Scientific Methods - Advanced

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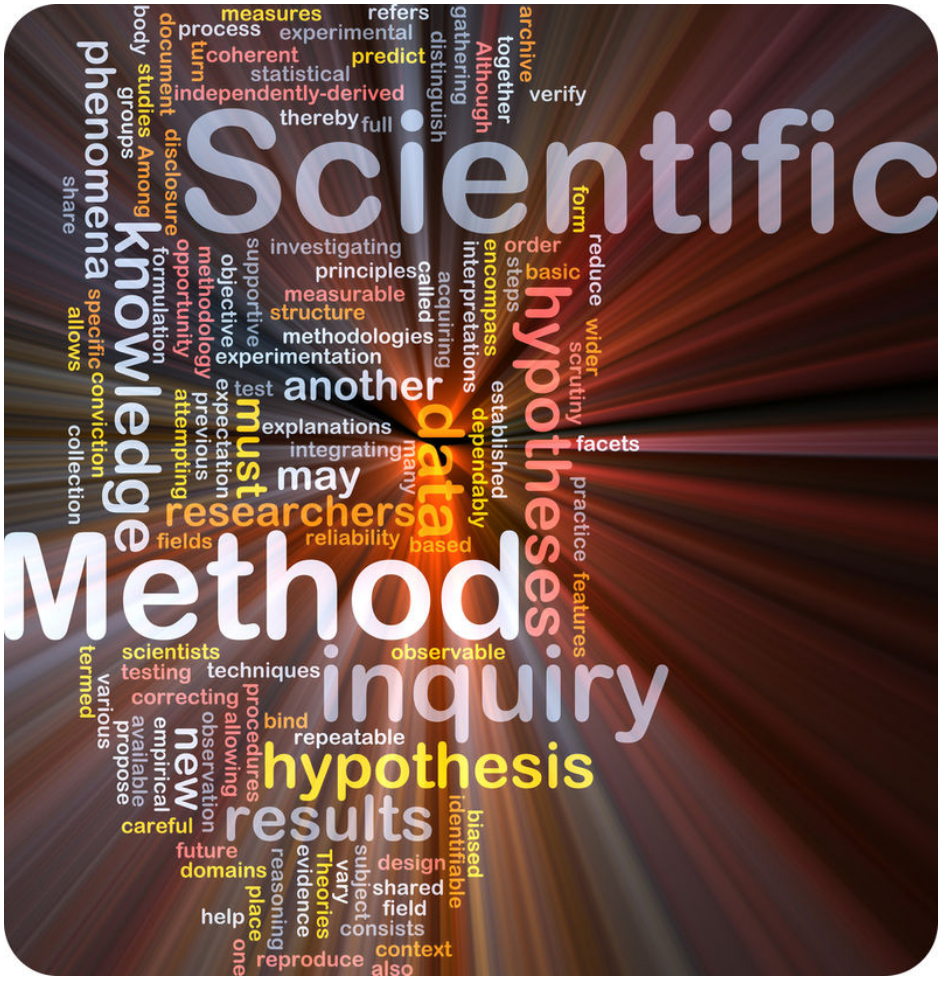
CHAPTER 1 Scientific Methods - Advanced

- Order the general steps of a scientific method.
- Outline a set of steps that are used in the scientific method of investigating a problem.
- Define hypothesis.
- Explain the importance of a hypothesis being falsifiable.
- Describe why a control group is used in an experiment.



What is the method of science?

How is science "done?" It can be difficult sometimes to define research methods in a way that will clearly distinguish science from non-science. However, there is a set of core principles that make up the “bones” of scientific research. These principles are widely accepted within the scientific community. Although there is no fixed set of steps that scientists always follow during an investigation, and there is no single path that leads scientists to knowledge, there are certain features of science that give it a distinct way of investigating.

Scientific Methods

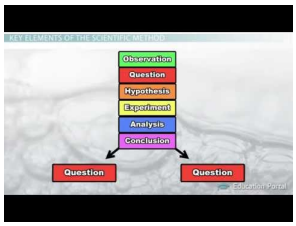
Scientific investigations examine, gain new knowledge, or build on previous knowledge about phenomena. A **phenomenon**, is any occurrence that is observable. It can be simply a burning match shown in the **Figure** 1.1,

as well as the structure of a cell and the prey of a lion. A phenomenon may be a feature of matter, energy, or time. For example, Isaac Newton made **observations** of the phenomenon of the moon's orbit, Galileo Galilei made observations of phenomena related to swinging pendulums and Charles Darwin made observations of unique plant and animal species. Although procedures vary from one field of scientific inquiry to another, certain features distinguish scientific inquiry from other types of knowledge. **Scientific methods** are based on gathering observable, empirical (produced by **experiment** or observation), and measurable **evidence** that is critically evaluated.

FIGURE 1.1

The combustion of this match is an observable event and therefore a phenomenon.

The Scientific Method Video can be seen at http://www.youtube.com/watch?v=BVfI1wat2y8 (4:25).



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Scientific Investigations

The scientific method is not a step by step, linear process. It is a way of learning about the world through the application of knowledge. Scientists must be able to have an idea of what the answer to an investigation should be. In order for scientists to make educated guesses about the answers, they will base their guesses on previous knowledge, with the notion of extending that knowledge. Scientists will often make an observation and then form a **hypothesis** to explain why a phenomenon occurred. They use all of their knowledge and a bit of imagination in their journey of discovery.

A hypothesis is a suggested explanation of a question or problem, based on evidence that can be tested by observation or experimentation. A hypothesis absolutely must be testable– it gains credibility by being tested over and over again, and by surviving attempts to prove it wrong. Scientists may test and reject several hypotheses before solving a problem.

Scientific investigations involve the collection of data through observation, the formation and testing of hypotheses

by experimentation, and analysis of the results that involves reasoning. Scientific investigations begin with observations that lead to questions.

We will use an everyday example to show what makes up a scientific investigation. Imagine that you walk into a room, and the room is dark.

- You observe that the room appears dark, and you question why the room is dark.
- In an attempt to find explanations to this phenomenon, you develop several different hypotheses. One hypothesis might be that the room does not have a light source at all. Another hypothesis might be that the lights are turned off. Still, another might be that the light bulb has burnt out. Worse yet, you could be going blind.
- To discover the answer, you experiment. You feel your way around the room and find a light switch and turn it on. No light. You repeat the experiment, flicking the switch back and forth; still nothing.
- This means your first two hypotheses, that the room is dark because (1) it does not have a light source; and (2) the lights are off, have been disproved.
- You think of more experiments to test your hypotheses, such as switching on a flashlight to prove that you are not blind.
- In order to accept your last remaining hypothesis as the answer, you could predict that changing the light bulb will fix the problem. If your predictions about this hypothesis succeed (changing the light bulb fixes the problem), the original hypothesis is valid and is accepted.
- However, in some cases, your predictions will not succeed (changing the light bulb does not fix the problem), and you will have to start over again with a new hypothesis. Perhaps there is a short circuit somewhere in the house, or the power might be out.

The general process of a scientific investigation is summed up in **Figure** 1.3.

TABLE 1.1: Common Terms Used in Scientific Investigations

Term	Definition
Scientific Method	The process of scientific investigation.
Observation	The act of noting or detecting phenomenon by the senses. For example, taking measurements is a form of observation.
Hypotheses	A suggested explanation based on evidence that can be tested by observation or experimentation.
Scientific Reasoning	The process of looking for scientific reasons for observations.
Experiment	A test that is used to rule out a hypothesis or validate something already known.
Rejected Hypothesis	An explanation that is ruled out by experimentation.
Confirmed Hypothesis	An explanation that is **not** ruled out by repeated experimentation, and makes predictions that are shown to be true.
Inference	Developing new knowledge based upon old knowledge.
Theory	A widely accepted hypothesis that stands the test of time. Theories are often tested, and usually not rejected.

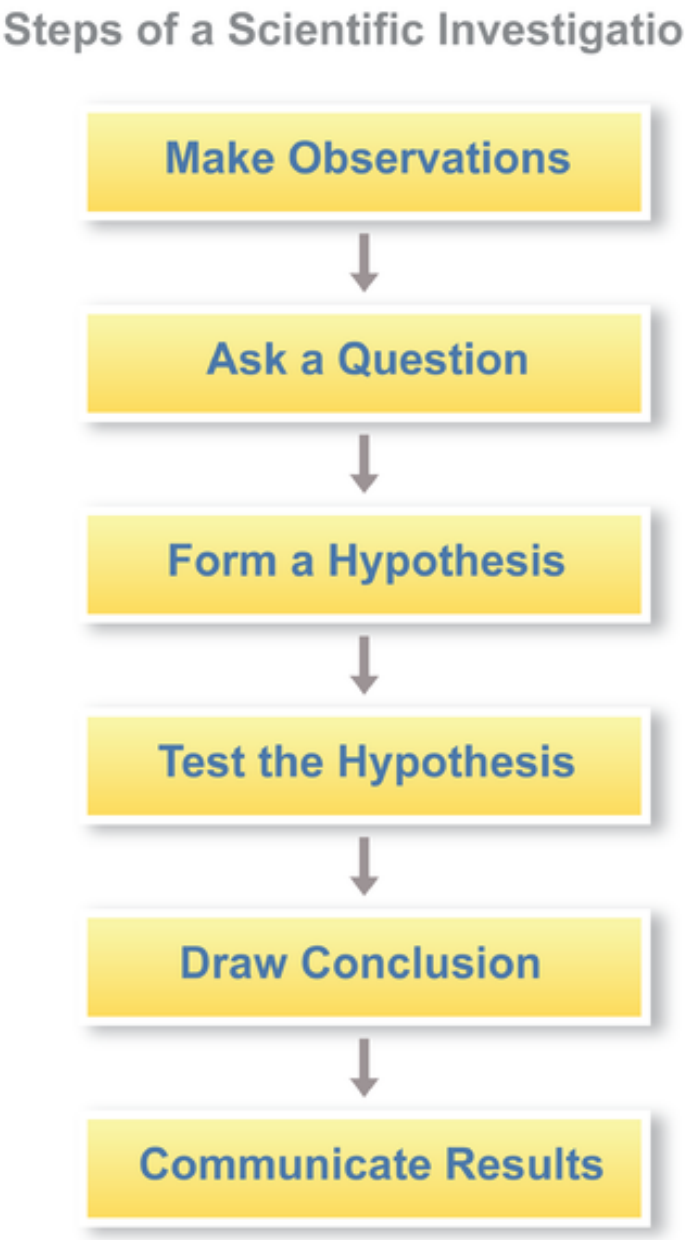

FIGURE 1.2

The general pathway of a scientific investigation. A scientific investigation typically has these steps, though the pathway is often modified for a specific scientific investigation.

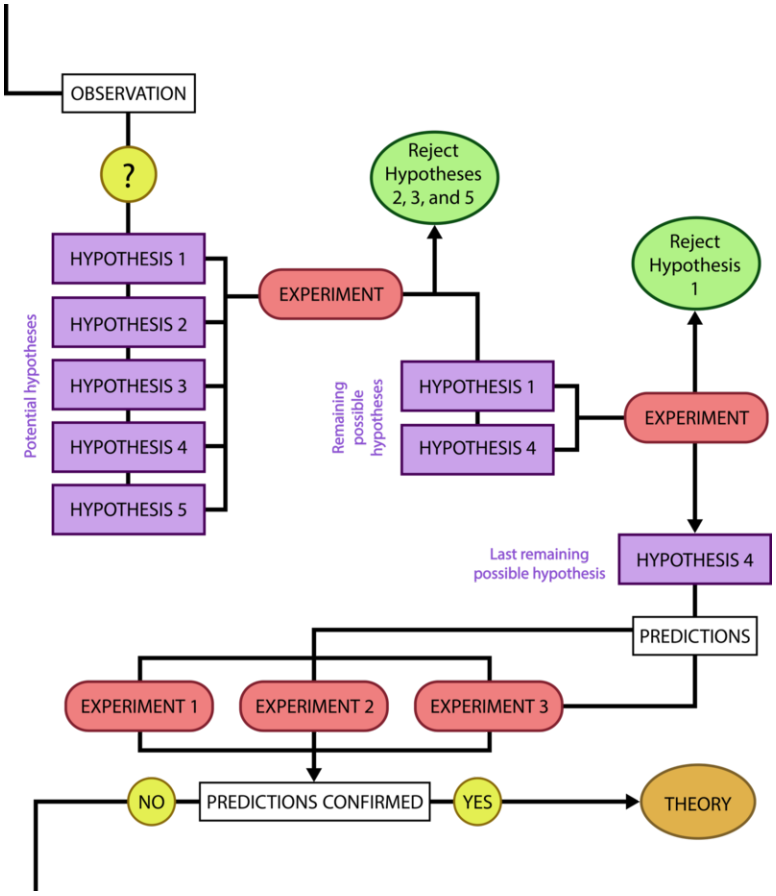

FIGURE 1.3

The general process of scientific investigations. This diagram illustrates how scientific investigations move from observation of phenomenon to a theory. The progress is not as straightforward as it looks in this diagram. Many times the hypothesis is falsified, which means the investigator will have to redevelop/revise a hypothesis.

The Scientific Method Made Easy explains the scientific method: http://www.youtube.com/watch?v=zcavPAFiG14 (9:55).

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Making Observations

Scientists first make observations that raise questions. An **observation** is the act of noting or detecting phenomenon through the senses. For example, noting that a room is dark is an observation made through sight.

Developing Hypotheses

In order to explain the observed phenomenon, scientists develop a number of possible explanations, or hypotheses. A hypothesis is a suggested explanation for a phenomenon or a suggested explanation for a relationship between many phenomena. Hypotheses are always based on evidence that can be tested by observation or experimentation. Scientific investigations are required to test hypotheses. Scientists mostly base hypotheses on prior observations or on extensions of existing scientific explanations.

Though many people describe a hypothesis as an "educated guess," that definition is not scientifically accurate. To define a hypothesis as "an educated guess" is like calling a tricycle a "vehicle with three." This definition of a tricycle leaves out its most important and characteristic feature: its wheels. The "educated guess" definition of a hypothesis also leaves out the concept's most important and characteristic feature: the purpose of the hypotheses. People generate hypotheses as early attempts to explain patterns observed in nature or to predict the outcomes of experiments. For example, in science, one could correctly call the following statement a hypothesis: identical twins can have different personalities because environment influences personality.

Evaluating Hypotheses

Scientific methods require hypotheses that are **falsifiable**, that is, they must be framed in a way that allows other scientists to prove them false. Proving a hypothesis to be false is usually done by observation and experimentation. However, confirming or failing to falsify a hypothesis does not necessarily mean the hypothesis is true.

For example, a person comes to a new country and observes only white sheep. This person might form the hypothesis: "All sheep in this country are white." This statement can be called a hypothesis, because it is falsifiable - it can be tested and proved wrong; anyone could falsify the hypothesis by observing a single black sheep, shown in **Figure** 1.4. If the experimental uncertainties remain small (could the person reliably distinguish the observed black sheep from a goat or a small horse), and if the experimenter has correctly interpreted the hypothesis, finding a black sheep falsifies the "only white sheep" hypothesis. However, you cannot call a failure to find non-white sheep as proof that no non-white sheep exist.

Vocabulary

- **evidence**: Any type of data that may be used to test a hypothesis.

FIGURE 1.4

The statement “there are only white sheep in this country” is a hypothesis because it is open to being falsified. However, failure to see a black sheep does not necessarily falsify the hypothesis. A better scientific hypothesis may be that "only white sheep can survive in this country because of the existing ecosystems."

- **experiment**: A test that is used to rule out a hypothesis or validate something already known; a test that is used to eliminate one or more of the possible hypotheses until one hypothesis remains.
- **falsifiable**: Can be proved false.
- **hypothesis** (plural, **hypotheses**): A suggested explanation based on evidence that can be tested by observation or experimentation.
- **observation**: The act of noting or detecting phenomenon through the senses.
- **phenomenon**: Any occurrence that is observable.
- **scientific investigation**: A plan for asking questions and testing possible answers.
- **scientific methods**: Procedures based on gathering observable, empirical (produced by experiment or observation) and measurable evidence that is critically evaluated.

Summary

- Scientific investigations involve the collection of data through observation, the formation and testing of hypotheses by experimentation, and analysis of the results that involves reasoning.

Review

1. Describe the scientific method.
2. What is an hypothesis?
3. How is a hypothesis developed and evaluated?
4. What is meant by falsifiable?
5. What happens if a hypothesis is false?

References

1. Jeff Turner. The combustion of this match is an observable event and therefore a phenomenon . CC BY 2.0
2. Hana Zavadska. A simple summary of the steps of a scientific investigation . CC BY-NC 3.0
3. Laura Guerin. A broader summary of how scientific investigations move from observation of a phenomena to a theory . CC BY-NC 3.0

4. David Schiersner. http://www.flickr.com/photos/freaky_designz/8732089237 . CC BY 2.0