4. The classical steps of scientific method:

i. Observation:

Observation is the key tool of the scientist. The scientific method requires observations of nature to formulate and test hypotheses. Observation helps a researcher to identify promising aspects of natural phenomena that are worth knowing about. The scientist is specifically looking for causal relationships in nature that (taken together with other knowledge) will help to explain in the broadest terms how natural systems work.

For the purpose of reproducibility, standardization and possible human errors, it is best for observers to compare notes. To magnify human powers of observation, other scientific instruments such as weighing scales, clocks, telescope, microscopes, thermometers, cameras, tape recorders etc. were developed. Instruments such as indicator dyes, voltmeters, spectrometers, infrared cameras, oscilloscopes, interferometers, Geiger counters, x-ray machines, radio receivers and so on were also developed to assist human translate into perceptible the imperceptibles of the human senses.

However, there is a significant problem with observation called the *observer effect* in science that needed to be talked about. For example, it is not normally possible to check the air pressure in an automobile tire without letting out some of the air, thereby changing the pressure. For this reason, science tries as much as possible to reduce the effects of observation to insignificance by using better instruments.

ii. Questions:

Inductive questions are asked as to what, why and how certain things have to happen the way they are happening. This will eventually lead to formulating ideas and concepts. Deductions are thus made which influences a hypothesis that will be tested.

iii. Hypothesis:

A hypothesis is simply an untested fact or a specific statement of prediction. It describes in concrete (rather than theoretical) terms what you expect will happen in your study. Not all studies have hypotheses. Sometimes a study is designed to be exploratory (see inductive research). The word hypothesis basically means "a possible solution to a problem based on knowledge and research". It is a statement that defines what you think the outcome of your research will be or a reasoned proposal suggesting a possible correlation between or among a set of phenomena. Normally, hypotheses have the form of a mathematical model. Sometimes, but not always, they can be formulated as existential statements, stating that some particular instance of the phenomenon being studied has some characteristic and causal explanations, which have the general form of universal statements, stating that every instance of the phenomenon has a particular characteristic. For example, if I notice that some tomatoes on my farm are doing well than others, I may want to make inquiry into the reason why. My hypothesis may be, some of the tomatoes are doing better than the others because they are positioned in a place where they receive more sunlight than the others.

- **Hypothesis and Predictions:**

Any useful hypothesis will enable predictions by reason of induction or deduction. It might predict the outcome of an experiment in a laboratory setting or the observation of a phenomenon in nature. The prediction can also be statistical (about probabilities) or otherwise. It is essential that the outcome is currently unknown. It is only in this case that the eventuations increase the probability that the hypothesis be true. If the outcome is already known, it is called **a consequence** and should have already been considered while formulating the hypothesis. If the predictions are not accessible by observation or experience, the hypothesis is not yet useful for the method, and must wait for others who might come afterward, and perhaps rekindle its line of reasoning. For example, a new technology or theory might make the necessary experiments feasible.

iv. Experiments:

Once predictions are made, they can be tested by experiments. If test results contradict predictions, then the hypotheses are called into question and explanations may be sought. Sometimes experiments are conducted incorrectly and are faulty. If the results confirm the predictions, then **the hypotheses are considered likely to be correct,** yet, might still be wrong and are subject to further testing. The **experimental control** is a technique for dealing with **observational error**. This technique uses the contrast between multiple samples (or observations) under differing conditions, to see what varies or what remains constant. We vary the conditions for each measurement; to help isolate what has changed. Depending on the predictions, the experiments can have different shapes. It could be a classical experiment in a laboratory setting, a double-blind study or an archaeological excavation.

Scientists assume an attitude of openness and accountability on the part of those conducting an experiment. Detailed record keeping 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.

- **Experiment and its Problematic**

At any stage of experimentation, it is possible to refine its accuracy and precision so that some considerations may lead the scientist to repeat an earlier part of the process. Failure to develop an interesting hypothesis may lead a scientist to re-define the subject they are considering. Failure of a hypothesis to produce interesting and testable predictions may lead to reconsideration of the hypothesis or of the definition of the subject. Failure of the experiment to produce interesting results may lead the scientist to reconsidering the experimental method, the hypothesis or the definition of the subject.

- **The need for Confirmation in Experimentation**

Science is a social enterprise, and scientific work tends to be accepted by the community when it has been confirmed. Crucially, experimental and theoretical results must be reproduced by others within the scientific community. Researchers have given their lives for this vision; Georg Wilhelm Richmann was killed by ball lightning (1753) when attempting to replicate the 1752 kite-flying experiment of Benjamin Franklin (See, *Physics Today*, 59(1):42: Richmann was electrocuted in St. Petersburg in 1753). To protect against bad science and fraudulent data, governmental research-granting agencies such as the **National**

Science Foundation, and **Science Journals** including *Nature* and *Science*, have a policy that researchers must archive their data and methods so that other researchers can access it, test the data and methods and build on the research that has gone before.

- **The need for Communication among Science Community**

Frequently a scientific method is employed not only by a single person, but also by several people cooperating directly or indirectly. Such cooperation can be regarded as one of the defining elements of a scientific community. Various techniques have been developed to ensure the integrity of that scientific method within such an environment.

- **The Relevance of Peer review to Experimentation**

Scientific journals use a process of *peer review*, in which scientists' manuscripts are submitted by editors of scientific journals to (usually one to three) fellow (usually anonymous) scientists familiar with the field for evaluation. The referees may or may not recommend publication, publication with suggested modifications, or, sometimes, publication in another journal. This serves to keep the scientific literature free of unscientific or pseudoscientific work, to help cut down on obvious errors, and generally otherwise to improve the quality of the material. The peer review process can have limitations when considering research outside the conventional scientific paradigm: problems of "groupthink" can interfere with open and fair deliberation of some new research.

- **The Importance of Documentation and Replication in Experimentation**

Sometimes experimenters may make systematic errors during their experiments, unconsciously veer from a scientific method for various reasons, or, in rare cases, deliberately report false results. Consequently, it is a common practice for other scientists to attempt to repeat the experiments in order to duplicate the results, thus further validating the hypothesis.

- **The Importance of Archiving**

Researchers are expected to practice scientific data archiving in compliance with the policies of government funding agencies and scientific journals. Detailed records of their experimental procedures, raw data, statistical analyses and source code are preserved in order to provide evidence of the effectiveness and integrity of the procedure and assist in reproduction. These procedural records may also assist in the conception of new experiments to test the hypothesis, and may prove useful to engineers who might examine the potential practical applications of a discovery.

- **The Relevance of Data Sharing**

When additional information is needed before a study can be reproduced, the author of the study is expected to provide it promptly. If the author refuses to share data, appeals can be made to the journal editors who published the study or to the institution which funded the research.

- **Some Limitations to Experimentation**

Since it is impossible for a scientist to record *everything* that took place in an experiment, facts selected for their apparent relevance are reported. This may lead, unavoidably, to problems later if some supposedly irrelevant feature is questioned. For example, Heinrich Hertz did not report the size of the room used to test Maxwell's equations, which later turned out to account for a small deviation in the results. The problem is that parts of the theory itself need to be assumed in order to select and report the experimental conditions.

v. Conclusion:

You have asked questions and performed an experiment to confirm your hypothesis; your conclusion is the record of the final findings in your experiment. A conclusion is simply a summary of the experiment. The conclusion, plain and simple, is the answer to your question and it should be *clear, concise* and *stick to the point*. There are two possible outcomes to your experiment: either the experiment supported the hypothesis and considered true or the experiment disproved the hypothesis as false. If the hypothesis is false, the steps in the scientific method is repeated to make adjustment in your tested hypothesis but if the hypothesis corroborates with your conclusion then the experiment is certified true/correct.

If the hypothesis turns out to be false, there are some questions to ask to find out why:

1. What was wrong with the original hypothesis? 2. Did you make poor observations?

3. Was your experiment flawed?

Test Questions:

1. What are the problems with the classical conception of scientific methods?
2. How objective is scientific method? Can scientific method bring fourth objective knowledge?
3. Of what importance and relevance is control experiment to research methodology?
4. Do you agree with the postmodernist that the practice of science involves many pathways as against the classic linear process?
5. Of what importance is peer review to scientific research, particularly, to unscientific and pseudoscientific works or obvious errors in researches?
6. To what extent is documentation and replication guide against systemic error in experimentation?

Recommended Texts:

Born, Max (1949), *Natural Philosophy of Cause and Chance*, Peter Smith, also published by Dover, 1964. From the Waynflete Lectures, 1948.

Brody, Thomas A (1993), *The Philosophy Behind Physics*, Springer Verlag, (Luis De La Peña and Peter E. Hodgson, eds.)

Fleck, Ludwik (1975), *Genesis and Development of a Scientific Fact*, Univ. of Chicago, (written in German, 1935, *Entstehung und Entwickelung einer wissenschaftlichen Tatsache: Einführung in die Lehre vom Denkstil und Denkkollectiv*) English translation

Gauch, Hugh G., Jr. (2003), *Scientific Method in Practice*, Cambridge University Press, http://books.google.com/?id=iVkugqNG9dAC 435 pages

Godfrey-Smith, Peter (2003), *Theory and Reality: An introduction to the philosophy of science*, University of Chicago Press.

Kuhn, Thomas S.(1962), *The Structure of Scientific Revolutions*, University of Chicago Press, Chicago, IL, 2nd edition 1970. 3rd edition 1996.

Popper, Karl R., *The Logic of Scientific Discovery*, 1934, 1959.