For Discussion:
Main Points from *The Nature of Science*

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Abstract

The Nature of Science is intended to communicate "what science is, how science works, and how you can get involved." The main points of the show are presented, along with examples for discussion.

What is Science?

In simple terms, science is a way of looking at stuff and figuring stuff out. It is a system of building human knowledge — an expression of our natural curiosity.

Scientists, both professional and amateur, investigate the natural world by asking questions, making observations, and testing their ideas with experiments.

Science is not a religion or belief system — it is a knowledge system. Science knows no boundary of race, nationality, or faith in its practitioners.

Science deals in empirical, testable evidence, gathered with structured observations and interactions with the natural world. Supernatural phenomena are beyond the reach of science. As such, science can not render an opinion on matters of faith or spirituality.

The Words Mean Something

Scientists use words to talk about what they do. Over time, some of these words have been co-opted by the general public. As a result, the meanings of the words in common, every day language are different from the meanings of the same words in scientific language (McComas, 1998).

In every day language, "laws" are very concrete — they are things that can not (or should not) be broken.

The every day language meaning of "theory" tends to be something like a hypothetical or untested idea.

In scientific language, a "law" is a description, or model, of something you can observe in nature. Scientific laws do not explain why a model works, they only describe its observable features and dynamics.

In science, a "theory" is the most up-to-date, tested, evidence-supported, scientific explanation of how something works. A scientific theory makes predictions and is testable.

Scientific Theories DO NOT Become Scientific Laws

The idea that hypotheses "grow up" to become theories and that theories eventually become laws is false. This and other misconceptions have been perpetuated in flawed science textbooks over recent decades (Beaty, 1996; Gould, 1988; McComas, 1998).

"A theory is really the endpoint of an investigation into nature."

– Dr. Brad Carroll in The Nature of Science (2009)

In the whole of scientific research, you will not find a single instance of a theory becoming a law. In fact, scientific laws are often established before scientific theories (and this makes sense, because laws are relatively easy to figure out). A brief history of our understanding of gravity illustrates this principle.

In the early 17th century, Galileo's observations and experiments showed that falling objects undergo constant acceleration, regardless of their masses. Free-fall motion is described in equation 1 — this is an early form of "The Law of Gravity."

$$s=\frac{gt^2}{2}$$

Equation 1: Galilean free-fall motion in a vacuum, where *s* is the amount of displacement (or distance fallen), *g* is the gravitational acceleration, and *t* is the amount of time elapsed.

While Galilean kinematics are useful for calculating trajectories and free-fall times near the surface of Earth, it does nothing to explain why gravity works. Thus "The Law of Gravity" was established before "The Theory of Gravity."

Scientific Laws are not set in Stone

As our understanding grows, our scientific knowledge evolves. Less than a century after Galileo's work, Newton had his much fabled "apple moment." While he certainly did not discover gravity, Newton did advance The Law of Gravity with the model described by equation 2.

$$\vec{F}_g = \frac{GMm}{r^2}$$

Equation 2: Newtonian gravitational force between massive bodies, where *F_g* is the force due to gravity, *G* is the gravitational constant, *M* is the first massive object, *m* is the second massive object, and *r* is the distance between the massive objects' centers.

By observing the motion of the planets, Newton realized that gravitational acceleration "falls off" with distance — the more distant the planet, the slower it moves through its orbit. This principle was earlier described by Kepler, but Newton made the connection — he realized that planets orbit the sun for the same reason that apples fall to the ground.

While Newton's work improved The Law of Gravity, he was no closer to a "Theory of Gravity" than Galileo. Newton could very accurately predict the behavior of gravity, but he had no idea of what caused gravity to be, "...I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypothesis..." (Newton, 1720/1946).

So we have an improved law, but still no theory. Should we feel sorry for Newton? Of course not! Newton's Law of Gravitational Attraction is an extremely useful, elegant, and practical tool. After all, the Apollo missions rode Newtonian gravity to the Moon and back.

Creativity Spurs Inquiry

In 1907 a daydreaming Swiss patent clerk began to see his world differently. Within a few years and in the midst of global conflict, Einstein would become a household name.

Einstein imagined a universe surfing on the waves of space-time. He hypothesized that massive objects distort space-time and that mass interacting with distorted space-time produces the effects of gravity.

While Einstein's idea of General Relativity had plenty of great math to back it up, it made predictions that were difficult to test. The most accessible of these predictions is that light would be affected by gravity. Einstein suggested that one might test this prediction with a distant light source and a nearby massive object.

The most massive object around is the Sun and, conveniently enough, the Moon completely eclipses the Sun from time to time. During a total solar eclipse, the sky becomes dark and the stars beyond the Sun become visible. This presents a perfect opportunity to test the effects of gravity on light — if Einstein's prediction is correct, we should see a measurable difference between our star maps and the apparent positions of the stars beyond the Sun during the eclipse.

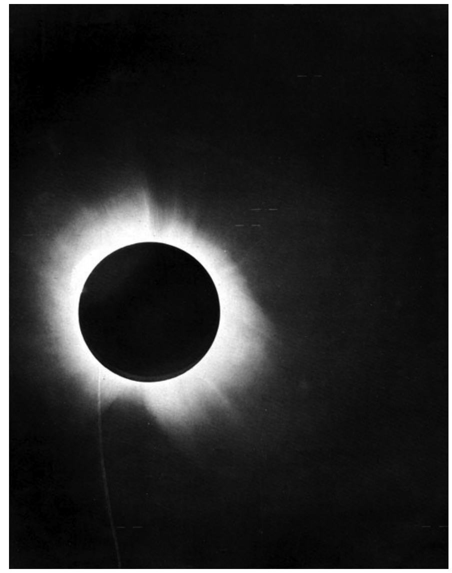

Figure 1: A telescopic photograph of the 1919 eclipse, captured by Eddington.

On May 29, 1919, the shadow of a total solar eclipse passed over the Island of Príncipe, near the African Continent. Sir Arthur Eddington was ready with telescopes and cameras. The photographs made that day became the first confirmation of General Relativity's predictions.

So finally, a Theory of Gravity begins to emerge (many years after the Law of Gravity was established and updated). But while Einstein's Theory of General Relativity gives us a fleeting glimpse at how gravity actually works, there is plenty of work yet to do.

Looking Forward

There are numerous opportunities for all ages and skill levels to participate in science. Getting involved is easy and there are a wide variety of things to do. As a citizen scientist, you and your students can connect with the global effort to advance human understanding — and have a lot of fun doing it!

As science educators, we have the responsibility to represent science as accurately as possible. When you encounter an error or anomaly in your lesson plans, books, or teaching standards, take time to speak up. Contact the publisher. Tell your colleagues.

It is time to stop perpetuating misconceptions. It must start with you.

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