It Is not *Just* a Theory, It *Is* a Theory!

Opinion

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Summary

A theory is not some hunch, or half-baked idea that you come up with while taking a shower, or being under the influence of something or other. A theory, as scientists understand the meaning of the word, is a scientifically tested principle or body of principles that incorporates and explains a significant body of evidence.

My theory on housework is, if the item doesn't multiply, smell, catch fire, or block the refrigerator door, let it be. No one else cares. Why should you?
Erma Bombeck

Every now and then we get into a discussion about the Big Bang theory or the theory of evolution, and the discussion occasionally ends with what is intended as a put-down:

"Well, after all, it's just a theory."

In the same vein, there was a flap at NASA a couple of years ago when someone insisted that the word "theory" be added after every mention of the Big Bang.

Both instances betray a misunderstanding of what a scientific theory is. It is not some hunch, or speculative idea that you come up with while taking a shower, or being under the influence of something or other.

As Michael Peshkin (2006) has said, "I always discuss the words, 'It's only a theory,' by saying that for practical purposes that's the same as saying 'It's only science, and the price we can pay for such contempt for science is high.'"

A theory, as scientists understand the meaning of the word, is a scientifically tested principle or body of principles that incorporates and explains a significant body of evidence. It is an important milestone in the search for knowledge of our Universe that begins with observations, usually followed by a batch of half-baked ideas, most of which are soon proven wrong by further observations.

The surviving ideas are formulated into hypotheses that must do more than explain the observations. To be taken seriously, a hypothesis must make predictions that can be tested by further observations.

It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong.
Richard P. Feynman

As a hypothesis matures, and is extended to include complementary hypotheses to explain more observations in a self-consistent way, it becomes a model. Models have a set of assumptions and, in physics, are described by a set of equations. The exploration of the implications of these equations leads to explanations of other phenomena, or to predictions.

Usually, a "model" is used to describe an intermediate step on the way to a "theory" that emerges if the model survives rigorous experimental and theoretical testing. Sometimes, the name sticks even after a particular model is the only one left standing. The Standard Model of particle physics is an example of a model that has become a theory, yet it is still referred to as a model.

It has been suggested that maybe scientists should drop the use of the word "theory" because it can be used in too many ways — Merriam-Webster's dictionary lists nine different meanings — and use "model" instead. Another term used for scientific theories that are well established is "law", as in Newton's laws of motion, and the laws of thermodynamics.

In any case, the transition from hypothesis to model or theory or law seldom goes smoothly. When Isaac Newton was standing on the shoulders of Galileo and Kepler to invent physics, he came up with a model for gravity and three laws of motion, but before he could work out the implications, he had to invent calculus!

Also, one of his main goals, to explain the motion of the Moon, didn't match the observations. It turned out that the observations were wrong — when the data on the radius of the Earth were updated to take into account new measurements, his model matched the observations, and he knew he had a legitimate theory.

With his three laws of motion (inertia, force = mass x acceleration, and action = reaction) plus the universal law of gravity, Newton could explain the orbits of the Moon, the planets and comets, as well as the twice-daily tides on Earth caused by the Sun and Moon, the flattening of the Earth at the poles, etc. These laws were subsequently used by others to discover the planet Neptune, and are still used today to discover planets around other stars. Now, that's a scientific theory!

Another example is the development of the theory of electrodynamics by James Clerk Maxwell. It incorporated the work of Michael Faraday and others into a set of four equations (now known as Maxwell's equations) that explained known phenomena associated with electricity and magnetism, and led directly to the discovery of radio waves a few years later.

Despite its awesome power, Newton's theory was not complete. For example, Newton's laws apply only for relative motion at speeds much less than the speed of light. At speeds approaching the speed of light, modifications provided by Einstein's special theory of relativity were necessary.

Likewise, when gravity becomes extremely strong, special relativity must be modified by Einstein's general theory of relativity. And finally, near the singularity inside a black hole's event horizon, the general theory of relativity must be modified by quantum gravity, although there is as yet no agreement on how to do this.

A similar fate has befallen Maxwell's theory. It has also been modified with special relativity at speeds close to the speed of light, and by quantum electrodynamics to account for the photonic nature of light.

A common misconception among laymen about scientific theories is that when they break down, the breakdown is catastrophic and the entire theory is discarded, that the textbooks have to be rewritten. A good example of this misconception appeared recently in a *Washington Post* article by columnist Charles Krauthammer:

If you doubt the arrogance, you haven't seen that Newsweek *cover story that declared the global warming debate over. Consider: If Newton's laws of motion could, after 200 years of unfailing experimental and experiential confirmation,* ***be overthrown****, it requires religious fervor to believe that global warming — infinitely more untested, complex and speculative — is a closed issue. (Bold italics mine).*

Of course, Newton's laws have not been overthrown. They give the same results as Einstein's theories at speeds much less than the speed of light and moderate gravity. The new theories, such as relativity theory or quantum theory, do not render the prior theories irrelevant, they just incorporate them into a larger domain.

What did change radically was the big picture. Like a scene in a great mural painting, the old theories were seen to be part of a much larger reality.

There could be no fairer destiny for any physical theory than that it should point the way to a more comprehensive theory in which it lives on as a limiting case.
Albert Einstein

Gravity isn't just about apples falling to Earth, the Moon orbiting the Earth, and the Earth orbiting the Sun. It is about matter causing curvature in space and bodies moving in straight lines through curved space. It is about black holes. The theory of relativity allows us to move back for a more comprehensive view of the Universe that is beautiful and magnificent to behold.

And guess what — scientists still don't know what the entire mural looks like. For example, the limits to the Big Bang theory are becoming increasingly apparent and are telling us that there is much more to be discovered.

There is a theory which states that if ever anyone discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable. There is another theory which states that this has already happened.
Douglas Adams

References

- Krauthammer, C. 2008, *Washington Post*, May 30, A13
- Peshkin, M. 2006, *Physics Today*, July, 46
- Quinn, H. 2007, *Physics Today*, January, 8
- Thorne, K. 1994, *Black Holes and Time Warps*, (New York: Norton) 84

Biography

Wallace Tucker, an astrophysicist, is science spokesman for the Chandra X-ray Center at the Harvard-Smithsonian Center for Astrophysics. He has authored or co-authored several non-technical books on astronomy, the latest of which is *Revealing the Universe*, written with Karen Tucker.