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What Do We Mean by Theory?

In the history of science the word theory has been most successfully employed as *the explanation of a reliable set of phenomena.* That is the sense in which we use the term. For example, consider the development of the theory of gravitation. In Newton's theory of gravitation, the inverse square law of attraction between two bodies explained both the parabolic motion of a projectile fired on Earth as well as comets and Kepler's description of the motion of the planets. Among other things, it left unexplained how gravitational force could act at a distance and the very slow perihelion procession of the orbit of the planet Mercury around the sun.

Einstein's general theory of relativity presented a new theory of gravitation that linked inertial force and gravitation. In a famous Gedanken-experiment, or thought experiment, a scientist in outer space is imagined in an elevator that is being uniformly accelerated upward. She would be unable to distinguish this state of affairs from being in a uniform gravitational field, Einstein predicted that light would bend in a gravitational field. Einstein's prediction was confirmed by a dramatic observational study performed in Great Britain in 1919 that caused an international sensation. It was particularly dramatic that after World War I an English team of scientists had tested a theory put forward by a German scientist when the two countries had so recently been at war (although Einstein was a Swiss citizen, he taught in Berlin). Einstein's theory of gravitation postulated that the path light takes in space and time *is* the curvature of what he called space-time. He then showed that differential curvatures on the surface of space-time can explain gravitational attraction. The theory resolved the problem of action at a distance. The gravitational field equations also explained the perihelion procession of Mercury's orbit.

Both Newton and Einstein relied on mathematics to state their theories concisely, and they used the implications of the mathematics to explain the phenomena they were studying. Newton developed the differential calculus (as did Leibnitz [1]) to make his calculations using his second law of motion that force equals mass times acceleration. Acceleration was the rate of change of velocity. The second law, coupled with the inverse square law of gravitational attraction, made it possible to show that all orbits are sections of a cone, so that the parabolic motion of a projectile fired from Earth, the Kepler phenomena, the orbit of the moon around the Earth, and the motions of comets could all be derived from these ideas. In his book, *Principia,* Newton presented all his calculations using only geometry, probably because he thought that his new calculus of "fluxions" would not be accepted.

Einstein's general theory of relativity used field equations that stated that the gravitational field was equal to the curvature of space-time, a curvature based on the distribution of mass. To write these equations he used the tensor calculus of Riemann's differential geometry, which contained the idea of "geodesics," the shortest curve between any two points on a surface.

Both Newton and Einstein can be considered applied mathematicians because they developed or employed mathematical methods to model scientific phenomena. Both theories of gravitation explained existing phenomena, and the mathematics predicted new phenomena. In Einstein's case, these phenomena included the bending of light in a gravitational field, the gravitational red shift, the fact that clocks would run differently at different places in a gravitational field, the expanding universe, and the existence of black holes. These highly successful theories also fit together well, and in creating his theory of gravitation, Einstein correctly insisted that it must reduce to Newton's theory under everyday conditions that did not involve high velocities or high mass densities.

The simplicity underlying both theories of gravitation could only be described as beautiful. Einstein was so moved by the discovery of this underlying beauty that he referred to it as understanding the mind of God, whom he called "der Alter," the Old One. Newton was also led to write theology. So profound were the effects of these successful scientific theories and of others that we have come to *expect* this beauty and simplicity as characteristic's of true theories of natural law.

The theory we present here is no different from the theories of gravi-

[1] The controversy as to who discovered calculus first — Newton or Leibnitz — was bitter and acrimonious, primarily on Newton's part. It is now generally accepted among historians of mathematics that Leibnitz should be credited with its discovery.

tation in that it is a mathematical modeling of stable, natural phenomena. The phenomena in our case are social, human phenomena rather than physical. Ironically, biographers have noted that such phenomena were most problematic in the personal lives of these two scientists. The humor is not lost on us that it took a few hundred years since Newton before some scientific interest would shift from gravitational attraction between two inanimate bodies to social attraction between members of our own species. (Newton was not particularly agreeable, and, indeed, was vindictive in many of his interactions with his contemporaries.)