Scientific Research Methods

The scientific method is the process by which scientists, collectively and over time, endeavor to construct an accurate (that is, reliable, consistent and non-arbitrary) representation of the world. Through the use of standard procedures and criteria we aim to minimize the cultural and personal perceptions that influences when developing a theory. As a famous scientist once said, "Smart people (like smart lawyers) can come up with very good explanations for mistaken points of view." In brief, the scientific method attempts to minimize the influence of bias or prejudice of the experimenter when testing a hypothesis or a theory.

There are a few common steps for any type of scientific research. They are as follow.

1- **Defining a Question (or a phenomenon):** This is the first step, in which you define your research question by observation and description of a phenomenon or a group of phenomena. Your question must be specific and something that has not been answered before. This means that you must have done a through literature review about your specific research question and be aware of the latest developments and also the shortcoming of previous researches.

2- **Formulating a hypothesis:** Based on your question you formulate a hypothesis to explain your research question.

3- **Literature Review:** Once you have set your hypothesis, then you must do a thorough literature review and gather information and sources about the methods that can confirm or disprove your hypothesis.

4- **Testing the Hypothesis (Methodology Selection):** Depending what the nature of hypothesis is, you may choose different methods to confirm or disprove your hypothesis.

5- **Interpreting the Results**

6- **Communicating the Results**

Hypothesis

A hypothesis is a provisional idea whose merit needs evaluation. A hypothesis must be falsifiable that one should confirm or disprove it with research. A confirmed hypothesis may grow to become a theory itself. A hypothesis can have a form of a mathematical model or a general form of existing statements. Any useful hypothesis will enable prediction by reasoning. It might predict an outcome of an experiment in a laboratory setting or the observation of a phenomenon in nature. The hypothesis may have a statistical nature and the prediction may only talk about probabilities. For example, a hypothesis can be "the lung sounds of asthmatic people are different from those of healthy people." In order to confirm or disprove this hypothesis one may choose only experimental method or mode the lung sounds of asthmatic and health people and show that they are substantially different. Or another hypothesis can be as simple as "the average height of Canadian infants is 52 cm." This hypothesis has a statistical nature and can be confirmed or disproved by a survey and statistical analysis.
Hypotheses, Models, Theories and Laws

In science and engineering disciplines, the words "hypothesis," "model," "theory" and "law" have different connotations in relation to the stage of acceptance or knowledge about a group of phenomena.

A hypothesis is a limited statement regarding cause and effect in specific situations; it also refers to our state of knowledge before experimental work has been performed and perhaps even before new phenomena have been predicted. To take an example from daily life, suppose you discover that your car will not start. You may say, "My car does not start because the battery is low." This is your first hypothesis. You may then check whether the lights were left on, or if the engine makes a particular sound when you turn the ignition key. You might actually check the voltage across the terminals of the battery. If you discover that the battery is not low, you might attempt another hypothesis.

The word model is reserved for situations when it is known that the hypothesis has at least limited validity. An often-cited example of this is the Bohr model of the atom, in which, in an analogy to the solar system, the electrons are described to have movements in circular orbits around the nucleus. This is not an accurate depiction of what an atom "looks like," but the model succeeds in mathematically representing the energies (but not the correct angular momentum) of the quantum states of the electron in the simplest case, the hydrogen atom. Another example is Newton’s second law. Newton’s "law" is based on the assumption that the mass doesn’t change with velocity and now we know that it fails if a particle travels with a sped close to the speed of light.

A scientific theory or law represents a hypothesis, or a group of related hypotheses, which has been confirmed through repeated experimental tests. Theories in physics are often formulated in terms of a few concepts and equations, which are identified with "laws of nature," suggesting their universal applicability.

Accepted scientific theories and laws become part of our understanding of the universe and the basis for exploring less well-understood areas of knowledge. Theories are not easily discarded; new discoveries are first assumed to fit into the existing theoretical framework. It is only when, after repeated experimental tests, the new phenomenon cannot be accommodated that scientists seriously question the theory and attempt to modify it. The validity that we attach to scientific theories as representing realities of the physical world is to be contrasted with the facile invalidation implied by the expression, "It's only a theory." For example, it is unlikely that a person will step off a tall building on the assumption that he will not fall, because "Gravity is only a theory."

Changes in scientific thought and theories occur, of course, sometimes revolutionizing our view of the world (Kuhn, 1962). Again, the key force for change is the scientific method, and its emphasis on experiment.
Testing the Hypothesis – Selecting Methodology

As just stated, experimental tests may lead either to the confirmation of the hypothesis, or to the ruling out of the hypothesis. The scientific method requires that a hypothesis be ruled out or modified if its predictions are clearly and repeatedly incompatible with experimental tests. Further, no matter how elegant a theory is, its predictions must agree with experimental results if we are to believe that it is a valid description of nature. In engineering, as in every experimental science, "experiment is supreme" and experimental verification of hypothetical predictions is absolutely necessary. Furthermore, it is crucial to design the experimental protocol in a right way such that the results can lead to confirm or disprove the hypothesis.

In order to design experiments to test your hypothesis, you must consider the research questions and then design the experiments such that the results answer the question with confidence. In another word if you design the experiments such that the outcomes are also affected by some factors other than what you considered as the inputs, then your results will not be conclusive. Therefore, in the design of an experiment or set of experiments it is crucially important to indentify the independent and dependant variables that affect the results. Data analysis technique has also to be chosen with care respect to the number of trials, number of available data and the assumptions that each data analysis technique may have. For example, if you use the power spectral analysis, your data must be stationary; otherwise, it will be meaningless to apply spectral analysis on non-stationary signals as its assumptions have been violated. You must also be careful in the design of the experiment to make sure about your signal to noise ratio and that you’re really recording signal and not just the environmental noise.

Error Sources

Errors in experiments have several sources. First, there is error intrinsic to instruments of measurement. Because this type of error has equal probability of producing a measurement higher or lower numerically than the "true" value, it is called random error. Sampling errors due to sample size, mismatch between the groups, etc. are in this category too.

Second, there is non-random or systematic error, due to factors which bias the result in one direction. No measurement, and therefore no experiment, can be perfectly precise.

At the same time, in science we have standard ways of estimating and in some cases reducing errors. Thus it is important to determine the accuracy of a particular measurement and, when stating quantitative results, to quote the measurement error. A measurement without a quoted error is meaningless. The comparison between experiment and theory is made within the context of experimental errors. Scientists ask how many standard deviations are the results from the theoretical prediction? Have all sources of systematic and random errors been properly estimated?

The Systematic Errors can be avoided by randomization, representative sampling, blinding, accurate recording and documentation, comprehensive data analysis.
The Random Errors can be avoided by increasing the sample size, stratification, matching the groups, avoiding disturbance variables and standardizing the recordings.

**Some Common Mistakes**

As stated earlier, the scientific method attempts to minimize the influence of the scientist's bias on the outcome of an experiment. That is, when testing a hypothesis or a theory, the scientist may have a preference for one outcome or another, and it is important that this preference not bias the results or their interpretation. The most fundamental error is to mistake the hypothesis for an explanation of a phenomenon, without performing experimental tests. Sometimes "common sense" and "logic" tempt us into believing that no test is needed. There are numerous examples of this, dating from the Greek philosophers to the present day.

Another common mistake is to ignore or rule out data which do not support the hypothesis. Ideally, the experimenter is open to the possibility that the hypothesis is correct or incorrect. Sometimes, however, a scientist may have a strong belief that the hypothesis is true (or false), or feels internal or external pressure to get a specific result. In that case, there may be a psychological tendency to find "something wrong", such as systematic effects, with data which do not support the scientist's expectations, while data which do agree with those expectations may not be checked as carefully. The lesson is that all data must be handled in the same way.

Another common mistake arises from the failure to estimate quantitatively systematic errors (and all errors). There are many examples of discoveries which were missed by experimenters whose data contained a new phenomenon, but who explained it away as a systematic background. Conversely, there are many examples of alleged "new discoveries" which later proved to be due to systematic errors not accounted for by the "discoverers."

In a field where there is active experimentation and open communication among members of the scientific community, the biases of individuals or groups may cancel out, because experimental tests are repeated by different scientists who may have different biases. In addition, different types of experimental setups have different sources of systematic errors. Over a period spanning a variety of experimental tests (usually at least several years), a consensus develops in the community as to which experimental results have stood the test of time.