

20. EINSTEIN VERSUS GALILEO: THEORIES OF GRAVITY

The first mathematical description of gravity was performed by Italian Galileo Galilei (1564–1642). Galileo, while perhaps best known for his observations with the telescope, also developed the first formulaic description of gravity. In studying gravity, Galileo determined that all objects fall with the same acceleration, no matter what their mass. The motion of a falling body depends on two things: the way in which the body was released, and its initial velocity. Thus, heavy objects fall as fast as lighter objects.

How did Galileo come to these conclusions? Gravity was known from ancient times as an attractive force. However, from the time of the first Greek scientists until the Renaissance, it was thought of as a force that only acted when two objects were touching each other.

Galileo refined this idea by thinking of gravity as a force that attracts any two masses to each other. He did a series of experiments to test his ideas, which involved rolling balls down ramps.

In Galileo's ramp experiments, he rolled balls down a series of ramps that ended above the ground. He then measured the trajectory of the balls after they left the ramp, recording the height at which they were released at the top of the ramp, and the distance they traveled from the bottom of the ramp before hitting the ground.

Galileo also did experiments by dropping objects from a tower. He showed that if he dropped a heavy cannonball and a lighter ball at the same

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time, they hit the ground at the same time. These experiments showed that the acceleration of gravity is independent of the mass of an object.

Of course, if Galileo had chosen to drop two objects of different shape, such as a feather and a cannonball, they would not have reached the ground at the same time. Why? The answer is air resistance, or drag, which is proportional to the surface area of an object. Two objects with the same shape, but different masses, will reach the ground at the same time. However, since a feather has more surface area than a ball, the feather will take more time to reach the ground than a compact object of the same mass. If two objects are dropped in a vacuum, however, they will reach the ground at the same time, independent of surface area, because there is no drag.

Galileo's experiments showed that the acceleration of gravity was the same for all falling objects and that any two objects would hit the ground at the same time if they were not subject to drag. This overturned previous notions, such as those of Aristotle, which assumed that heavier objects fell faster than lighter ones. Galileo's results, however, were purely experimental. He did not provide an explanation for how gravity worked, or any mathematical basis for his theories. Such mathematical formulations would come later, with the work of Sir Isaac Newton.

Galileo was the first to accurately describe the unyielding attraction of gravity, and his work also led to the first reliable methods of timekeeping. His discoveries allowed the creation of accurate pendulum clocks for the first time, since he found that the period of a pendulum, the time that it takes for one swing to take place, stays the same even as the

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system loses energy and the height of the pendulum's swing gets smaller. These discoveries paved the way for Newton's laws of motion and gravity, which more accurately and mathematically described the motion of falling objects. However, it was Einstein who eventually disproved both Galileo's view of a universal gravitational force, with the theory of general relativity, and the invariance of time, in the theory of special relativity. Of course, without Galileo's initial discoveries, Newton and Einstein would not have had theories to build on and disprove.

Galileo is primarily famous for his discovery of the four large satellites of Jupiter, the first celestial bodies proven to be orbiting around a planet other than the Earth. This discovery supported the heliocentric model of the solar system, which placed the sun at the center with all the planets orbiting it, eventually leading to its acceptance. Orbital mechanics was thought to be well understood until the nineteenth century, when it was realized that there was an anomaly in the orbit of the planet Mercury. Einstein finally resolved this paradox in 1915 with his theory of general relativity, which allowed for the distortions of space and time that resulted in the observed advance of the perihelion of Mercury.

21. EINSTEIN'S RESPONSE TO ISAAC NEWTON

Isaac Newton (1642–1727) developed the laws of motion, leading to the law of universal gravitation. Based on his studies of the motion of the moon around the Earth, Newton was able to formulate a theory of gravitation that applied both to the heavenly bodies and to falling objects on Earth.

Always the critic, Albert Einstein would later displace some of Newton's theories. Of particular interest is that, in his formation of special relativity, Einstein would show that space and time were not absolute. Newton had earlier posited that space and time existed absolutely, despite whatever motion or matter was present. Einstein shattered this theory with his pronouncement of special relativity. Without Newton's theories, however, Einstein wouldn't have had anything to respond to, and his concept of relativity might never have surfaced. The debt Einstein owed to Newton, despite challenging his theories, is enormous.

The lives of Newton and Einstein contained a number of parallels. Both were considered poor students early on, and both were thought to be "slow" by their teachers. Einstein and Newton both had a period of marked genius early on in their scientific careers, and both turned to politics and activism toward the end of their lives.

A major similarity between Einstein and Newton is that both their bodies of work were foundational; their research provided the basis for what would come to be modern science. Both Newton and Einstein wrote

formative papers that would both define their work and their legacies. Newton's "Philosophiae Naturalis Principia Mathematica," better known simply as the "Principia," was finished in 1687. It was written in several volumes, including "Of the Motion of Bodies" and "The System of the World." This masterpiece explained Newton's three laws of motion, as well as defining his theory of universal gravitation. Similarly, Einstein wrote three seminal papers in 1905; they were on the photoelectric effect, special relativity, and his formulation of a relationship between mass and energy ($E = mc^2$). These papers became the works Einstein is best known for and helped define his place in history.

Both Einstein and Newton were also interested in a true scientific formulation of gravity. Newton began this study with his law of universal gravity, and Einstein continued the work as he tried to combine gravity with his theory of special relativity. This combination led to the formulation of general relativity. Gravity continues to puzzle scientists today as they continue Einstein's ultimately-unsuccessful quest for a grand unifying theory of physics.

Einstein and Newton were innovators in the truest sense; they used reason and logic to create entirely new ways of viewing the universe. Both set precedents in the field of science and mathematics, and both realized the importance of history in achieving a future.

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25. HOW WAS EINSTEIN LIKE LEONARDO DA VINCI?

To take a step further back in time, Leonardo da Vinci (1452–1519) is yet another example of a famous scientist who didn't allow a disability to stifle his work. Da Vinci was born in Anchio, Italy during the Renaissance. He was a curious child, questioning everything and everyone around him.

Da Vinci had his first internship with Andrea del Verrocchio in 1466. With del Verrocchio, he learned sculpture, painting, metalworking, and other artistic skills. Da Vinci would open his own workshop in the following years and earned his own commissions for paintings and drawings. He would create some of the Renaissance's most famous works, including the *Mona Lisa* and *The Last Supper*.

While often remembered most for his painting, da Vinci was a true Renaissance figure. He used his skills in math and science to develop linear perspective in his two-dimensional work, and these advances would

form the basis for many future breakthroughs in various artistic fields. In his later years, da Vinci devoted more of his time to engineering. He actually worked on a project to re-channel the course of the Arno River. Like Einstein, then, da Vinci applied his immense intelligence and skill to many different areas of interest.

Another similarity between Einstein and da Vinci is that both were reputed to have learning disabilities. Einstein was late in learning to speak and was reputed to have had trouble expressing himself in writing throughout his career. Not that this problem stopped him from making incredible discoveries. He was also, of course, known for his more popular quotations, such as "Imagination is more important than knowledge" and "Gravitation is not responsible for people falling in love."

Leonardo da Vinci is thought to have had a learning disability, dyslexia, which is a condition that makes it difficult for people to learn to read and write. It says nothing of someone's natural intelligence, but can make primary school education a particularly trying process, especially in the fifteenth century when not much was known about this condition. Did his dyslexia slow da Vinci down? Not a chance. It was, however, a fairly significant part of his legacy. Most of da Vinci's handwritten notes that survive today were written backwards. He lettered from right-to-left, as a mirror image of what normal text would be. Many dyslexics share this interesting anomaly, and most aren't aware that they're doing it. This aspect of da Vinci's professional life certainly didn't seem to affect his ability to produce masterpieces that would be some of the greatest ever created.

“The most important thing is to have a good idea.”

Like Einstein, Leonardo da Vinci created world-changing masterpieces. Though their chosen fields were far apart from each other, there was actually some crossover. At various points in his career da Vinci played inventor, creating designs for buildings, machinery, airplanes, canals, and many more (and varied) items. Einstein also had the inventor's streak, producing designs for a noiseless refrigerator, among others; he held several patents for various other inventions, including a gyrocompass and a special airplane gyrocompass. This similarity begs the question: are all geniuses also inventors? Is there something about great minds that drives them to create?

26. HOW WAS EINSTEIN LIKE MICHELANGELO?

Michelangelo Buonarroti (1475–1564) was one of the most prolific artists of the Renaissance. He was skilled in painting, sculpture, poetry, architecture—the list goes on. The “genius” label is generally attributed to Michelangelo for the quality and creativity of his work, but also for the number of different aspects of art that he affected. He would influence the entire course of Western art.

Born in Caprese, a small village in Italy, Michelangelo spent most of his life working in Florence and Rome. In the Renaissance tradition, Michelangelo studied in the workshops of the masters, learning by internship from those who had already succeeded. He studied painting first under the tutelage of Domenico Ghirlandaio, and then studied sculpture in the Medici gardens. In 1498 he produced one of his first

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large-scale sculptures, the *Bacchus*, and, in 1500, he completed *Pieta* for St. Peter's Basilica in Rome.

Returning to Florence, he completed his famous *David* statue in 1504. Choice of subject matter, attention to facial expression, and amazing detail made this one of his most famous works. Michelangelo was called back to Rome in 1505 to work on frescoes for the Sistine Chapel ceiling. His career in architecture took off shortly thereafter; he designed the tomb for Julius II around 1515, the Laurentian Library in the 1520s, and the Medici Tombs between 1519 and 1534.

At this point he took a break from architecture to work on what was probably his most famous painting, *The Last Judgment*, between 1536 and 1541. After the completion of this work he returned to architecture. During this later period of his life, he created some of his signature works such as the Campidoglio (the Roman capitol building) and the Dome at St. Peters, his most famous architectural achievement. His last years were spent on frescoes for the Pauline Chapel in the Vatican.

Though Michelangelo predated Einstein by some 300 years, their lives followed similar paths to greatness. Like Einstein, Michelangelo was incredibly prolific. To some extent, Michelangelo's achievement is more comprehensible—scientific research is a difficult field for producing lots of results on demand. Another similarity is that Einstein's research crossed many interdisciplinary borders and boundaries, much like Michelangelo's.

Michelangelo had the advantage of being historically placed right in

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the middle of the Italian Renaissance (approximately 1420–1600). Italy was one of the focal points of this amazingly prolific period; the developments and achievements of this period went on to influence the entire course of art, science, and politics, and Michelangelo was both a contributor and an absorber of this culture. Similarly, Einstein was theorizing about science and physics as the Industrial Revolution (approximately 1700–1900) was coming to an end; great mechanized inventions were developing and becoming more common, and Einstein was surrounded by the influx of new technology.

Also like Einstein, Michelangelo was recognized as a genius during his own time. Michelangelo's work was acknowledged at the time as being inspired and amazingly well-executed, and history remembers his work in much the same way. Michelangelo was one of the most sought-after artists of the Renaissance for precisely this reason—his reputation preceded him and actually earned him many commissions. Similarly, most people knew Einstein's name during his lifetime because his achievements were of such monumental importance, and Einstein certainly had no lack of job opportunities.