Scientific 'Laws', 'Hypotheses' and 'Theories'

Meanings and Distinctions

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Science describes the world of phenomena in terms of scientific 'laws', 'hypotheses' and 'theories'. There appears to be a widespread confusion about the precise meaning and significance of the three terms. This article attempts to ascertain the meanings of the terms by examining their actual use in scientific literature.

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Science endeavours to give a meaningful description of the world of phenomena using what are known as laws, hypotheses and theories. Logicians and students of scientific method analyse the structure of scientific knowledge and try to determine the precise significance of these terms. But it is surprising to note the prevalence of a widespread confusion in books on logic and scientific method, regarding the meaning and significance of the terms 'laws', 'hypotheses' and 'theories'.

In the midst of a variety of views on the subject, it is possible to see that a particular view has found favour with a majority of the authors. According to that view, hypothesis, theory and law are successive stages in arriving at reliable knowledge about anything. As an example of a clear statement of this view, one can quote H E Cunningham, author of a popular textbook of logic. "Facts suggest, point to, indicate, an hypothesis" says the author, "and experience, practical and scientific, tends to confirm or validate it (or the contrary). As it becomes increasingly verified, the hypothesis changes from the status of a 'mere' hypothesis, and becomes more 'dignified' – it becomes a *theory*. This, in turn, may 'work' so well, i.e., it may become so generally accepted as an instrument of prediction and interpretation that it becomes a *law*". This is more or less the view held by most of the authors. According to this view, therefore, hypotheses, theories and laws have the same fundamental character. The

Box 1. Hypotheses, Theories, Laws

Judy Harvey writes (Letters, 6 September p. 1321) that after significant experimental support is gathered, a hypothesis becomes a theory. This much is true. She then writes that if, after further testing, the theory "proves true in all circumstances, then it becomes a law". This should be restated. A law is a concise verbal and mathematical statement of a relationship between experimentally observed parameters that is always the same under the same conditions. A theory does not become a law; rather, a theory explains a pre-existing law and the body of facts upon which that law is based.

Hypotheses explain laws, and well-tested, corroborated hypotheses become theories. Harvey states, "there is a law of Gravity and the laws of Thermodynamics, but there is not a law of Evolution..." This mixes apples with oranges. The laws of gravity and thermodynamics are mathematical equations. There is no law of evolution because the facts explained by the theory of evolution cannot for the most part be presented as a law, in a mathematical format. This is not a flaw of the theory, but rather an idiosyncrasy of the field. A theory that cannot explain significant data sets published in the peer-reviewed literature inevitably falls out of favour and is replaced by a better theory. So far, evolution has repeatedly since the mid-19th century, stood the test of time... Evolution must be taught, along with the data that both support and contradict the theory. A robust theory has nothing to fear from contradictory data; on the contrary, explaining confusing data strengthens a theory and leads to advances in science. Giving students all the facts will allow them to see the excitement and power of the scientific method.

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differences between them lie only in that they stand at different levels in their claim for acceptance. Thus they differ only in respectability and not in essence.

Usually the authors seldom give any example of a hypothesis, in the history of science, which got elevated to the rank of a theory, and which finally became a law. On the other hand, any number of examples can be cited which contradict this view. For example, the atomic theory, Arrhenius' theory of electrolytic dissociation, the kinetic theory of gases and Maxwell's electromagnetic theory of radiation are a few of the scientific theories which are well established and which 'are generally accepted as instruments of prediction and interpretation'. But, they are called 'theories' and not 'laws', even to this day. We have, on the other hand, Newton's laws of motion, the law of flotation, the law of parallelogram of vectors, Kepler's laws of planetary motion, the gas laws, the laws of chemical combination and Mendel's laws of inheritance which have not passed through historical stages in which they were called hypotheses and theories.

Such discrepancies between their understanding and actual usage are explained away by saying that working scientists sometimes use the terms loosely. This is somewhat like the scientist who, on observing natural phenomena at variance with his understanding of them, complains that nature sometimes behaves improperly. The simile is justified, because scientists act almost unconsciously, like nature, in this regard. When working scientists use these terms, they scarcely pause to consider whether they are using every time the appropriate term. Constant practice helps them to use the right term at the right place. The process is similar to our using grammatically correct language without knowing the rules of grammar. If a logician explains to the scientists, the precise significance of the terms they are using, it is possible that they may be surprised like the character in Moliere's play who discovered that he had spoken prose all his life without knowing it.

To ascertain what scientists mean by a law, one has to examine as many propositions as possible, which are known as laws in scientific literature and find out what is common to all of them. This applies to hypotheses and theories as well. When the problem is viewed from this standpoint, it becomes obvious that it is not the 'truth value' or the 'degree of certainty' of a proposition (or a set of propositions) which guides one to designate it as a law, theory or hypothesis; it is the nature of its content. Berzelius' hypothesis was a failure, and Avogadro's hypothesis, which replaced it, has stood the test of time. But both are referred to as hypotheses. What is common between them is something other than the truth or otherwise of what they state. Similarly, there is something common between Newton's laws, which are precise, the gas laws, which have a limited range of applicability, and the laws of probability. In order to find out those common attributes, we have to examine the *nature of the contents* of the various propositions and not the *degree of their certainty.* We have to

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examine *what* they seek to state and not *how true* the statements are.

Scientific Laws

In our daily lives our actions are performed invariably with certain expectations in view. When we pour water from a vessel, we expect it to flow down and not fly up. When we heat water, we expect it to boil and not freeze. Belief is implicit, in all such actions, that events in the world do not happen at random, but that they take place in an orderly manner.

A scientific law is nothing but a proposition, which points out any such orderliness or regularity in nature. *A law is a proposition, which points out the prevalence of an invariable association between a particular set of conditions and particular phenomena.* It is of the nature of a generalisation, which covers all cases in which the prevalence of such an association can be noticed.

Philosophers, however, have expressed varied views about the validity of scientific laws. Some of them question the objective existence of order in nature. They contend that the laws of science are pure concoctions of the human mind. Others hold the opposite view. According to the latter, the perception of natural laws is due, no doubt, to the synthetic activity of the mind, but it is possible only because the connection actually exists in reality. Again, there are thinkers who argue that in spite of abundant data, on which a particular generalisation is based, there is nothing to warrant the belief that the phenomenon in question is sure to recur. According to Pearson "Science for the past is a description; for the future a belief". However, it is difficult to deny that, in the scientific attitude, there is an implicit belief that order objectively exists in nature, and that scientific laws arrived at on the basis of the accepted canons of scientific inquiry do help us to predict natural happenings. However much philosophers differ as to the validity of scientific laws, there is no disagreement on the question of what the laws *seek* to assert.

If, as has been made out, the only condition to be satisfied by a scientific proposition in order to be called a law is that it should *seek to point out* a regularity or orderliness in nature, it follows that it is in no way necessary that it should faithfully represent the law, inherent in nature, in all its aspects. That is why we find that some scientific laws, like Bode's law in astronomy, are approximately true; some, like the gas laws, have only a limited range of applicability and still others are only of a statistical nature.

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It also follows that laws do not cease to be laws, merely because they did not start their careers as hypotheses and pass through the stage of theories as required by the logicians. The earliest laws, which man came to be aware of, are those empirical generalisations, which he imbibed through his everyday experience. For instance, the stone age man would not have believed the story that water flows up a hill in any other part of the world. He was aware of the law that water always flows from a higher level to a lower level though he might not have had the vocabulary to formulate it. He inferred the truth of the law on the basis of repeated experience without having to propose it as a hypothesis requiring verification. A number of such empirical laws were known to man long before the rudiments of modern science appeared: there cannot be rain without clouds in the sky; snow is always to be found on high mountains; spring is followed by summer; etc. It has been argued that hypotheses, however short-lived, are necessary steps to arrive at definite knowledge of things. It may be true of knowledge acquired by science in the later stages of its development; it cannot be true of the simple empirical laws mentioned above.

Some time later, in history, we acquired knowledge of an other kind of laws which are also empirical generalisations, but are based on planned experiments or organised collection of a mass of observational data. The law of constant composition in chemistry, the gas laws and Kepler's laws of planetary motion are laws of this category. It is doubtful if formation of hypotheses has played any role in the discovery of these laws either.

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At any rate, the scientific world has never referred to them as hypotheses or theories. They are known as laws from the very day they were made known by their discoverers. It is because they are statements about regularities in nature.

Later still, in the history of science, a new class of laws, the derived laws, came on the scene. These are laws deduced by reasoning (mathematical or otherwise) based on, and starting from, premises (which are of the nature of hypotheses) and already known laws. Stefan's law concerning black body radiation, Stokes' law concerning the descent of a body under gravity through a viscous medium, Hess' law of constant heat summation and Ostwald's dilution law derived by applying the law of mass action to the dissociation of an electrolyte, are all examples of such laws. If one needs examples of laws, which cannot possibly be claimed to have been suggested first as hypotheses, they are here. They are deductions from premises, which are often of the nature of validated hypotheses. If the laws are shown to be valid, by experimental verification, the premises gain support. For instance, Dalton provided support to his atomic theory by deducing from it the law of multiple proportions, which could be experimentally verified.

Laws, in the exact sciences, can often be expressed in the form of mathematical relationships. Newton's law of gravitation is summarised in the equation $f = G\,mm'/d^2$. His second law of motion is expressed as $f = ma$. The *derived laws*, in particular, are often more conveniently expressed in the form of mathematical relationships than in the form of statements or words. The Gibbs–Helmholtz equation, Clausius–Clapeyron equation, van der Waals's equation and such other 'equations' are essentially laws expressed in a mathematical form.

This, in brief, is the meaning and significance of the term 'laws' as inferred by an examination of propositions, which are called laws in scientific literature. In like manner, it is possible to ascertain the meaning and significance of what scientists call hypotheses and theories.

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