Definition of Scientific Hypothesis: A Generalization or a Causal Explanation?

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Abstract: This study reviewed and discussed the nature of scientific hypothesis described in philosophy, the philosophy of science, science, and science education. In these descriptions, a hypothesis was defined as one of five types: hypothesis as an assumption, hypothesis as a prediction, hypothesis as a tentative explanation, hypothesis as a tentative law, and hypothesis as a tentative causal explanation. Most scholars agreed that a hypothesis is a proposition or a set of propositions proposed as an explanation for an observed situation. In this view, a hypothesis is a possible answer to or an explanation of a question that accounts for all the observed facts. Also, it is a statement that explains why things happen in nature or an explanation for an observation that can be tested. In the five types of hypothesis meanings, a tentative explanation includes a tentative law and a tentative causal explanation. However, tentative laws are not explanation but description which are general statements drawn from specific experiences by way of a process known as induction. A number of studies also have distinguished hypothesis from assumption, tentative explanation, tentative law, and prediction. Therefore, a hypothesis is concluded to be a proposition or a set of propositions proposed as a tentative causal explanation for an observed situation.

Key words: hypothesis, assumption, tentative explanation, tentative law, causal explanation, prediction

I. Introduction

The goal of science is to develop new knowledge such as facts, laws, and theories (Lawson 1995) in particular, the theory provides a basis for understanding a phenomenon being studied. The scientific method is a sequence of steps for arriving at the theory. The sequence starts with a question. One must ask a meaningful question or identify a significant problem, and one should be able to state the problem or question in a way that is conceivably possible to answer it. Now one can propose a solution or answer to the problem or question. In science, this suggested solution or answer is called a scientific hypothesis. Next, one must test the hypothesis before it is corroborated and given any real validity. If the hypothesis fails the test, it must be rejected and either abandoned or modified. If the hypothesis passes further tests, it is considered to be a corroborated hypothesis. The final step of the scientific method is to construct, support, or cast doubt on a scientific theory.

Among the steps of the scientific method, generating a scientific hypothesis is one of the most important steps, because the hypothesis functions as a bridge that connects descriptive knowledge with explanatory knowledge (Klahr & Dunbar, 1988 Kuhn *et al.*, 1988 Kwon *et al.*, 2000 Lawson, 1995). Then, what is the hypothesis?

From the Greek hypo (under) and tithenai (to put), a hypothesis is a foundation or supposition (Reese 1980). In general, a hypothesis is an assumption, a supposition, a conjecture, a presumption, a tentative explanation, or a probable cause. In logic, it is a conditional clause in a hypothetical proposition. In methodology, it is a principle offered as a conditional explanation of a fact or a group of facts (Runes 1982).

In science and science education, the term "hypothesis" is used with various meanings. Walker (1998) defined a hypothesis as a prediction based on a theory. Enger and Ross (2003) described a hypothesis as a statement that explains why things happen in nature or an explanation for an observation that can

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be tested. Simpson and Anderson (1981) remarked that hypothesizing is stating a tentative generalization that may be used to explain a relatively large number of events. Lawson (1995) stated that a hypothesis is a single proposition intended as a possible explanation for an observed phenomenon, that is, a possible cause for a specific result. A hypothesis is one of the most important concepts, but as in above definitions, no term in science contributes a greater ambiguity to us than does a hypothesis (Darian, 1995).

This study reviews and discusses some of the meanings of a hypothesis that was used in the literature such as the dictionaries of philosophy, philosophy of science literature, introductory science textbooks, and science education literature. In addition, we then defined the concept of a scientific hypothesis on the basis of the discussion.

II. Nature of scientific hypothesis

In philosophical literature, a hypothesis has been defined as one of four ideas: assumption, tentative explanation, tentative cause, and prediction. For example, Barnhart (1953) asserted that a hypothesis is a proposed explanation, a tentative cause for some specific observation or related observation. Reese (1980) stated that the term hypothesis is often taken to mean a provisional explanation that, depending upon its degree of confirmation, may come to be regarded as an accepted theory or law. According to Runes (1982), there are two kinds of explanatory hypotheses: the hypothesis of law and the hypothesis of cause. Flew (1985) remarked that a hypothesis is a suggestion that still has overtones of the arbitrary or the speculative. Parker (1989) also said that a hypothesis is a proposition, which is assumed to be true in proving another proposition. However, Walker (1988) has defined a hypothesis as a prediction based on theory, an educated guess derived from various assumptions, which can be tested using a range of methods, but it is most often associated with experimental procedure; a proposition put forward for proof or discussion.

In summarizing the previous review, the meanings of a hypothesis written in the philosophical literature are shown as in Table 1.

In philosophy of science literature, a hypothesis has been defined as one of four ideas: assumption, tentative explanation, tentative cause, and tentative law. Aristotle might hold a view that a hypothesis is an assertion capable of proof but accepted and used in a demonstration without proof (Reese, 1980). Descartes spoke as though hypotheses were statements not known to be true or false but convenient starting points for deducing sets of conclusions (Reese, 1980). Lotze also regarded a hypothesis as the conjectural filling up or out of the logical space between necessary postulates and experience (Reese, 1980). Hempel (1966) explained that many scientific hypotheses are expressed in quantitative terms. In the simplest case, they will then represent the value of one quantitative variable as a mathematical function of certain other variables. Quine and Ullian (1988) asserted that a hypothesis, where successful, is a two-way street, extending back to explain the past and forward to predict the future. Darian (1995) stated that a hypothesis is a possible cause or reason for something, a possible solution to a problem.

In summarizing the previous review, the meanings of a hypothesis written in philosophy of science

Table 1

Meanings of a hypothesis written in philosophical literature

Scholar	Assumption	Tentative explanation	Tentative cause	Tentative law	Prediction
Barnhart (1953)			○		
Reese (1980)		○			
Runes (1982)		○			
Flew (1985)	○				
Walker (1988)					○
Parker (1989)	○				

Table 2

Meanings of a hypothesis written in philosophy of science literature

Scholar	Assumption	Tentative explanation	Tentative cause	Tentative law	Prediction
Aristotle (in Reese 1980)	○				
Descartes (in Reese 1980)	○				
Lotze (in Reese 1980)	○				
Hempel (1966)				○	
Quine & Ullian (1988)		○			
Darian (1995)			○		

literature are shown as in Table 2.

In science literature, a hypothesis is defined in various ways. According to Slabaugh and Parsons (1976), a scientific law is not an explanation, but a generalization based on observations. They asserted that deriving an explanation for a law is one of the most productive and respectable activities in science. This activity often begins when the scientist assumes a hypothesis, a possible explanation, which is then tested. Brown and LeMay (1981) explained that scientists seek general relations that will unify their observations. A tentative general relation is called a hypothesis. Tarbuck and Lutgens (1994) stated that a hypothesis is a tentative explanation that is tested to determine if it is valid. Kimball (1994) said that a hypothesis is a scientific explanation. He explained that perhaps the intravenous injections caused something to be produced that actively suppresses the ability of the animal to become sensitized to the chemical. Each of these possible explanations is a hypothesis. Postlethwait and Hopson (1995) asserted that tentative generalization is called a hypothesis. For example, a person who knows, for example, that bright red strawberry frogs and red-and-yellow coral snakes are poisonous might conclude through inductive reasoning that all brightly colored organisms are dangerous. Such a generalization is a hypothesis in their view. Hazen and Trefil (1996) explained that once we have summarized experimental and observational results, we can form a hypothesis--a tentative, educated guess--about how the world works. "When I drop something, if falls." In this case, the formation of the hypothesis may be stated in the form of mathematical equations. Moore *et al.* (1998) remarked that what enables resistance to polish whiteflies in some plants but not others? These are the kinds of causal questions that are at the heart of the scientific method. Science is fundamentally about finding answers to such questions. To find these answers, botanists use past experiences, ideas, and observations to propose hypotheses that may produce predictions. Raven *et al.* (1999) said that a hypothesis is a temporary working explanation or supposition based on accumulated facts and suggesting some general principle or relation of cause and effect; a postulated solution to a scientific problem that must be tested by experimentation and, if disproved or shown to be unlikely, is discarded. In Murphy and Nance's view (1999), a hypothesis is a tentative proposal put forward to explain the behavior of a natural phenomenon. A hypothesis is tested to determine its validity and is less firmly founded than a theory. Theory is a hypothesis that has withstood repeated testing and application, but has not been proven conclusively to a degree to be accepted as a law. Uno and Moore (2001) remarked that the similarity between your friend's allergy and your rash leads to the hypothesis that your rash is also caused by an allergy to the grass. Hinrichs and Kleinbach (2002) stated that after many observations, a hypothesis is usually proposed when one tries to generalize the observations. A hypothesis that has been supported by a large body of observations and experiments becomes a theory. Enger and Ross (2003) remarked that a hypothesis is a possible answer to or explanation of a question that accounts for all the observed facts and is testable. A hypothesis is a statement that explains why things happen in nature or an explanation for an observation that can be tested.

In summarizing the previous review, the meanings of a hypothesis written in the introductory science texts are shown as in Table 3.

Table 3
Meanings of a hypothesis written in science literature

Scholar	Assumption	Tentative explanation	Tentative cause	Tentative law	Prediction
Slabaugh & Parsons (1976)			○		
Brown & LeMay (1981)				○	
Tarbuck & Lutgens (1994)		○			
Kimball (1994)			○		
Postlethwait & Hopson (1995)				○	
Hazen & Trefil (1996)				○	
Moore *et al.* (1998)			○		
Raven *et al.* (1999)		○			
Murphy & Nance (1999)				○	
Uno & Moore (2001)			○		
Hinrichs & Kleinbach (2002)				○	
Enger & Ross (2003)			○		

In science education literature, a hypothesis has been defined as one of three ideas: assumption, tentative cause, and tentative law. According to BSCS (1968), scientists have developed their own methods, which are often little more than common sense, for seeking answers to their questions. The scientist uses whatever little information he has to make a statement that may be the answer to the question he is asking. This statement is a hypothesis. Simpson and Anderson (1981) remarked that hypothesizing is stating a tentative generalization that may be used to explain a relatively large number of events but which is subject to immediate or eventual testing by one or more experiments. Heimler (1986) said that a hypothesis is a possible solution fo

r a problem; formed after studying facts and ideas relating to the problem. Ramsey *et al.*(1986) explained that the discovery of a general pattern among a set of observations allows a general statement to be made about similar situations. Scientists call a statement based on observations a hypothesis. A good hypothesis can be made only after a pattern is seen in the observations. The pattern is a natural or chance design in observations or events. Lawson (1995) stated that a hypothesis is a single proposition intended as a possible explanation for an observed phenomenon-that is, a possible cause for a specific result. Victor and Kellough (1997) said that a hypothesis is a speculation--a guess that remains untested. Whereas facts are accepted truths, that is, realities that are directly observable and consistently demonstrated, theories, on the other hand, are in a constant state of revision.

In summarizing the previous review, the meanings of a scientific hypothesis written in science education literature are shown as in Table 4.

As seen in the previous reviews of the literature in philosophy, the philosophy of science, science, and

Table 4
Meanings of a hypothesis written in science education literature

Scholar	Assumption	Tentative explanation	Tentative cause	Tentative law	Prediction
BSCS (1968)	○				
Simpson & Anderson (1981)				○	
Heimler (1986)		○			
Ramsey *et al.* (1986)				○	
Lawson (1995)			○		
Victor & Kellough (1997)	○				

science education, the meaning of a hypothesis falls into one of five types: a hypothesis-as-assumption, a hypothesis-as-prediction, a hypothesis-as-tentative explanation, a hypothesis-as-tentative law, and a hypothesis-as-tentative causal explanation.

A hypothesis-as-assumption. A hypothesis-as-assumption has the most extensive meaning. The hypothesis has been used in this sense not only by the philosophers of science in the dictionaries of philosophy and philosophy of science literature (Aristotle, Descartes, & Lotze in Reese, 1980 Flew, 1985 Parker,1989) but also by many writers on science in schools (BSCS, 1968 Victor & Kellough, 1997). In this view, the hypothesis is a guess, an assumption, a supposition, a conjecture, a presumption, and a possible solution for a problem; formed after studying facts and ideas relating to the problem.

A hypothesis-as-prediction. Walker (1988), in science and technology dictionary, said that a hypothesis is an educated guess and a prediction derived from a theory. This concept of hypothesis is also found in UNESCO (1980), which gives "Birds will not eat chenille worms" as an example. It is significant as an example of ambiguity currently surrounding the term "hypothesis" in science education, since, if the assessment criteria are followed (Enger & Ross, 2003 Hazen & Trefil, 1996 Lawson, 1995 Postlethwait & Hopson, 1995 Quine & Ullian, 1988 Runes, 1982 Simpson & Anderson, 1981 Uno *et al.*, 2001), it would not be regarded as a hypothesis but as a prediction.

A hypothesis-as-tentative explanation. This meaning appears in the dictionaries of philosophy, in the literature of the philosophy of science, and also in introductory science texts (Heimler, 1986 Quine & Ullian, 1988 Raven *et al.*, 1999 Reese, 1980 Runes, 1982 Tarbuck & Lutgens, 1994). In this definition a hypothesis is a tentative explanation or supposition based on accumulated facts and a postulated solution to a scientific problem that must be tested by experimentation. A hypothesis is often taken to mean a provisional explanation, which, depending upon its degree of confirmation may come to be regarded as an accepted theory or law. In this usage, the meanings of explanatory hypotheses are unspecialized into two types of hypotheses: the hypothesis of law and the hypothesis of cause.

A hypothesis-as-tentative law. The term hypothesis is used in this meaning not only by writers on the philosophy of science and science education (Brown & LeMay, 1981; Hempel, 1966 Ramsey *et al.*, 1986 Simpson & Anderson, 1981) but also by many scientists (Hazen & Trefil, 1996 Hinrichs & Kleinbach, 2002 Murphy & Nance, 1999 Postlethwait & Hopson, 1995). These hypotheses propose relationships such as the law of gravity, or patterns such as the early versions of the periodic table. The law of gravity, for instance, describes the natural phenomenon of gravitational attraction between two bodies. In this concept of hypothesis, a hypothesis is a tentative generalization that may be used to predict a relatively large number of events but which is subject to immediate or eventual testing by one or more experiments.

A hypothesis-as-tentative causal explanation. Hypothesis-as-tentative-causal explanation is most widely used in recent writings on science and science education, by which a cause is proposed for an observed effect (Barnhart, 1953: Darian, 1995 Enger & Ross, 2003 Kimball, 1994 Lawson, 1995 Moore *et al.*, 1998 Slabaugh & Parsons, 1976 Uno & Moore, 2001). This meaning of a hypothesis has been simply summarized as a reasoned explanation of why they think something has happened or will happen... an "I think... because"statement. In the same set of criteria, a hypothesis is clearly distinguished from a prediction, which is characterized as a simple "What I think will happen" statement.

In summarizing the previous discussions, the meanings of a hypothesis written in the literature of philosophy, the philosophy of science, science, and science education can be described as in Fig. 1.

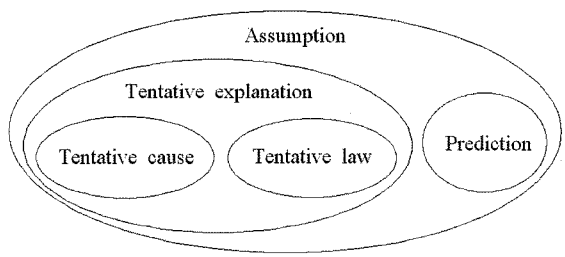

Fig. 1 *The meanings of hypotheses used in science education literature*

Ⅲ. Discussions and Conclusions

As shown in Fig. 1, all the philosophers, scientists, and science educators in the literature consider a hypothesis as an assumption. In addition, they think that the key word of the definition of a hypothesis is tentative, and the essence of a hypothesis is its tentativeness. However, all assumptions are not the hypotheses. For example, when people examine hundreds of species of insects, they observe that several kinds have six legs. From theses observations, they may develop a generalization that six legs is a fundamental characteristic of insects. On this basis, they assume that the new species of insects they are examining will also have six legs. Is the assumption that "the new insect will have six legs" a hypothesis? The answer is no. Instead it is better referred to as a prediction based on simple class logic that proceeds as follows: "All insects have six legs. This is an insect. Therefore, it will have six legs."The prediction that the new insect will have six legs is derived by a process referred to as deduction. The prediction is logically deduced from a theory, a law, or a hypothesis (Lawson, 1995). Therefore, a hypothesis is not a prediction, which is characterized as a simple "What I think will happen" statement. Furthermore, most philosophers, scientists, and science educators clearly distinguish hypothesis from prediction (Enger & Ross, 2003 Hazen & Trefil, 1996 Lawson, 1995 Postlethwait & Hopson, 1995 Quine & Ullian, 1988 Runes, 1982 Simpson & Anderson, 1981 Uno & Moore, 2001).

Many philosophers said that the combination of explanation and hypothesis may be regarded as an answer to a why-question (Hempel, 1966 Lawson, 1995; Mayer, 1993; Nagel, 1961; Salmon, 1998), such as: "Why do the planets move in elliptical orbits with the sun at one focus?"; "Why does the moon look much larger when it is near the horizon than when it is high in the sky?" However, very little reflection is needed to reveal that the word "why" in ambiguous, and that with varying contexts, different sorts of answers are relevant responses to it (Nagel, 1961). What is the meaning of explanation?

According to the Fig. 1, the meaning of explanation includes the meanings of law and causal explanation. However, law is not explanation but description, that is, general statement drawn from specific experiences by way of a process known as induction (Lawson, 1995). Mayer (1993) also clearly discriminates descriptive knowledge from explanatory knowledge. Description refers to the specification of relations among observable variables that may be stated as verbal rules or quantitative laws, and explanation refers to the mechanisms that underlie and connect descriptive rules (Mayer, 1993). Tentative rules and provisional laws are not explanations, but merely description. Therefore, tentative laws are not hypotheses.

For example, Mendel's experiments, from 1858 to 1866 Gregor Mendel worked in the garden of his monastery in the town of Brno, breeding garden peas and examining the offspring of these mating (Kimball, 1994). In one of his first experiments, Mendel crossbred a round-seeded variety with a wrinkled-seeded variety. This parental generation we call the P generation. Pollen from the stamens of the round -seeded variety was dusted on the stigmas of the wrinkled-seeded variety. The reciprocal cross was also carried out by placing pollen form the stamens of the wrinkled -seeded variety on the stigmas of the round-seeded variety. In both cases every one of the seeds produced by these cross-fertilized flowers was round. It is Mendel's law of dominance. The second generation is called the F_1 generation. According to Kimball (1994), Mendel planted all of his F_1 round seeds; 253 F_1 plants grew to maturity. The F_1 flowers were allowed to self-fertilize in the normal way. In effect, Mendel was breeding the F_1 (hybrid) generations together. From the pods of these F1plants, Mendel recovered 7324 seeds, the F_2 generation. Of these, 5474 were round and 1850 were wrinkled, yielding a ration of 2.96 round seeds to 1 wrinkled seed. It is Mendel's law of segregation.

What is the significance of these results? How could this result be explained? In an attempt to explain these laws, Mendel made a series of assumptions. These assumptions we call a hypothesis. They were as follows (Kimball, 1994):

1. In each organism is a pair of factors that controls

the appearance of a given characteristic.

2. The organism gets these factors from its parents, one from each.

3. Each of these factors is transmitted as a discrete, unchanging unit.

4. When the sex cells are formed, the factors separate and are distributed as units to each gamete.

5. If an organism has two unlike factors for a given characteristic, one may be expressed to the total exclusion of the other.

In the preceding example, Mendel generated the law of dominance and the law of segregation. According to Hempel's deductive-nomological explanations, the D-N model, all scientific explanation involves sub-sumption under laws (Hempel, 1966). His D-N model was often called causal explanations (Salmon, 1998; Slabaugh & Parsons, 1976). In this view, Mendel's laws are explanation. However, this view is not accurate. Hempel (1966) explicitly notes that some laws, such as the laws of Boyle and of Charles, as well as Ohm's law were non-causal. For instance, ideal gas law "PV = nRT" are description. This law states a mathematical functional relationship among several quantities- pressure P, volume V, temperature T, number of moles of gas n, universal gas constant R but gives no hint as to how a change in one of the values would lead causally to changes in others. Therefore, Mendel's laws are not causal explanation but descriptions that arise from induction simply summarize a set of specific data. They are generali-zations that are believed to be a truth concerning natural phenomena (Bunge, 1979; Slabaugh & Parsons, 1976).

On the other hand, in an attempt to explain these laws, Mendel made a series of assumptions. They are not observations; they are not facts. They are the mechanisms that underlie and connect descriptive Mendel's laws. To understand this notion, consider another example of explanation. A textbook may describe the mechanism underlying the expansion rule in terms of the movement of particles: When a steel rod is heated, its particles move around and bump into each other more. Because the particles knock each other further apart, the space between the particles grows. Thus, the rod expands. Similarly, it is not a scientific explanation of the Aurora to associate the increased activity of sunspots with regularly antedate the appearance of the glow in the sky. A scientific explanation can tell why and how the sunspots are associated with the Aurora, and this involves discussions of the nature of the sunspots and of the paths of electrons that leave the sun. These discussions are relevant only because we have some idea about the nature of the Aurora, and know a good deal about the discharge of electricity in tenuous gases. In short, to explain the Aurora we demonstrate the mechanism producing the phenomenon, and so come to see why sun-spots are associated with the Aurora (Harré, 1978). Therefore, Mendel's laws are not hypotheses but description.

On the other hand, descriptive knowledge is generated upon making observations and collecting facts of a particular aspect of nature (Mayer, 1993). The investigators may find a pattern that permits him to draw up a generalization. This is inductive reasoning. It occasionally results in the formulation of a rule ora law. Explanatory knowledge is generated through the following process: Once a set of scientific facts are gathered, investigators want to know what caused this phenomena, and try to explain how or why the phenomena happen in the manner observed. They accomplish this task by constructing a tentative causal explanation, which is called a scientific hypothesis. When a hypothesis has survived extensive scrutiny, a hypothesis may be elevated to the status of a scientific theory (Brown & LeMay, 1981 Darian, 1995 Enger & Ross, 2003 Kimball, 1983 Lawson, 1995 Moore *et al.*, 1998 Slabaugh & Parsons, 1976 Uno & Moore, 2001).

In the process of explanatory knowledge generation, the meaning of a hypothesis is a tentative causal explanation, which is the concept of hypothesis-as -tentative causal explanation. In this view, a hypo-thesis is a possible answer to or an explanation of a question that accounts for all the observed facts. Furthermore, it is also a statement that explains why things happen in nature or an explanation for an observation that can be tested.

In conclusion, a hypothesis is a proposition or a set of propositions proposed as a tentative causal

explanation for an observed situation. In addition, although philosophers of science often differ as to the precise definition of the term of theory, the view of hypothesis-as-tentative causal explanation remarks that theory is a causal explanatory hypothesis that has stood the test of time and is supported well by the empirical evidence.

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