UNIT 3 EVOLUTION OF THE DISTINCT METHODS OF SCIENCE

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3.0 OBJECTIVES

The main object of this Unit is to give a pre-taste of different methods of science. In this unit we shall try to give a definition of scientific method, both etymological and real; then we shall proceed to know how different scientific methods developed in the history of science. Further we shall discuss about the scientific method and its components, the scope and importance of scientific methods in our life and how to use the different methods of science in our day to day life. At the end we come to know that a scientific method consists of the collection of data through observation and experimentation, and the formulation and testing of hypotheses and it enhances the life of humanity in different ways. Thus by the end of this Unit you should be able: to have a basic understanding of methods of science; to know the development of the scientific methods; to understand the all-comprehensive character of scientific methods; to know the importance of scientific methods both at the theoretical and practical levels; to know how to apply scientific methods in experiments.

3.1 INTRODUCTION

The term "science" is used to identify the various sciences, or domains of activity. First to be recognized were the natural sciences, such as physics, astronomy, chemistry, geology, and biology. The human and social sciences have also been termed sciences. Some of these are psychology, economics, education, geography, and sociology. Science has contributed much to the development of human beings. By using scientific principles, man has pulled back the curtain of ignorance and advanced the quality of life. The essence of science is the scientific method where a hypothesis is tested by experiment. Instead of endless philosophical discussions to prove a point, experiment becomes the final arbitrator of truth and a successful approach. To make an experiment we need to have distinct methods to prove a point or truth. The so called “method” is so engrained in our way of approaching science today that we tend to take it for granted. The scientific method is the process by which scientists, collectively and over time, endeavour to construct an accurate representation of the world. Let us venture into the exploration of different scientific methods in this unit.

3.2 DEFINITION OF SCIENTIFIC METHOD

The scientific method or process is fundamental to the scientific investigation and acquisition of new knowledge based upon physical evidence. Science manages new assertions about our world with theories, hypotheses and observations. Predictions from these theories are tested by experiment. If a prediction turns out correct, the theory survives, but if a prediction fails the theory fails. The scientific method is essentially an extremely cautious means of building a supportable, evidenced understanding of our world. A scientific method consists of the collection of data through observation and experimentation, and the formulation and testing of hypotheses. Scientific method refers to a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge. To be termed scientific, a method of inquiry must be based on gathering observable, empirical and measurable evidence subject to specific principles of reasoning. The scientific method is the basic method, guide, and system by which we originate, refine, extend, and apply knowledge in all fields.

The word science has its origins in the Latin verb *scire*, meaning “to know.” Although, one can “know” through tenacity, authority, faith, intuition, or science, the method of science or the scientific method is distinct in its notion of inter-subjective certification. In other words, it should be possible for other investigators to ascertain the truth content of scientific explanations. “Scientific knowledge thus rests on the bedrock of empirical testability”. Empirical replication depends on a comparison of “objective” observations of different researchers studying the phenomenon.

The Scientific Method has Four Steps:

- Observation and description of a phenomenon or group of phenomena.
- Formulation of a hypothesis to explain the phenomena.
- Use of the hypothesis to predict the existence of other phenomena, or to predict quantitatively the results of new observations.
- Performance of experimental tests of the predictions by several independent experimenters and properly performed experiments.

3.3 THE EVOLUTION OF SCIENTIFIC METHODS

Modern western science had its beginnings with the Greeks, who conceived the revolutionary idea that the universe was a kind of machine governed by inflexible laws. This idea became the mechanistic model of science. The Greek philosophers devoted themselves to the task of discovering, through intellectual reasoning alone, the laws of the universe. Modern scientific thought, thus, evolved from the Greek philosophers who were influenced by the Egyptians, Babylonians, and Assyrians. Their greatest successes were in the field of geometry. The Greek successes are attributable to two techniques: abstraction and generalization. So successful were these techniques in developing mathematical theory that the concepts were extended to other disciplines, but with much less success. However, the process of looking for absolute truth through reasoning alone was so ingrained in the Greek thinking patterns that they ignored the experiential evidence which was contrary to their elegant theorems and proofs.

The Renaissance thinkers, however, brought a fresh outlook. The most famous turning point came in 1543 when the Polish astronomer Copernicus published a book which proposed the sun, not the earth, as the centre of the universe. Although this hypothesis had been put forth in 200 B.C.E, it was in 1543 diametrically opposed to the assumptions of the Greeks and the teachings of the Church that caused a great uproar within the intellectual world. It was left to Galileo to have the audacity to test the Greek theories. His most famous experiment probably never happened, but it makes a good story. Galileo supposedly dropped two cannon balls of different weights from the leaning tower of Pisa to prove Aristotle's theory that the heavier body would hit the ground first. The resounding thump of the two spheres hitting the ground simultaneously killed Aristotelian physics and elevated inductive reasoning as a scientific tool. Inductive reasoning begins with observations and derives generalizations (axioms) from the observations; whereas deductive reasoning, the method of the Greeks, begins with generalizations and proceeds to predict observations. But it was the recognition during the Renaissance that no amount of deductive reasoning can render a generalization completely and absolutely valid that turned the Greek philosophy upside down.

Francis Bacon offered four steps for scientific work: observe, measure, explain, and verify. And then there was René Descartes who also gave four rules for his method to find the truth in 1961. The rules are as follows:

- Never to accept anything for true which I do not clearly know to be such.
- Divide each of the difficulties under examination into as many parts as possible.
- Begin with the simplest and easiest and then work step by step to the more complex.
- Make enumerations so complete and reviews so general that I might be assured that nothing is omitted.

The essentially contemporaneous writings of Galileo, Bacon and Descartes revolutionized scientific procedures and gave rise to what has been called the scientific method. The collective ideas which Galileo, Bacon, and Descartes brought to scientific endeavour have changed somewhat since the 17th century. By the 19th century, the method developed into six steps, and in the 20th century the method developed into seven, namely:

- Pose a question about nature, not necessarily as the result of an observation.
- Collect the pertinent, observable evidence.
- Formulate an explanatory hypothesis, defining relevant assumptions.
- Deduce its implications.

- Test all of the implications experimentally.
- Accept, reject, or modify the hypothesis based upon the experimental results.
- Define its range of applicability.

The scientific method's essential elements are iterations, recursions interleavings, and orderings of the following four steps:

- Characterization
- Hypothesis (a theoretical, hypothetical explanation)
- Prediction (logical deduction from the hypothesis)
- Experiment (test of all of the above)

Iteration is the repetition of a process, it is a repetition in a specific form of repetition with a mutable state and recursion is a particular way of specifying or constructing a class of objects with the help of a reference to other objects of the class: a recursive definition defines objects in terms of the already defined objects of the class. Interleaving is a way to arrange data in a non-contiguous way to increase performance. Orderings formalizes the intuitive concept of an ordering, sequencing, or arrangement of the elements of a set.

Characterization

The scientific method depends upon a careful characterization of the subject of the investigation. Here the subject may also be called the problem or the unknown. Observation demands careful measurement and the use of operational definitions of relevant concepts. Formally, these terms have exact meanings which do not necessarily correspond with their natural language usage. For example, mass and weight are quite distinct concepts. New theories may also arise upon realizing that certain terms had not previously been clearly defined. For example, Albert Einstein's first paper on relativity begins by defining simultaneity and the means for determining length. These ideas were skipped over by Newton with, "I do not define time, space, place and motion, as being well known to all." Einstein's paper then demonstrates that these widely accepted ideas were invalid.

3.4 HYPOTHESIS

A hypothesis is a suggested explanation of a phenomenon, or a reasoned proposal suggesting a possible correlation between or among a set of phenomena. A hypothesis includes a suggested explanation of the subject. It will generally provide a causal explanation or propose some correlation. Observations have the general form of existential statements, stating that some particular instance of the phenomenon being studied has some characteristics. Causal explanations have the general form of universal statements, stating that every instance of the phenomenon has a particular characteristic. It is not deductively valid to infer a universal statement from any series of particular observations. This is the problem of induction. Scientists use whatever they can, their own creativity, ideas from other fields, induction, systematic guessing etc.; to imagine possible explanations for a phenomenon under study. There are no definitive guidelines for the production of new hypotheses. The history of science is filled with stories of scientists claiming a "flash of inspiration", or a hunch, which then motivated them to look for evidence to support or refute their idea. Michael Polanyi made such creativity the centre piece of his discussion of methodology.

Prediction from the Hypothesis

A useful hypothesis will enable predictions, by deductive reasoning that can be experimentally assessed. If results contradict the predictions, then the hypothesis under test is incorrect or incomplete and requires either revision or abandonment. If results confirm the predictions, then the hypothesis might be correct but is still subject to further testing. Einstein's theory of General Relativity makes several specific predictions about the observable structure of space-time, such as a prediction that light bends in a gravitational field and that the amount of bending depends in a precise way on the strength of that gravitational field. Observations made during a 1919 solar eclipse supported General Relativity rather than Newtonian gravitation.

Predictions refer to experiment designs with a currently unknown outcome; the classic example was Edmund Halley's prediction of the year of return of Halley's comet which returned after his death. A prediction differs from a consequence, which does not necessarily bear a time-dependent connotation. Thus, one consequence of General Relativity, which Einstein deduced, was the size of the precession of the perihelion of the orbit of the planet Mercury. The observed value, on the order of 42 arc-seconds per century, was one of the pieces of evidence for Einstein's characterization of his theory of General Relativity. This consequence was known to Einstein, in contrast to his predictions, in which he had enough confidence to publish.

Experiment

Once a prediction is made, an experiment is designed to test it. The experiment may seek either confirmation or falsification of the hypothesis. Yet an experiment is not an absolute requirement. In observation based fields of science actual experiments must be designed differently than for the classical laboratory based sciences. Scientists assume an attitude of openness and accountability on the part of those conducting an experiment. Detailed recordkeeping is essential, to aid in recording and reporting on the experimental results, and providing evidence of the effectiveness and integrity of the procedure. They will also assist in reproducing the experimental results. Integrity may be augmented by the introduction of a control. Two virtually identical experiments are run, in only one of which the factor being tested is varied. This serves to further isolate any causal phenomena. For example in testing a drug it is important to carefully test that the supposed effect of the drug is produced only by the drug itself. Doctors may do this with a double-blind study: two virtually identical groups of patients are compared, one of which receives the drug and one of which receives a placebo. Neither the patients nor the doctor know who is getting the real drug, isolating its effects.

Once an experiment is complete, a researcher determines whether the results or data gathered are what was predicted. If the experimental conclusions fail to match the predictions/hypothesis, then one returns to the failed hypothesis and re-iterates the process. If the experiments appear "successful" i.e. fits the hypothesis, its details are published so that others may reproduce the same experimental results.

3.5 THEORY-DEPENDENCE OF OBSERVATION

The scientific method depends on observation, in defining the subject under investigation and in performing experiments. Observation involves perception, and so is a cognitive process. That is, one does not make an observation passively, but is actively involved in distinguishing the thing being observed from surrounding sensory data. Therefore, observations depend on some underlying understanding of the way in which the world functions and that understanding may influence what is perceived, noticed, or deemed worthy of consideration. Empirical observation is supposedly used to determine the acceptability of some hypothesis within a theory. When someone claims to have made an observation, it is reasonable to ask them to justify their claim. Such a justification must itself make reference to the theory - operational definitions and hypotheses - in which the observation is embedded. That is, the observation is a component of the theory that also contains the hypothesis it either verifies or falsifies. But this means that the observation cannot serve as a neutral arbiter between competing hypotheses. Observation could only do this "neutrally" if it were independent of the theory.

Thomas Kuhn denied that it is ever possible to isolate the theory being tested from the influence of the theory in which the observations are grounded. He argued that observations always rely on a specific paradigm, and that it is not possible to evaluate competing paradigms independently. By "paradigm" he meant, essentially, a logically consistent "portrait" of the world, one that involves no logical contradictions. More than one such logically consistent construct can each paint a usable likeness of the world, but it is pointless to pit them against each other, theory against theory. Neither is a standard by which the other can be judged. Instead, the question is which "portrait" is judged by some set of people to promise the most in terms of "puzzle solving". For Kuhn, the choice of paradigm was sustained by, but not ultimately determined by, logical processes. The individual's choice between paradigms involves setting two or more "portraits" against the world and deciding which likeness is most promising. In the case of a general acceptance of one paradigm or another, Kuhn believed that it represented the consensus of the community of scientists. Acceptance or rejection of some paradigm is, he argued, more a social than a logical process. That observation is embedded in theory does not mean that observations are irrelevant to science. Scientific understanding derives from observation, but the acceptance of scientific statements is dependent on the related theoretical background or paradigm as well as on observation. Coherentism and skepticism offer alternatives to foundationalism for dealing with the difficulty of grounding scientific theories in something more than observations.

Demarcation

Scientific Method is touted as one way of determining which disciplines are scientific and which are not. Those which follow the scientific method might be considered sciences; those that do not are not. That is, method might be used as the criterion of demarcation between science and non-science. If it is not possible to articulate a definitive method, then it may also not be possible to articulate a definitive distinction between science and non-science, between science and pseudo-science, and between scientists and non-scientists. Feyerabend denies there is a scientific method, and in his book *Against Method*, argues that scientific progress is not the result of the application of any particular method. In essence, he says that anything goes. Thus the demarcation helps us to know the divergence of scientific methods and non- scientific methods.

3.6 SCOPE OF SCIENCE AND SCIENTIFIC METHODS

The scopes of scientific methods are massive and very useful in our life. Scientific method is not a recipe. It requires intelligence, imagination, and creativity. It is also an on-going cycle, constantly developing more useful, accurate and comprehensive models and methods. Science is not merely a collection of facts, concepts, and useful ideas about nature, or even the systematic investigation of nature, although both are common definitions of science. Science is a method of investigating nature, a way of knowing about nature that discovers reliable knowledge about it. In other words, science is a method of discovering reliable knowledge about nature. There are other methods of discovering and learning knowledge about nature. These other knowledge methods or systems will be discussed below in contradistinction to science, but science is the only method that results in the acquisition of reliable knowledge.

Reliable knowledge is knowledge that has a high probability of being true because its veracity has been justified by a reliable method. Reliable knowledge is sometimes called justified true belief, to distinguish reliable knowledge from belief that is false and unjustified or even true but unjustified. The important distinction that should be made is whether one's knowledge or beliefs are true and, if true, are justifiably true. Every person has knowledge or beliefs, but not all of each person's knowledge is reliably true and justified. In fact, most individuals believe in things that are untrue or unjustified or both: most people possess a lot of unreliable knowledge and, what's worse, they act on that knowledge. Other ways of knowing, and there are many in addition to science, are not reliable because their discovered knowledge is not justified. Science is a method that allows a person to possess, with the highest degree of certainty possible, reliable knowledge, justified true belief about nature. The method used to justify scientific knowledge, and thus make it reliable, is called the scientific method. The scientific method has proven to be the most reliable and successful method of thinking in human history, and it is quite possible to use scientific thinking in other human endeavours.

Importance of Scientific method

It is of great national importance that the scientific method, which is not just for scientists but is really a general problem solving method for everyone. Centuries of study, debate, and experimentation has established that the best of all methods of obtaining and originating reliable knowledge in all fields is the scientific method. The scientific method is the guide to the mental activities and systems needed to solve the complex competitiveness problems. It is, rather, an attitude, a philosophy, an ethic to guide the process humans use to make sense out of the deluge of sensory experience which is the foundation of our progression to Paradise. As it has evolved, the method is so pervasive that it can be used in any discipline, forcing the theoretician and experimentalist to complement one another. It bridges the gap between ideas and facts, between speculation and experience, between chaos and order. It allows the sorting of the relevant and useful from the impertinent and delusive. It allows the exploitation of those rare moments of intuitive inspiration and insight which have proven so indispensable to scientific progress. However, the method cannot replace intuition, conjure good luck, dissuade misuse, or speed the slow process of intellectual growth and seasoning.

3.7 PREVALENT MISTAKES IN APPLYING THE SCIENTIFIC METHOD

In applying scientific methods we are inclined to make some mistakes. 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 does 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. To ignore or rule out data which do not support the hypothesis is another common mistake. 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.

One more common mistake arises from the failure to estimate quantitatively systematic 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, a consensus develops in the community as to which experimental results have stood the test of time. The scientific method attempts to minimize the influence of bias or prejudice in the experimenter when testing a hypothesis or a theory. Let us realize this and try to learn the correct way of applying scientific methods.

3.8 LET US SUM UP

We have learnt about the what, why and how of different scientific methods and the evolution of different scientific methods also have shed light upon how to use them in our experiments, decision making and problem solving in our day to day life. The scientific method is intricately associated with science, the process of human inquiry that pervades the modern era on many levels. While the method appears simple and logical in description, there is perhaps no more complex question than that of knowing how we come to know things. The scientific method distinguishes science from other forms of explanation because of its requirement of systematic experimentation. We have also tried to point out some of the criteria and practices developed by scientists to reduce the influence of individual or social bias on scientific findings. Further investigations of the scientific method and other aspects of scientific practice may be found in the references listed below.

3.9 KEY WORDS

Hypothesis is a suggested explanation of a phenomenon, or alternately a reasoned proposal suggesting a possible correlation between or among a set of phenomena.

Iteration is the repetition of a process. It is a repetition in a specific form of repetition with a mutable state.

Recursion is a particular way of specifying or constructing a class of objects with the help of a reference to other objects of the class: a recursive definition defines objects in terms of the already defined objects of the class.

Interleaving is a way to arrange data in a non-contiguous way to increase performance. Orderings formalize the intuitive concept of an ordering, sequencing, or arrangement of the elements of a set.

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