Understanding Hypotheses, Predictions, Laws, and Theories

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Abstract

This paper discusses the relationships between the terms *hypothesis*, *prediction*, *theory*, and *law*. In so doing, it addresses some misconceptions found in the literature and suggests that the only interpretation of the term *hypothesis* needed is that of a causal hypothesis. A more valid depiction of the relationships between these key nature-of-science terms is then presented in diagrammatic form.

In a recent article in *The Science Teacher*, Maeng and Bell (2013) aimed to explain the relationships between the terms *hypothesis*, *theory*, and *law*, using Figure 1 to summarise their position. However, as reflected in the comments I have added in the two text boxes in Figure 1, I find the position advocated in that article problematic. Let us first discuss the issues involved and, in so doing, provide support for the following that run counter to key claims found in the Maeng and Bell article:

- A hypothesis is not a prediction.
- A theory is not necessarily a well-supported explanation.
- A (causal) hypothesis does not become a theory if it subsequently becomes well-supported by evidence.

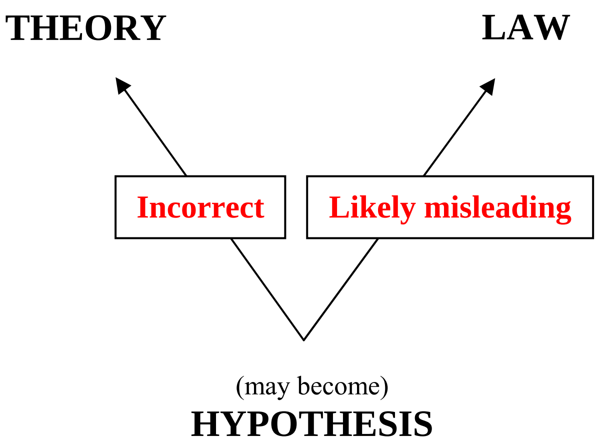

Figure 1. The figure used by Maeng and Bell (2013) to represent the relationship between a hypothesis, theory, and law, but with the comments in text boxes added.

Definitions

The following definitions are used in this paper:

- A (causal) **hypothesis** is a proposed explanation.
- A **prediction** is the expected result of a test that is derived, by deduction, from a hypothesis or theory.

- A **law** (or rule or principle) is a statement that summarises an observed regularity or pattern in nature.
- A scientific **theory** is a set of statements that, when taken together, attempt to explain a broad class of related phenomena.
- An **embedded theory** is a theory that is supported by much convincing evidence and that has become central to the way scientists understand their world.

Hypotheses, Predictions, and Laws

The term *hypothesis* is being used in various ways; namely, a causal hypothesis, a descriptive hypothesis, a statistical and null hypothesis, and to mean a prediction, as shown in Table 1. Let us consider each of these uses.

At its heart, science is about developing explanations about the universe. This requires the use of the scientific method, or scientific process, as some prefer to label it (also referred to as the hypothetico-deductive, or hypohetico-predictive approach) that comprises the following steps:

1. Asking a causal question about a puzzling observation.
2. Advancing a causal hypothesis (defined as a proposed explanation) for what has been observed (e.g., "the grass grows better on this side of the building because it is exposed to more sunlight on this side").
3. Planning a test of the hypothesis that incorporates the generation of a prediction from the hypothesis.
4. Conducting the test and comparing the results with the prediction.
5. Drawing a conclusion as to whether the results of the test support or contradict the hypothesis.

For further reading on the difference between causal and non-causal questions, the different ways in which they need to be treated, and the scientific method, please see Eastwell (2010 [freely available online], 2012). Two important things follow from this:

1. The notion of a causal hypothesis is essential to how science is done and progresses as a field.
2. It is a mistake—albeit one that is commonly being made—to not distinguish a hypothesis and a prediction. While a causal hypothesis is a proposed explanation, a prediction is the expected result of a test that is derived, by deduction, from a hypothesis (or theory, a notion I will discuss shortly). The expected result is a logical consequence of assuming that the hypothesis (or theory) being tested is correct. So, one way to test the hypothesis that "the grass grows better on this side of the building because it is exposed to more sunlight on this side" would be to use a sunlight reflector to deliver additional sunlight to some of the grass on the shaded side during the times that this grass would normally be shaded and see how this affects plant growth. Growth similar to that observed on the other side would be in accord with the prediction from the hypothesis and thereby support the hypothesis, while a different result would contradict it.

While a causal hypothesis is defined as a proposed explanation, a descriptive hypothesis is defined as a proposed description. My experience has been that when a descriptive hypothesis is referred to it describes a trend, pattern, or regularity, as in the following examples; heavier objects fall faster than lighter ones, all swans are white. Like causal hypotheses, descriptive hypotheses are open to being tested and either supported or contradicted by the results of a test. However, proposed descriptions of this form, which some also call generalizing hypotheses, may also be described as tentative laws, or trial laws, where a law (or rule or principle) is defined as a statement that summarises an observed regularity or pattern in nature. So, by using the term tentative, or trial, law instead of descriptive hypothesis, we can avoid any need to use the term descriptive hypothesis.

Table 1
The Status of Different Uses of the Term Hypothesis

Use of the term *hypothesis*	Suggested status
Causal hypothesis	Essential
Descriptive hypothesis	Valid, but use of the alternative term *tentative* (or *trial*) *law* would likely promote clarity associated with use of the term hypothesis
Statistical and null hypothesis	Mathematical terms not needed in science and science education research and best not used in these contexts
To mean a prediction	Wrong

The other use of the term hypothesis shown in Table 1 is in connection with the terms statistical hypothesis (e.g., students grouped in heterogeneous cooperative groups will perform significantly higher than those grouped in friendship cooperative groups) and null hypothesis (e.g., there will be no difference in the performance of students in the heterogeneous cooperative and friendship cooperative groups). While these terms are found commonly in the science education research literature, for example, Lawson (2008 [freely available online]) has shown that the use of these terms in science and science education research is unnecessary. While the concepts these terms represent certainly provide a powerful statistical tool for the researcher in science and science education, avoiding the use of the term names proper would further help in promoting the correct use of the term hypothesis because, combined with the previous advice about not using the term descriptive hypothesis, we are left with the causal hypothesis as being the type of hypothesis that is being referred to when the term hypothesis is used in science.

With this as background, we can now see why I am suggesting that the right-hand branch of the diagram of Figure 1 is misleading. A descriptive hypothesis in the form of a generalizing hypothesis may, after testing, become a law. However, a causal hypothesis (an explanation) can never become a law (a regularity or pattern) because these are two different kinds of knowledge and, by not making this distinction clear in the figure, I fear that Figure 1 is likely to convey the misconception that it can.

Hypotheses and Theories

A scientific theory is a set of statements that, when taken together, attempt to explain a broad class of related phenomena. Examples are spontaneous generation theory, biogenesis theory, and atomic-molecular theory. However, while theories are tested, and thereby supported or contradicted, in the same way hypotheses are as a part of the scientific method, there is no requirement that a theory need be a well-supported explanation. Let us consider a few examples in support of this position.

When Alfred Wegener first described the idea of continental drift, a lack of both detailed evidence and knowledge of a force sufficient to drive the movement saw this theory not generally accepted and heavily criticised by distinguished scientists of the day (Wikipedia, 2014). When an explanation is proposed, it is first tested using the inference of retroduction, a reasoning process in which one asks whether the explanation explains what we already know (Lawson, 2009), but this is the most introductory of evidence. Further testing of the explanation is required to potentially give us confidence in the explanation and, in the case of Wegener and continental drift, it took 50 years for his idea to be eventually incorporated into the theory of plate tectonics, which is now a well-substantiated theory that provides extraordinary explanatory and predictive power. In fact, the most powerful knowledge in science is an embedded theory, defined as a theory that is supported by much convincing evidence and that has become central to the way scientists understand their world. Examples include the theory of plate tectonics, the theory of evolution, and the kinetic-molecular theory. Those making the misleading claim that evolution is "just a theory" are displaying a lack of understanding of the nature of science, because an embedded theory represents the pinnacle of the scientific endeavour; science cannot do any better.

As a second example, consider the spontaneous generation theory that comprised three basic components:

- Living things arise spontaneously from nonliving materials when an unseen life-giving vital force enters the nonliving material.
- Different kinds of nonliving materials give rise to different kinds of living things (e.g., rotting meat gives rise to flies, while old rags give rise to mice).
- Spontaneous generation has occurred in the past and occurs today.

While testing may have seen this theory rejected rather than ever reaching the stage of being considered well-substantiated, it is still a theory. As a final example, we presently have a number of competing theories for the origin of life. None of them are well-substantiated, but the results of further testing will determine the usefulness of each.

We can now compare a (causal) hypothesis and a theory. Both actually represent the same type of scientific knowledge; that is, they are both explanatory in nature. In fact, the distinction between a causal hypothesis and a theory can be somewhat arbitrary. While a hypothesis attempts to explain a specific puzzling observation (or group of closely-related observations), a theory is more complex, more general, and more abstract and may even reflect the convergence of various hypotheses. What is clear, though, is that a (causal) hypothesis does not become a theory if it subsequently becomes well-supported by evidence, contrary to what is shown by the left-hand branch of the diagram of Figure 1. As Lawson (2011) wrote in a Misconception Alert in his biology textbook:

> In a previous science course you may have been told that a hypothesis that gains support becomes a theory. This is wrong! Instead a hypothesis that gains support becomes a supported hypothesis—what some may want to call a fact. Regardless of the amount of support that a hypothesis may gain, it can never become a theory. This is because . . . hypotheses and theories differ in complexity, generality, and abstractness, not in the amount of support. (p. 49)

The Relationship Between Hypotheses, Predictions, Laws, and Theories

Based on the foregoing, I offer the diagram of Figure 2 as a valid depiction of the relationships between the terms hypothesis, prediction, law, and theory. One of the pathways shown, namely the Puzzling observation → Law → (Causal) hypothesis or theory pathway, deserves elaboration, as the background to this has not been addressed previously in this paper. Puzzling observations are explained by (causal) hypotheses or theories, but sometimes a puzzling observation may take the form of a law (i.e., a statement that summarises an observed regularity or pattern in nature). Take, for example, an investigation to answer the non-causal question: "How does the volume of a gas vary with changing pressure?" The result of this investigation, Boyle's law, would constitute a puzzling observation in need of an explanation.

Summary

The main points made in this paper are:

- The only interpretation of the term *hypothesis* needed in science is that of a causal hypothesis, defined as a proposed explanation (and for typically a puzzling observation).
- A hypothesis is not a prediction. Rather, a prediction is derived from a hypothesis.
- A causal hypothesis and a law are two different types of scientific knowledge, and a causal hypothesis cannot become a law.
- A theory is not necessarily a well-supported explanation.
- The most powerful knowledge in science is an embedded theory, defined as a theory that is supported by much convincing evidence and that has become central to the way scientists understand their world.
- A (causal) hypothesis does not become a theory if it subsequently becomes well-supported by evidence. Rather, it becomes a well-supported hypothesis.

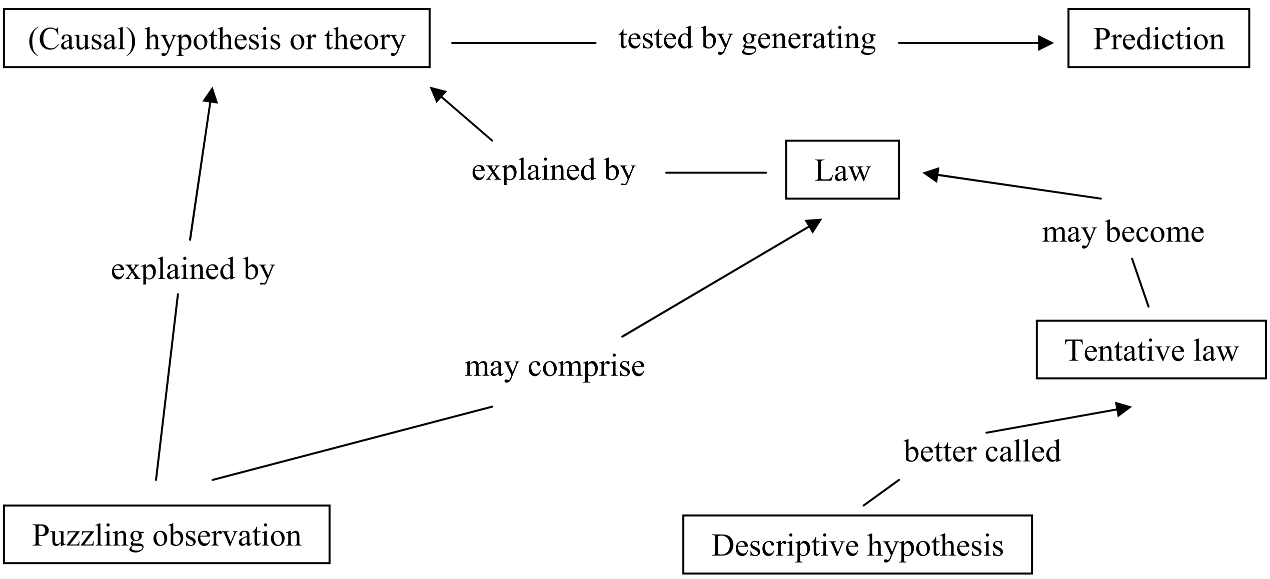

Figure 2. Overview of the relationship between hypotheses, predictions, laws, and theories.

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