Module 1
Nature of Scientific Inquiry

Objectives

After completing this module, you should be able to:

1. Differentiate the scientific inquiry from other forms of inquiry.
2. Describe the elements in scientific inquiry
3. Describe the process involved in scientific inquiry

1.0 Define the scientific Inquiry

Inquiry is defined as:

> ….."a dynamic process of being open to wonder and puzzlement and coming to know and understand the world. As such, it pervades all aspects of life and is essential to the way in which knowledge is created. Inquiry is based on the belief that understanding is constructed in the process of people working and conversing together as they pose and solve the problems, make discoveries and rigorously testing the discoveries that arise in the course of shared activity".
>
> (Galileo.Organizational Network, no date).

The process of inquiry results in a greater understanding of the subject matter, hence the focus on the following questions (BSCS, 2005):.

- How do we know?
- What is the evidence?
- What can we do to find out?

The knowledge building definition of scientific inquiry is made more evident by the definition forwarded by Darden (1990; 1991) as follows:

> …. an on-going process of error correcting--constructing plausible hypotheses, generating as many plausible rivals as possible, designing new experiments, correcting errors in hypotheses in the face of anomalies. Cycles of discovery and testing and revision characterize scientific change:.

The American Association for the Advancement of Science (1989) enumerated the following **features which differentiate scientific inquiry from other forms of inquiry** (emphasis added). These are:

Science Demands Evidence

[T]he validity of scientific claims is settled by referring to observations of phenomena. Hence, scientists concentrate on getting accurate data. Such evidence is obtained by observations and measurements taken in situations that range from natural settings (such as a forest) to completely contrived ones (such as the laboratory). To make their observations, scientists use their own senses, instruments (such as microscopes) that enhance those senses, and instruments that tap characteristics quite different from what humans can sense (such as magnetic fields). Scientists observe passively (earthquakes, bird migrations), make collections (rocks, shells), and actively probe the world (as by boring into the earth's crust or administering experimental medicines).

In some circumstances, scientists can control conditions deliberately and precisely to obtain their evidence. They may, for example, control the temperature, change the concentration of chemicals, or choose which organisms mate with which others. By varying just one condition at a time, they can hope to identify its exclusive effects on what happens, uncomplicated by changes in other conditions. Often, however, control of conditions may be impractical (as in studying stars), or unethical (as in studying people), or likely to distort the natural phenomena (as in studying wild animals in captivity). In such cases, observations have to be made over a sufficiently wide range of naturally occurring conditions to infer what the influence of various factors might be. Because of this reliance on evidence, great value is placed on the development of better instruments and techniques of observation, and the findings of any one investigator or group are usually checked by others.

Science Is a Blend of Logic and Imagination

Although all sorts of imagination and thought may be used in coming up with hypotheses and theories, sooner or later scientific arguments must conform to the principles of logical reasoning—that is, to testing the validity of arguments by applying certain criteria of inference, demonstration, and common sense. Scientists may often disagree about the value of a particular piece of evidence, or about the appropriateness of particular assumptions that are made—and therefore disagree about what conclusions are justified. But they tend to agree about the principles of logical reasoning that connect evidence and assumptions with conclusions.

Scientists do not work only with data and well-developed theories. Often, they have only tentative hypotheses about the way things may be. Such hypotheses are widely used in science for choosing what data to pay *attention to and what additional data to seek, and for guiding the interpretation of data. In fact, the process of formulating and testing hypotheses is one of the core activities of scientists. To be useful, a hypothesis should suggest what evidence would support it and what evidence would refute it. A hypothesis that cannot in principle be put to the test of evidence may be interesting, but it is not likely to be scientifically useful.*

The use of logic and the close examination of evidence are necessary but not usually sufficient for the advancement of science. Scientific concepts do not emerge automatically from data or from any amount of analysis alone. Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers. Sometimes discoveries in science are made unexpectedly, even by accident. But knowledge and creative insight are usually required to recognize the meaning of the unexpected. Aspects of data that have been ignored by one scientist may lead to new discoveries by another.

Science Explains and Predicts

Scientists strive to make sense of observations of phenomena by constructing explanations for them that use, or are consistent with, currently accepted scientific principles. Such explanations—theories—may be either sweeping or restricted, but they must be logically sound and incorporate a significant body of scientifically valid observations. The credibility of scientific theories often comes from their ability to show relationships among phenomena that previously seemed unrelated. The theory of moving continents, for example, has grown in credibility as it has shown relationships among such diverse phenomena as earthquakes, volcanoes, the match between types of fossils on different continents, the shapes of continents, and the contours of the ocean floors.

The essence of science is validation by observation. But it is not enough for scientific theories to fit only the observations that are already known. Theories should also fit additional observations that were not used in formulating the theories in the first place; that is, theories should have predictive power. Demonstrating the predictive power of a theory does not necessarily require the prediction of events in the future. The predictions may be about evidence from the past that has not yet been found or studied. A theory about the origins of human beings, for example, can be tested by new discoveries of human-like fossil remains. This approach is clearly necessary for reconstructing the events in the history of the earth or of the life forms on it. It is also necessary for the study of processes that usually occur very slowly, such as the building of mountains or the aging of stars. Stars, for example, evolve more slowly than we can usually observe. Theories of the evolution of stars, however, may predict unsuspected *relationships between features of starlight that can then be sought in existing collections of data about stars.*

Scientists Try to Identify and Avoid Bias

When faced with a claim that something is true, scientists respond by asking what evidence supports it. But scientific evidence can be biased in how the data are interpreted, in the recording or reporting of the data, or even in the choice of what data to consider in the first place. Scientists' nationality, sex, ethnic origin, age, political convictions, and so on may incline them to look for or emphasize one or another kind of evidence or interpretation. For example, for many years the study of primates—by male scientists—focused on the competitive social behavior of males. Not until female scientists entered the field was the importance of female primates' community-building behavior recognized.

Bias attributable to the investigator, the sample, the method, or the instrument may not be completely avoidable in every instance, but scientists want to know the possible sources of bias and how bias is likely to influence evidence. Scientists want, and are expected, to be as alert to possible bias in their own work as in that of other scientists, although such objectivity is not always achieved. One safeguard against undetected bias in an area of study is to have many different investigators or groups of investigators working in it.

Science Is Not Authoritarian

It is appropriate in science, as elsewhere, to turn to knowledgeable sources of information and opinion, usually people who specialize in relevant disciplines. But esteemed authorities have been wrong many times in the history of science. In the long run, no scientist, however famous or highly placed, is empowered to decide for other scientists what is true, for none are believed by other scientists to have special access to the truth. There are no preestablished conclusions that scientists must reach on the basis of their investigations.

In the short run, new ideas that do not mesh well with mainstream ideas may encounter vigorous criticism, and scientists investigating such ideas may have difficulty obtaining support for their research. Indeed, challenges to new ideas are the legitimate business of science in building valid knowledge. Even the most prestigious scientists have occasionally refused to accept new theories despite there being enough accumulated evidence to convince others. In the long run, however, theories are judged by their results: When someone comes up with a new or improved version that explains more phenomena or answers more important questions than the previous version, the new one eventually takes its place.

2.0 Process of the scientific inquiry

As implied in the quoted paragraphs above, the process of scientific inquiry involves generating questions, designing investigations to answer questions, making predictions based on scientific concepts, gathering data, using evidence to propose explanations, and communicating scientific explanations

BSCS (2005) identified three elements of scientific inquiry: science as a way of knowing, scientifically testable questions, and scientific evidence and explanations.

Science as a Way of Knowing
An important aspect of scientific inquiry is that science is only one of many ways people explore, explain, and come to know the world around them. There are threads of inquiry and discovery in almost every way that humans know the world. All of the ways of knowing contribute to humanity's general body of knowledge.
Each way of knowing addresses different issues and answers different questions. Science is a way of knowing that accumulates data from observations and experiments, draws evidence-based conclusions, and tries to explain things about the natural world. Science excludes supernatural explanations and personal wishes.

In some ways of knowing, the meaning of statements or products is open to interpretation by any viewer. Science is different because it is characterized by a specific process of investigation that acquires evidence to support or reject a particular explanation of the world. While the meaning of the evidence can be debated, the evidence itself is based on careful measurement and can be reproducibly collected by any individual using appropriate techniques.

Science is often presented as a collection of facts, definitions, and step-by-step procedures. However, science is much more than this. Through science we ask questions, collect data, and acquire new knowledge that contributes to our growing understanding of the natural world.

Scientifically Testable Questions

Questions foster interest in science, leading to observations and conduct investigations. Asking questions is part of the process of scientific inquiry, but not all questions can be answered using scientific investigations. Questions can be divided into two categories: existence and causal. Existence questions, which often begin with why, generally require recall of factual knowledge. Causal questions, which begin with how, what if, does, and I wonder, can be addressed through scientific investigations. True cause and effect is very difficult to prove scientifically. Often, scientists rely on statistical and other analytical methods to determine the likelihood that certain relationships exist.

Science answers questions that are different from those answered by other ways of knowing. Testable questions are answered through observations or experiments that provide evidence. A testable question meets these criteria:

- *The question centers on objects, organisms, and events in the natural world.*
- *The question connects to scientific concepts rather than to opinions, feelings, or beliefs.*
- *The question can be investigated through experiments or observations.*
- *The question leads to gathering evidence and using data to explain how the natural world works.*

Scientific Evidence and Explanations

Through science we ask questions, collect data, and acquire new knowledge that contributes to our growing understanding of the natural world. Scientists conduct investigations for a variety of reasons. They might want to discover why a particular phenomenon happens, explain something they only recently observed, or test conclusions of other investigations that they or their peers have conducted. Investigations might involve experiments, observations, or modeling. All these investigations provide evidence for the patterns, relationships, or phenomena that scientists are studying. Evidence is free of opinion and can be gathered by others with similar results.

Scientific explanations are based on a body of evidence and use scientific principles.[9] Scientists use evidence to establish relationships and causes of phenomena. They recognize that scientific explanations must be based on evidence. Knowing when they cross the line into explanations that are not consistent with their evidence is part of what makes an effective scientist and what makes science different from other ways of knowing about the world.

Readings

Galileo.organizational Network. No date. What is Inquiry?. Available at http://www.galileo.org/inquiry-what.html. Last accessed on 20 October 2010.

BSCS. 2005 by BSCS. Doing Science: The Process of Scientific Inquiry. Available at http://science.education.nih.gov/supplements/nih6/inquiry/guide/info_process-c.htm. Last accessed on 20 October 2010.

American Association for the Advancement of Science. 1990. Available at http://www.project2061.org/publications/sfaa/online/chap1.htm?txtRef=&txtURIOld=%2Ftools%2Fsfaaol%2Fchap1.htm. Last accessed on 20 October 2010.

Suggested Reading (Uploaded in the course site)

Darden, Lindley. 1998. The Nature of Scientific Inquiry. Available at http://www.philosophy.umd.edu/Faculty/LDarden/sciinq/. Last accessed 29 October 2010.