on the y; back then, it wasn't obvious that you could plot equations in this way. (Descartes, for all his contributions, emerges as mean-spirited and intent on demeaning Fermat.)

The invention of modern calculus by Newton and Leibniz some three decades later makes for snappy reading. Newton comes across as an astonishing genius, but secretive and paranoid. He found a way to calculate areas under curves while still a student at the University of Cambridge, yet was wary of sharing his insights. A few years later, Leibniz, "the most versatile genius in a century of geniuses that included Descartes, Galileo, Newton and Bach", came up with his own methods.

Female scholars, too-often unheralded, are here given their due. African American mathematician Katherine Johnson (featured in Margot Lee Shetterly's 2016 book *Hidden Figures*, and the film of the same name) used calculus to plot the trajectory of US astronaut John Glenn's 1962 Earth orbit (see go.nature.com/2dvorxu). At the turn of the nineteenth century, French mathematician Sophie Germain used a male pseudonym to obtain lecture notes, but was the first woman to win a prize from the Paris Academy of Sciences. She solved the puzzle of Chladni patterns — standing-wave formations on vibrating rigid surfaces. Russian mathematician Sofia Kovalevskaya — the first woman ever to gain a maths PhD (in 1874, at the University of Göttingen in Germany) — showed that calculus has limits, by proving that one can't predict the behaviour of certain physical systems, even if they follow deterministic laws.

Strogatz uses the right amount of technical detail to convey complex concepts with clarity. If you can grapple with simple graphs and algebraic equations, you can grasp the details of the origins, genesis and meaning of calculus and the role of infinity. Anyone who can't might find the going tough.

When it comes to applications, the book occasionally feels forced. Take the invention of the computed tomography scanner. It's true that calculus is essential for inferring and reconstructing the structure of tissue in the path of X-rays, but the physics, materials science and engineering are equally important and exciting.

That said, Strogatz excels when he explains the role of calculus in understanding how DNA coils and twists and how enzymes act on it, and why calculus was essential to modelling how the number of T cells in the immune system infected with HIV changes after patients are given a protease inhibitor. It was calculus that showed the virus could be fought more effectively by three drugs at once, leading to the now-standard triple-drug therapy. If calculus is the "language God talks", as physicist Richard Feynman put it, nowhere is this more obvious than when it meets biology.

Barring a few odd notes, *Infinite Powers* evocatively conveys how calculus illuminates the patterns of the Universe, large and small. ■

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