Newton and Leibniz: Crash Course History of Science #17

Crash Course: History of Science
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The standard story of the Scientific Revolution culminates with the long life of one man: Sir Isaac Newton—a humble servant of the Royal Mint, two-time parliamentarian, and a scientific titan whose name, along with Einstein's, is synonymous with physics today.

But there was also another Isaac Newton. I mean, it was the same guy, but this Newton was very different from the mythic, hyper-rational one.

This Sir Isaac Newton was also an alchemist, obsessed with the occult—with hidden, non-rational truths. And every story's leading character has to have a foil, right? Enter Gottfried Wilhelm von Leibniz, an equally remarkable master of mathematics.

Together, these rival geniuses would change the worlds of math and science forever. [INTRO MUSIC PLAYS] Ike was born prematurely on what was then—it's a long story—Christmas Day in 1642 in the delightfully named hamlet of Woolsthorpe-by-Colsterworth. Which is known for… mostly just being the place where Isaac Newton was born. Newton's family was not well off.

His dad died, and his mom remarried and had a bunch more kids. Farming in rural Lincolnshire? Not fun.

And in school, Ike was bullied. But he discovered that he loved learning, and so, to no one's surprise, he did fine at Trinity College, Cambridge, on scholarship. And by "did fine," I mean that he first dreamed up the mathematical system that would become calculus before he even graduated.

Calculus is the mathematics that describes how a thing change instantaneously, whether that thing is velocity, acceleration, displacement, height, weight, volume, or whatever. It provided a new mathematical connection between displacement, velocity, and acceleration— all of which are required if you want to understand things like planetary motion. This is all the more amazing because Ike was poor, he wasn't tutored at the best schools, and—at the time he went there in 1661—Cambridge was a backwater college.

Fifty years after Bacon's new, experiment-focused science, Cambridge was still teaching Aristotle! In 1666, soon after Newton graduated, Cambridge closed for the year due to fear of the bubonic plague. Newton went back home to Lincolnshire and had what we now call his annus mirabilis or "miracle year." In one year, Newton… discovered the laws of gravity when an apple supposedly fell on his head—although this probably didn't actually happen.

And he laid down the core ideas that would lead to his inventing calculus—or co-inventing it. And he started to develop the theory of light and colors, which holds that white light is made up of seven visible colors. By any measure, Newton had an outstanding 1666.

That was not true of everyone, however: that fall, a Great Fire swept through London for four days, destroying much of the city. Plus, you know, plague. But, like I mentioned, there was another side of this legendary thinker: Newton was a wee bit eccentric.

This almost created a professional problem for him, because for a while, Cambridge required professors to become Anglican priests, and he wasn't exactly an orthodox Christian. Newton thought the Holy Trinity was nonsense. He believed he had unique access to a secret treasure of wisdom—both religious and scientific—passed down from God to Noah, then Moses, then Pythagoras, and then himself.

Newton was also a major alchemist—as were his buddies, Robert Boyle and John Locke. But Newton was obsessed with alchemy, or thinking philosophically about stuff by changing it. While he didn't view alchemy as separate from his more scientific-looking investigations into "what is stuff," he didn't stray far from the alchemical mainstream.

He kept his furnaces burning for days on end, transmuting metals. In fact, the largest section of his complete works concerns alchemy! That said, Newton wasn't interested in trying to turn lead into gold.

He was just trying to understand everything. Newton returned to work at Cambridge in 1667, continuing to work on his revolutionary insights. He first published on optics, in 1672 in the Philosophical Transactions of the Royal Society.

With what became known as his "crucial experiment," Newton showed that light is composed of rays of different colors that can be split using a prism, and that these rays can't be further split by a second prism. And that the color of light can be brought back to white using a mirror. BOOM.

Okay, this may not sound like a mic drop by today's standards. But at the time, there was a lot of debate about the relationship between color and light. Newton theorized that light is made of different colors that are visible only when refracted, or bent.

Newton's fellow science-genius, Robert Hooke, believed that light is wave, whereas Newton, like René Descartes, believed light is a "corpuscle," or particle. Newton's paper on optics earned him membership in the Royal Society. It also proved to be quite controversial.

Many of Newton's peers still believed in an Aristotelian version of optical physics, and others believed in Descartes's version. The debate went on for decades, leading Newton to shun public life. Through his work on optics, Newton also developed the first functional reflecting telescope, using a mirror to focus light.

Newton's work on light was collected in the 1704 book Opticks. By then, Newtonian optics had beaten out its Aristotelian and Cartesian competitors. But that's not all, because it's Newton, so of course it's not.

He concluded Opticks with a series of "queries," or questions. Though they weren't really questions, but rhetorical statements meant to guide further research. In the first edition, there were sixteen queries.

As he continued his own research, Newton added more queries in subsequent editions, up to thirty one. The queries went way beyond optical physics, concerning the nature and transmission of heat, the possible cause of gravity, electricity, how God created matter "in the Beginning," the proper way to do science, and the ethical conduct of human beings. As much as the work on optics itself, these queries influenced science for centuries.

But a new paradigm in optics isn't what Newton is best known for. Nor for making the first calculation of the speed of sound. Nor for all of his other brilliant ideas.

Newton is best known as the person who… one, mathematically perfected the astronomical system of Copernicus, Kepler and Galileo, which we spent two episodes on; Two, mathematically described how gravity works, setting the stage for classical mechanics; and, three, introduced calculus to the world. You may think this is too much to cram into one book—but then you wouldn't be Ike. Newton dropped The Mathematical Principles of Natural Philosophy, or simply Principia, in 1687.

Work on the book began a few years earlier, when Edmund Halley—the astronomer after whom Halley's comet is named—asked Newton about his thoughts about Kepler's model of planetary

motion. How did the sun invisibly control the planets? Newton took a few years, but what he delivered was a book that gave a fairly complete answer.

In fact, almost none of Newton's contemporaries could fully understand Principia, the math was so dense! Principia was made up of three books. It begins with axioms, or core principles.

In the introduction, Newton explains that, if you take his system, you get Galileo's law of falling bodies. Book one focused on the motion of bodies in free space, laying out the core principles of calculus, the branch of mathematics that concerns derivatives and integrals. Newton described how centripetal force works, exploring the implications of his math regarding how objects move.

But Newton discussed calculus in terms of geometry because—remember—no one else had ever heard of calculus before! Book two concerned the movement of bodies in a restricted medium like a fluid, instead of a free space. This was Newton's answer to Descartes, whose system proposed that the planets move through a fluid æther.

Book three, finally, turned to celestial mechanics. Newton specified for the first time that gravity was the force holding all of the planets in their orbits around the sun. With this book, he unified the work of Descartes, Galileo, Kepler, and Copernicus into one mathematically sound system.

This was the first time that natural philosophers in Europe had had a single system for understanding what stuff is and how it moves since Aristotle. Newton's work in math is a good example of a new mechanical intelligibility in science. Mechanical intelligibility is just the idea that a fact about nature is true because we can do stuff with it—say, predict the motions of planets—even if we don't understand what it—like, gravity—really is.

Now, for all the awesomeness that is Newton, the story of the other person who invented calculus is equally impressive. Introduce us, Thought Bubble! Gottfried Wilhelm von Leibniz was born in Leipzig, in what was then the Holy Roman Empire, in 1646.

He wrote his first book, De Arte Combinatoria, or On the Combinatorial Art, at the age of nineteen, in that fateful year, 1666. Leibniz worked on almost every area of natural philosophy—reshaping how libraries work, inventing the mechanical calculator, creating the binary notation that would centuries later be central to computer science, and becoming a major figure in philosophy. Leibniz worked out elements of calculus in 1675, independently of Newton.

And we actually use Leibniz's version, not Newton's! But in 1676, Leibniz traveled to London. This trip would become the primary evidence in the long-standing priority dispute, or argument about who invented calculus first.

The English math posse accused the German of having glimpsed Newton's unpublished notes. What did Leibniz discover back in 1675, over a decade before the publication of Principia? He used integral calculus for the first time in history to find the area under the graph of a function.

Which might not sound impressive, but it is. In doing so, he made up some important notation, or symbols, including the d for differentials and the integral sign, which is a long S standing for the Latin word "summa," or highest. We still use Leibniz's notation today.

But Leibniz didn't publish his calculus until 1684. And he didn't lay out his full theory, expressing the inverse relation of integration and differentiation—AKA the fundamental theorem of calculus—until 1693, well after Principia. This delay, along with a growing rivalry between thinkers from different nations, meant that Leibniz never really got the credit he deserved.

The Royal Society favored Newton from the start. They never gave Leibniz a chance to offer his version of events, ruling in favor of Newton—the Society's president—in 1713. Thanks Thoughtbubble.

Until he died, Leibniz had to fight to prove that he had invented calculus without consulting Newton's notes. And there is still no complete edition of the writings of Leibniz available in English! Now, the role of the Royal Society in this dispute is worth pointing out here, because this was the time when scientific societies were first coming into existence.

These were salons where natural philosophers could debate ideas. The first major scientific society—mentioned in our first episode—was the Royal Society of London, founded in 1660 and given a royal charter in 1662. Here, natural philosophers held weekly discussions.

The Society consisted of elected members or "Fellows of the Royal Society," who add the letters "FRS" after their names. Robert Hooke became the Royal Society's official Curator of Experiments, and Newton served as president between 1703 and 1727. The Royal Society was not alone.

The Academy of Sciences in Paris was established in 1666, based out of the Louvre. The Academy maintained the royal observatories and held public salons. The nearby Royal Garden, founded in 1626 and opened to the public in 1640, also served as a way of spreading new ideas about science.

Importantly, scientific societies functioned as publishers. In addition to journals sharing the latest discoveries, such as the Royal Society's Philosophical Transactions, they printed field-defining books such as Hooke's Micrographia in 1665 and Newton's Principia in 1687. Scientific societies were also a place for debate, including the super unfair one between Newton and Leibniz over calculus.

With the exchange of ideas that scientific societies facilitated, natural philosophy became a public enterprise. Printing and the availability of mail between nations—even rivals, sometimes at war with one another—became crucial for the production of knowledge. But the societies also helped generate a new need in early modern Europe for expert knowledge, by showing the utility of science, securing government patronage, and helping to develop commercial applications for the discoveries of their members.

We can never properly repay Woolsthorpe-by-Colsterworth for its contribution to the history of science. But the bigger point is that Newton was part of a whole scientific culture engaged in lively internal debate about what counts as valid knowledge and what to do with it. By the time Newton left Cambridge to become superintendent of the Royal Mint, in 1696, the paradigm for scientific knowledge production in Europe had definitively shifted away from Aristotle and toward Galileo and Bacon… and Ike and Leibniz.

Next time—get ready to get your phlogist-on—and then gone: we're revolutionizing chemistry with Lavoisier! Crash Course History of Science is filmed in the Dr. Cheryl C. Kinney Studio in Missoula, MT. And it is made possible with the help of all these nice people. And our animation team, is Thought Cafe.

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