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SCIENCE - THE PURSUIT OF KNOWLEDGE

M.C.M. Iqbal
Plant Biology, Institute of Fundamental Studies, Kandy.

As humans, we are curious. We are different from other species in that we possess and seek knowledge beyond our need for survival on this planet. This knowledge was acquired in ancient times through various sources: sensory perception, development of skills, accumulation of past experiences, and spiritual teachings, among others. The Greek philosophers used logical reasoning to seek universal truths. We seek explanations (causes) for the various phenomena (effects) which occur around us. In the past, and even now, humans found causes in spiritual and mythological sources. Science as a source of knowledge is different: it looks for causes and effects which are solely governed by physical laws. Thus, cause and effect was reduced to a mechanistic explanation, which unlike mythological explanations, also had predictive capabilities.

The Scientific Method

The scientific method that we practice today evolved during the 16th and 17th centuries as a means of acquiring knowledge. The scientific process of investigation is open and transparent. The methods used are explicitly described and available to anybody to repeat and establish what is claimed through a process of open verification.

The scientific method is initiated with a hypothesis. A hypothesis is a speculation, based on observed facts, put forward to explain a phenomenon. It is the first step to explain the cause of an effect. Natural phenomena, for which we seek explanations, come in two forms: those directly observable (apples falling, birds flying, ocean tides etc.) and those that are not directly observable (cause of certain diseases, global warming, atoms and molecules etc.). The former can be directly tested by experiments, but the latter requires indirect or proxy experiments to explain the observations. This is where the ingenuity of the scientist is called upon to formulate a hypothesis and design experiments that can validate or disprove the proposed hypothesis.

The essential steps of the scientific method are shown in Fig. 1. The process of hypothesis testing is at the core of the scientific method based on a cycle of hypothesis proposal, observations, experiments, acceptance or rejection of hypothesis.

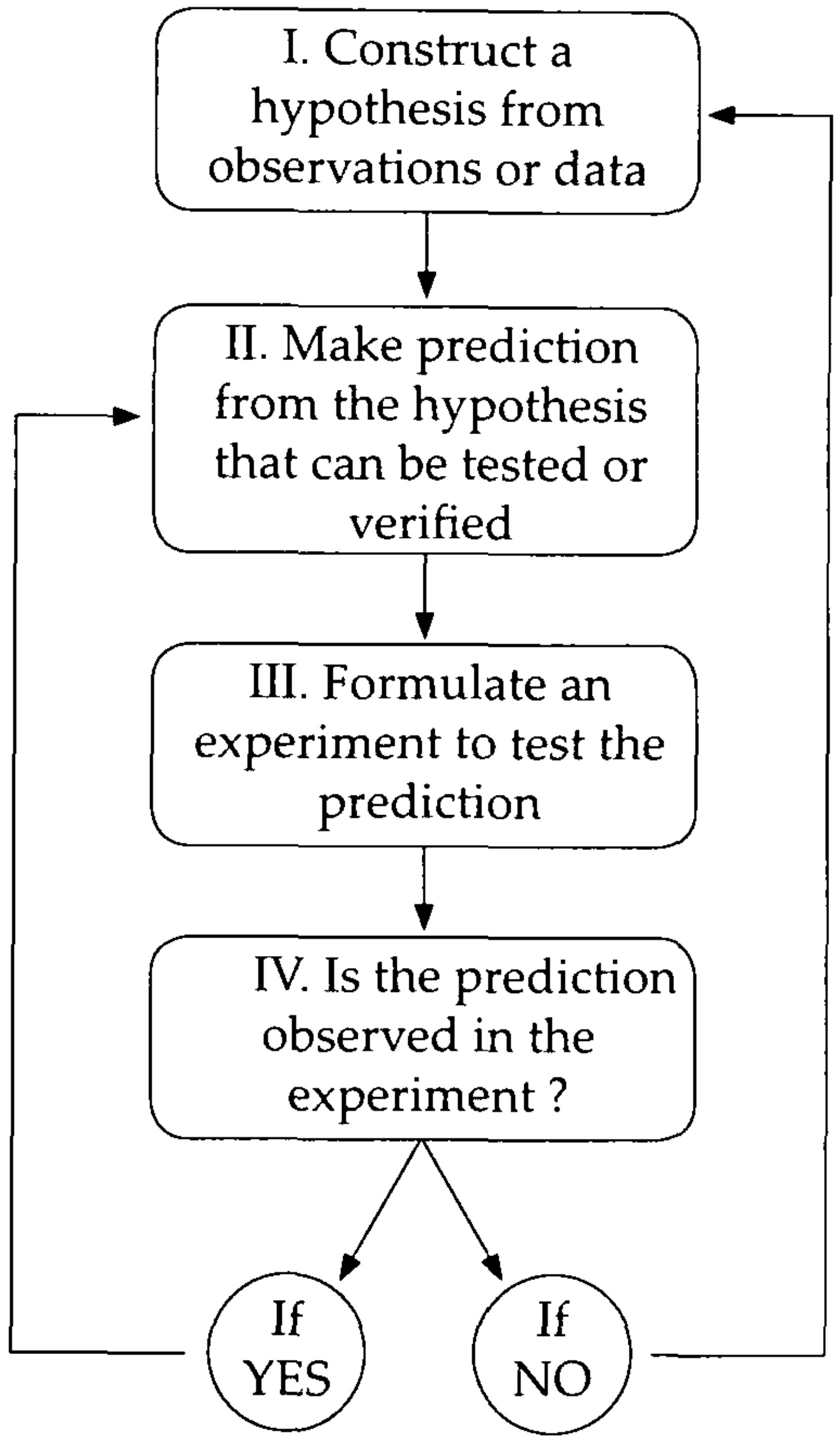

Figure 1. The sequence of steps in the scientific method

Hypothesis and Hypothesis Testing

In everyday life, we propose a variety of hypothesis to explain different phenomena that affect our lives: the politics in our country, the cost of living, the changing morality in our society etc. We hypothesize because we do not know the answers or the truth. This popular pastime may be regarded as speculation. At the same time, we do not bother any more as to why the sun rises from the east or why coconuts fall down from the tree. So, what characterizes a hypothesis in science? A fundamental character of science is that a hypothesis should be *testable* to prove whether it is correct or not. Statements that cannot be proved or disproved are useless in science, whose ultimate objective is to arrive at the truth.

To explain a natural phenomenon or a problem that needs a rational explanation, scientists resort to the scientific method. This requires that we make observations and gather all the relevant information available on the problem. From this a good "guess" is made from the information available and the available background knowledge. This logical or educated guess is a hypothesis to explain the problem or phenomenon observed. To determine if the hypothesis is correct or not it has to be tested. Predictions are made from the hypothesis which can be tested by experiments. If the observations or results are in agreement with the prediction made from the hypothesis, the hypothesis is retained; if not it is rejected and a new hypothesis is formulated and further tested. A good scientist is one who is ready to discard his/her hypothesis at the first signs of disagreement with the observations.

Science is based on testing the validity of a proposed hypothesis, which seeks to explain a natural phenomenon or a question. This is done by conducting experiments and recording observations. Chapter 16 describes how you should record observations carefully and what steps should be followed to obtain reliable and unbiased observations. A scientist begins a research project with a certain objective: to prove or disprove a fact, to find explanations for an inexplicable phenomenon, to find the cause of a particular effect, to determine the outcome of a particular treatment etc. All these add to the available knowledge in that particular field. The ultimate objective of the experiment is framed as a hypothesis, at the beginning of the research project. It is vital to answer or test the hypothesis that observations are made with an open mind without any preconceptions of what we are looking for. We should not look for observations that would prove our hypothesis correct – which is a common failing among many scientists. Such an approach is adopted to prove that one's pet theory is correct. Such a path is useless since science is an open enterprise and a flawed conclusion would be eventually exposed by others. In practice, a scientist looks for evidence to support his or her theory, but is always on the lookout for observations that may contradict the theory. If such evidence arises, the hypothesis should be formulated again. A good scientist always looks at the results with skepticism or doubt. Skepticism is important for the progress of science. Scientific results are always open to correction, as new methodologies, analytical abilities and observations arise with time. Thus, scientific facts are never absolute.

Requirements of a Hypothesis

The fundamental characteristics of a hypothesis are:

- It should be testable
- It should be able to make predictions
- It should be falsifiable (can be proven wrong)

The concept of 'falsifiability' was introduced by the Austrian philosopher Sir Karl Popper (1902-1994). He argued that facts in this universe cannot be proven correct, but can only be proven incorrect. His famous example was: All ravens (or crows) are black based on our previous observations. Our intuition tells us that this is a correct statement. It can be tested by observing samples of crows from different parts of the world. However, it *cannot be proven wrong*. We cannot observe all the crows in the universe – thus the statement cannot be falsified. One can only show that the statement is true.

Here is another statement: "Coconuts would fall to the ground."
This is easily proven by releasing a coconut from a height. It can also be proven wrong: if coconuts are found anywhere that does not fall down when released from a height (e.g. they float in the air).

A hypothesis also makes predictions and can be generalized or is universal: any object released from a height would fall to the ground. The statement on the colour of crows does not allow any universal predictions.

What is the correct Question?

Research projects always begin with a question. It is therefore absolutely important that the correct question is asked. Asking the wrong question would lead us to a dead-end or a meaningless answer. A very confusing question is "Which came first: the chicken or the egg?" where the question is limited to chickens and eggs, which does not provide the entire picture. This is because we are looking at a very specific phenomenon. However, if we look at the evolutionary process of life, an answer would be forthcoming. At what stage during the evolution of the vertebrates did the precursor of the egg appear? The question now focuses on the evolutionary process leading to the egg, which should now provide an answer.

How does one come up with a hypothesis? Although there are some sources for ideas, it is ultimately the ability of the scientist, based upon the background information one has accumulated and the analytical capability, to suggest an innovative solution. Some sources for ideas are:

- Comparing the problem with other similar situations
- Identifying patterns
- By developing new methodologies
- Imagination and intuition

The Limits of Science

Does science have answers to all the questions? No. Science is limited to the observable universe which is the world we live in. Science does not and is incapable of answering questions of religion such as: Is God behind the Theory of Evolution and the Theory of Gravitation? Did God create the universe and life etc? Answers to these questions are based on belief, faith and individual reasoning. Science operates on factual data or empirical evidence. It cannot be applied to subjective judgments such as evaluating what is good or bad, deciding on ethical implications of an outcome in science (e.g. genetic engineering, nuclear energy, stem cells etc.), and the morality of human actions. Today, science has not only understood many of the phenomena in our environment, but is able to manipulate previously unthought of changes: plants can be engineered to deliver products not in their original genomic blueprint, babies are produced in test tubes, and the energy binding sub-atomic particles within the atom can be unleashed, to name a few.

The Philosophy of Science

The philosophy of science seeks to identify what is science and thereby exclude disciplines that do not belong to science or where the methods in science cannot be successfully applied. Establishing the correct foundations of science, and determining the methods of investigation are the purpose and the responsibility of philosophy, which by a process of discussions, arguments and evaluations can point the way to possible answers, which are more often than not equivocal. Thus, in essence, the scientific process tells us what "is" and not what "ought" to be. Science provides the basic understanding of how the various processes on earth function, and technology has extended this to practical applications, which have transformed society irrevocably. This transformation has meant improved standards of living, giant strides in the acquisition of knowledge and in our comprehension of the universe.