Online Material and Guideline for Study	
1.Name of the Department	Education
2.Course Name	B.Ed. (2 Year)
3.Semester	II-Semester
4.Subject	Education
5.Paper Name	B.Ed.203: Pedagogy-I: Teaching of Physical Science
6.Teacher Name	Mr. Devi Prasad Singh
7.Type of e-content	Reference e-Book, pdf file, youtube-link
8. Covered topic	Unit-I

Learning Topic: *Concept, Nature and Importance of Science*

1. Follow this link **https://youtu.be/Fjlcheqh9YA**
2. pdf file: Read carefully below attached pdf file related to above topic.

Chapter 1

Nature of Science

1.1 WHAT IS SCIENCE?

Humans are curious by nature. This curiosity has driven them since time immemorial to explore the world around them. Over time, manipulation and controlling nature for the benefit of humans has become an objective of exploration.

Initially the pace of exploration was slow. But with the availability of better tools of exploration in the last few hundred years and also as a result of industrial revolution in the west, the pace of exploration has increased manifold. Unfortunately, the industrial revolution introduced an undesirable element into the exploration of nature. Exploration became a tool for not only modifying and controlling nature for the benefit of all, but also for controlling natural resources for the benefit of a select few.

Humans' exploratory activities have resulted in the accumulation of a vast source of knowledge called natural science. In natural science, we study about nature which means the entire universe. The knowledge is now organised in several disciplines for the convenience of study. This knowledge is based on inquiry, observations and logical extensions, and is testable by experiment or has logically convincing explanation. It is this organised knowledge with inquiry, logical reasoning and experimentation as its central themes, that we call science. Science may rightly be said to be a domain of inquiry.

ACTIVITY 1.1

Is political science a science? Discuss in the light of the definition of science given above. Can they be compared? Give reasons for your answer.

1.2 NATURE OF SCIENCE

Science has certain characteristics which distinguish it from other spheres of human endeavour. These characteristics define the nature of science. These also set the terms on which you can engage with science. These are discussed below.

1.2.1 Science is a particular way of looking at nature

- A morning walker looks at the rising sun, pays obeisance to the sun-god for bestowing the earth with light and energy and may offer prayer to propitiate Him. Another walker with a scientific bent of mind or scientific attitude, while recognising it to be the source of all energy on the earth, may wonder where the sun gets its energy from, tries to understand the process of energy generation and may think of duplicating this process on the earth for the benefit of humankinds.
- At the time of an epidemic, people take to praying and seek divine intervention to save humanity. A scientist, on the other hand, seeks to isolate the pathogen responsible for the epidemic and develops preventive and curative strategies to fight the disease and save people.
- At the time of an eclipse, people pray, observe fast, and give alms as insurance against any ill effects flowing from the phenomenon. A

scientist considers eclipse a natural phenomenon, enjoys the sight and tries to understand what caused the event and investigates whether it could have any ill effects.

ACTIVITY 1.2

Cite two examples from your experience which bring out the difference between the outlook of a common person and a scientist.

1.2.2 Science is a rapidly expanding body of knowledge

Newer disciplines are being discovered and established everyday and the older ones are being enriched by researches being carried out in institutes of higher learning. Not only is the volume of knowledge increasing at a furious pace, but the newer knowledge is also replacing some of the older knowledge. Look around and you notice that the technology at the base of almost everything that you use has been overhauled in the last five to ten years. For example, the audio tape is now almost obsolete; its place has been taken by compact disc, which itself is being rapidly replaced by other media devices. In this respect science is a highly dynamic body of knowledge.

1.2.3 Science is an interdisciplinary area of learning

Science flourished in ancient cultures like Indian, Chinese, Greek, Egyptian and others. But the science as we know today is not older than a few hundred years. In fact, the words science (meaning knowledge) and scientist are of comparatively recent origin. Earlier, science was called *Natural Philosophy*, alluding to the fact that science inquired into all natural phenomena—be they on the earth, be they in the sky, be they under water in the oceans, or be they inside the human body. However, when the volume of knowledge became too large, scientists started specialising in certain areas. It is then that knowledge was organised for convenience into disciplines like physics, chemistry, biology, geology, astronomy, etc. though no natural phenomenon falls completely under just any one of these disciplines. Therefore, there cannot be any rigid demarcation of one discipline from another. Several scientific topics fall under more than one discipline. In fact, at the present time the trend is towards studying more than one discipline, or interdisciplinary subjects. Consider, for example, the new and powerful disciplines like biotechnology, molecular biology and biochemistry which have emerged in recent times that necessitate the study of biology along with physics, mathematics and chemistry. Can you imagine the disease diagnostic tools of today being developed without the experts from the fields of physics, chemistry, biology, mathematics, computer science, and others, pooling their expertise and cooperating with one another?

Let us take an example of thermodynamics which shows the interdisciplinary nature of science.

- **Thermodynamics** is a branch of science which deals with relationships between the various forms of energy and the rules governing their inter-conversion. The zeroth law of thermodynamics is the statement of thermodynamic equilibrium, that is, when two systems at different temperature are brought together, the heat energy is exchanged between the two till the two have the same temperature. In fact, this law forms the basis of the definition of temperature of a system as a whole. Through its first law thermodynamics tells us that the total energy of an isolated system is conserved, it can simply get transformed from one form to another. The second law asserts that heat cannot be transferred from a body at a lower temperature to a body at a higher temperature without providing extra energy. Because of the far reaching consequences of these laws, we need a deep knowledge of thermodynamics in understanding all processes in nature, whether they are physical, chemical or biological processes belonging to different branches of science.

  Let us consider physical processes. Suppose we heat a given volume of water. Its temperature increases. If we keep supplying heat energy, the water starts boiling and then its temperature stops increasing even if we keep supplying heat energy. How do you understand this strange behaviour? You need knowledge of thermodynamics to get the answer. How do the two phases of water— liquid and gas— coexist in equilibrium? Again, we need thermodynamics to get an answer. As another example of a physical process, suppose we wish to cool a room. It would imply that we have to transfer heat from the colder air of the room to the hotter air outside. Thermodynamics tells us that we need to spend extra energy to do so. This extra energy is supplied by electricity which enables an air conditioner to cool the room. As yet another example, let us consider if there is a limit on the efficiency of a heat engine, say the kind that propels a car? Thermodynamics tells us that no engine can be 100% efficient; the maximum efficiency is prescribed by the Carnot heat engine, which is an ideal engine.

  Thermodynamics is involved in all chemical processes too. We have already stated that thermodynamics governs the equilibrium of different phases of matter. How much heat is evolved or absorbed in a chemical reaction, say formation of rust on the surface of an iron object or in the process of photosynthesis, can be calculated by the application of thermodynamics. We cannot understand the behaviour of a mixture of gases, such as the atmosphere of the earth, without an appeal to thermodynamics. This has an important implication— the environmental studies must include the study of thermodynamics.

Thermodynamics is involved in all biological processes also. Take life process such as digestion or respiration or cell division. They all involve exchange of heat energy, and therefore, thermodynamics. Moreover, metabolism in all living organisms is nothing, but chemical process. These systems cannot be studied without understanding the laws of thermodynamics. In fact, specialised subjects such as *biological thermodynamics* have been developed which study thermodynamics of biochemical reactions.

- **Biomolecules** are chemical compounds found in living organisms. For example, carbohydrates, proteins, vitamins, nucleic acid, lipids, etc. Study of biomolecules is closely related to several areas of study such as *biochemistry, molecular biology, bioengineering* and the like. Biomolecular structure can be studied using X-ray crystallography or Nuclear Magnetic Resonance (NMR) spectroscopy which involves understanding of physics.

- **Surface Chemistry** deals with the phenomena that occur at the interface of surfaces. Some of these phenomena that are observable at the interface are *adsorption, corrosion, heterogeneous catalysis, crystallisation,* and *colloid formation*. Let us take the example of *adsorption* which arises due to the fact that surface particles of the adsorbent are not in the same environment as the particles inside the bulk. Inside the bulk, forces acting on the particles are balanced, but surface particles are subjected to unbalanced or residual attractive forces. During *adsorption* there is decrease in residual forces, because particles of *adsorbate* (substance getting adsorbed) attach to *adsorbent* (surface on which *adsorption* is taking place). Therefore, there is decrease in surface energy which is released as heat. Thus, the concepts of *force* and *energy* which are important for understanding *adsorption* in chemistry come from physics. Surface chemistry is closely related to surface physics and surface engineering. Surface physics aims to study the topics like *spintronics, nanostructure, surface diffusion* and surface engineering aims at modifying chemical composition of the surfaces using suitable materials.

ACTIVITY 1.3

Search the resources in your library or on the internet to write a paragraph on the central theme of each of the following subjects – Population dynamics, Material science and Palaeontology. Discuss their interdisciplinary nature.

1.2.4 Science is a truly international enterprise

There is another aspect of modern science that needs consideration, i.e., it is a truly international enterprise. Men and women of all countries participate in the progress of science and its applications. Most big projects in science are undertaken by teams of scientists drawn from many countries. This is because the human and financial resources needed for most big projects are beyond the reach of any single country. The mapping of Human Genome involved scientists from many countries. The Large Hadron Collider, at the European Organization for Nuclear Research (CERN), has been built by scientists drawn from many countries including India. The experiments on this machine is being conducted by scientists from many countries including many Indian scientists. The payloads to carry out experiments on space satellites bear international imprints. International collaboration in most projects is the order of the day. In this sense, science does not belong to any single country or a group of countries, and it would be morally and ethically wrong to deny the fruits of scientific development to any country in the world.

ACTIVITY 1.4

Search for two more examples of international collaboration in science. Share your findings with your classmates.

1.2.5 Science is always tentative

All theories, even the seemingly well-founded ones, can be revised or improved upon, or abandoned altogether whenever new evidence emerges, either as new experimental observations or as new theoretical developments.

- The earliest theories of the universe held the earth to be the centre of the universe. Such a universe was called the geocentric universe. So strong was the belief in this theory that it became part of the religious faith. Those who thought that the Sun was at the centre of the universe were ignored. Elaborate schemes, involving epicycles (several epicycles in some cases), were developed to fit the observations of planets to the *geocentric theory* (Fig. 1.1).

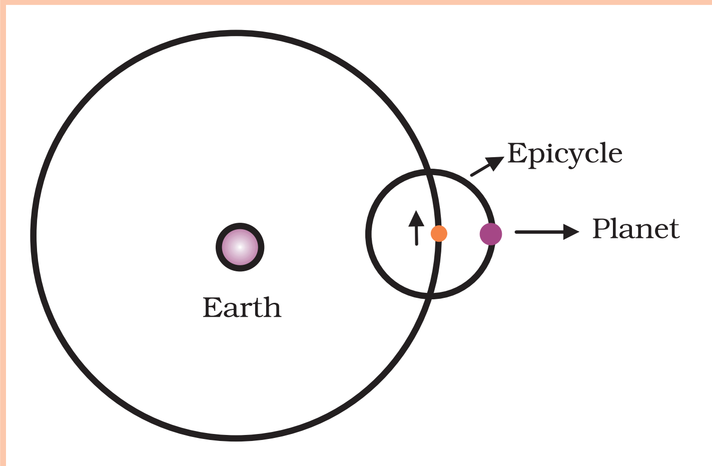


Fig. 1.1 *Geocentric theory: The planet moves on an epicycle whose centre moves around the earth in a circle*

Even when, due to the work of Copernicus, Kepler and Galileo, it became apparent that the Sun must be at the centre of the universe (*heliocentric universe*), scientists were reluctant to let go of the *geocentric theory*. Religious authorities went to the extent of even punishing Galileo for advancing the argument that the earth was not at the centre of the solar system. Ultimately, of course, the weight of argument against the geocentric universe became so heavy that it had to be abandoned and be replaced by the *heliocentric universe*.

- Newton's theory of mechanics held sway for almost two hundred years. So strong was the belief in this theory that it became part of the popular culture. Its key concept of determinism (determinism holds that if we know the position of a particle now, we can determine exactly its position at any time in the future, or in the past) found echo in a new school of philosophy. Yet when observations relating to sub-atomic particles and very massive systems (such as planets and stars) did not fit in the Newton's theory, a new theory came into existence. Particular mention should be made to the precession of the perihelion of the orbit of planet Mercury around the Sun. The new theory, the *theory of relativity of Einstein*, was an improvement over Newton's theory because it could explain the observations relating to the very small and the very massive systems. For ordinary systems, it gave results identical to Newton's theory.

- The vastness of biodiversity has always attracted not just lay persons but also scientists. Depending on their individual backgrounds, they reacted differently. There was a belief that all living beings on earth were created by God. However, Darwin and Wallace in 1850s came up with the idea that life forms evolved on the earth. In other words, the biodiversity pattern has changed over millions of years and that various forms of life can arise only from previously existing forms of life. That, however, leaves the question of the origin of life on the earth unanswered. Scientists have various hypotheses about the rise of the first forms of life on the earth. They are testing these hypotheses to find out the fact. At present, we are far from having any satisfactory answer to this question. However, scientists do believe that life can only arise out of previous forms of life. Before Darwin, the observation that many organisms shared similarities in their phenotype was explained away by the argument that they belonged to a group (taxon). Recall that the phenotype is the sum total of the physical and physiological features of an organism, such as its shape, size, colour and behaviour, which results from the interaction of the genes of the organism with the environment in which it lives. However, the observation of many organisms sharing similarities led Darwin to propose that they are similar, because they come from common parents. Notice how scientific theories move over time.

So, since theories can change over time, **all theories in science have the status as we know them at this instant,** what happens tomorrow we cannot say. This should not be considered a weakness of science. It is actually its great strength. It is the tentativeness, or that the last word has not been said on any topic, that prompts scientists to keep striving to work for new theories or for the improvement of the existing theories, or for new explanations of the known phenomena. Scientists are always searching for evermore refined theories. That is how science prospers. If everything were final, there would be nothing new to discover, and science would never progress.

If scientific theories are always tentative and are likely to change any time, does it mean that we should not make any effort to learn the existing theories? No, we should make every effort to learn the existing theories, for reasons such as to make sense of the world around us we need the current scientific knowledge; to overhaul them when need arises and to incorporate most of the content of the existing theories.

ACTIVITY 1.5

Explain, giving at least one example (other than those given here), how science is tentative in nature. What implication does it have for the study of science?

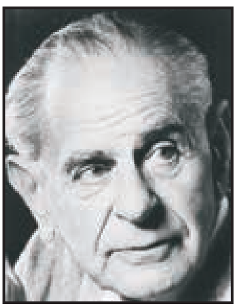
1.2.5(a) Tentative nature of scientific theories

We have seen above how scientific theories take decades, sometimes centuries, to develop into a reasonable shape. Sometimes, it so happens that there are two competing theories trying to explain a certain set of observations related to a certain phenomenon. **Scientists prefer a theory which explains larger number of observations by making fewer assumptions.** This can be said to be scientists' perception of beauty. A theory, which makes a new assumption every time a new phenomenon or a new observation needs to be explained, is obviously not any good.

There was a time when both the *geocentric* and the *heliocentric* theories could explain all the planetary observations existing then. However, geocentric theory had to introduce a new assumption (or a new epicycle) every time a new planetary observation was reported. On the other hand, the beauty of the heliocentric theory was that with just one assumption, that all the planets were revolving round the sun, it could explain every available observation. That is the theory which eventually survived.

In this respect, Newton's theory of gravitation is an excellent theory. It makes few assumptions, and yet is able to explain all the known gravitational interactions.

There is another criterion that a good scientific theory must fulfil. It must be able to predict phenomena that can, at least in principle, prove the theory wrong, or falsify it. This means that any number of observations consistent with a theory cannot prove the theory, but just one observation which goes against the predictions of the theory can falsify it. This view has been asserted by Karl Popper, one of the most influential philosophers of science of the twentieth century. This view is now widely accepted by scientists.



Karl Popper
(1902–1994)

Born in Australia, Sir Karl Raimund Popper is regarded as one of the greatest philosophers of science of the twentieth century. He received a Ph.D in 1928 from University of Vienna and in 1929 qualified to teach mathematics and physics. He served as a Professor at London School of Economics. He wrote extensively on philosophy and history of science. His book *Objective Knowledge : An Evolutionary Approach* published in 1972 popularised the concept of 'falsifiability' as a criterion to distinguish science from non-science. He was knighted by Queen Elizabeth II in 1965 and was elected as a Fellow of the Royal Society in 1976.

To understand what Popper says, suppose we observe a white swan. Then, we observe another one. This, too, is white. Based on these observations, we form a hypothesis that all swans are white. Observation of any number of white swans cannot prove the hypothesis, since we cannot claim to have observed all swans in the world. However, a single observation of a black swan can falsify the hypothesis. It is in this respect that Popper considered Einstein's theory of relativity to be a sound scientific theory. It was possible to deduce from this theory, the consequent attraction of light towards massive bodies. This consequence was highly improbable in the Newtonian theory which was the dominant theory at that time. So, the theory of relativity had within it the seeds of its falsification. The attraction of light by massive bodies was confirmed by Eddington in 1919, when he measured the deflection of light as it passed near the Sun during a total solar eclipse (Fig. 1.2). If this observation had not been made, the theory of relativity would have been abandoned.

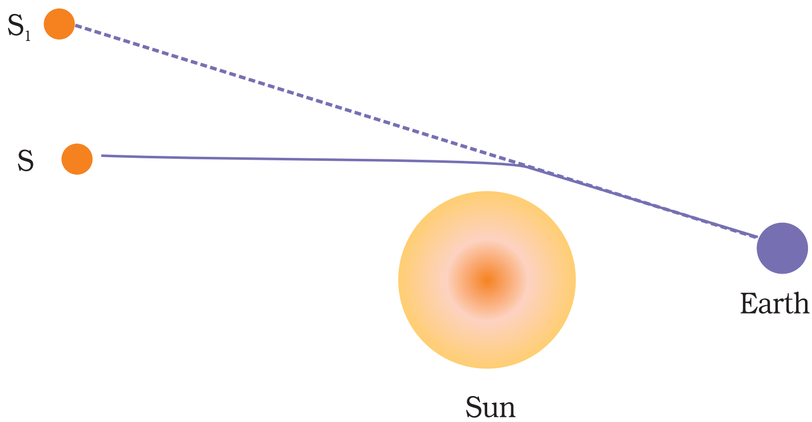
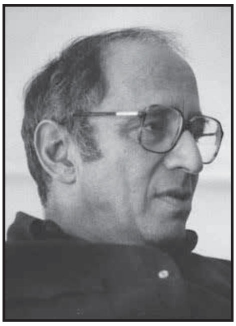


Fig. 1.2 *As the light from the star S passes near the Sun, it gets bent because of the attraction due to the Sun. As a consequence, the star S appears to be at* S_1.

Another influential philosopher of the twentieth century **Thomas Kuhn,** however, maintains that a single contrary or anomalous observation may not falsify a scientific theory. However, when several anomalous observations have accumulated, the existing theory is in a state of crisis. It is time to break new ground and look at all the observations from an entirely new perspective. In this process a new theory is born which subsumes within its fold the results of the existing theory as well as the anomalous results. Science undergoes such paradigm shifts, or revolutions, periodically.



Thomas Kuhn
(1922–1996)

Thomas Samuel Kuhn was an American philosopher and historian of science. He is also regarded as one of the most influential philosophers of science of the twentieth century. He received his Ph.D. degree in physics from Harvard University in 1949. Among a number of publications, his most renowned work is one of the books titled *The Structure of Scientific Revolution* (1962) that he wrote when he was a graduate student at Harvard. He claimed that scientific fields undergo periodic *paradigm shifts*, rather than progressing in a linear way. He received many awards and held honorary degrees from various institutions.

Consider, for example, Planck's theory of black body radiation. In order to reconcile several observations which did not conform to the existing Rayleigh-Jeans law and Wien's displacement law, Planck made a complete break from the past and introduced the revolutionary idea of the quantum of radiation. He asserted that the energy of an oscillator was not continuous, but can be expressed as an integral multiple of a fundamental unit of energy, i.e., $E = h\nu$, where $h\nu$ is the quantum of radiation. Using this idea, Planck was able to explain the radiation emitted by a hot body in its entirety. The Planck's law of black body radiation subsumed both the Rayleigh-Jeans law and the Wien's law as its limits on long wavelength side and the short wavelength side, respectively. This was nothing, but short of a paradigm shift.

Bohr's theory of the atom was another break from the past. It postulated stationary energy states for the electron, the states in which the electron does not radiate energy while revolving round the nucleus, contrary to the classical notions. This, too, marked a revolution in science.

Whatever the view we take of the development of scientific theories, **the fact remains that scientific theories are tentative and are always subject to change.**

ACTIVITY 1.6

Look for other instances in the history of science where a paradigm shift took place. Explain one such shift in your words.

1.2.6 Science promotes scepticism; scientists are highly sceptic people

Scientists are highly sceptic people. Scientists look at everything with suspicion. Every new observation or a new theory is received with a lot of scepticism. It leads to a lot of debate among scientists. A new observation is accepted only when experimental observations have been checked by independent individuals or groups at various places with identical results. Similarly, a new theory is accepted when theoretical calculations have been repeated by other scientists independently with identical results. **In this debate the status of the scientist who proposes something new does not matter; science breeds a truly egalitarian culture.**

One of the stories making headlines in scientific circles in 2011 was *Nobel Laureate Retracts Two Papers.* The story said that the scientist who shared the Nobel Prize in physiology in 2004, has retracted (taken back) two scientific papers after she and her colleagues were unable to repeat the findings reported in those papers. So, it does not matter who you are (even Nobel Laureates are not spared); if the results reported by you cannot be reproduced, they are not acceptable.

These checks and counterchecks also help check frauds. **Scientific process presupposes that scientists will acquire, analyse and report data honestly.** However, sometimes temptation for power and drive for achievement overpower good sense, and some scientists do indulge in fudging, cooking or misreporting data and the results derived from that data. But the game does not remain hidden for long and the fraud is exposed.

One of the most well known recent cases of scientific fraud relates to the research conducted on stem cells. During a particular year the scientist published many papers in highly respected science journals. Among the many claims he and his team made, some were:

- creation of an embryonic stem cell by somatic cell nuclear transfer method;
- creation of 11 human embryonic stem cells using 185 eggs; and
- cloning of a dog.

This work made the scientist world famous. But soon enough trouble started when his own associates expressed reservations on his work. Investigations showed that all 11 of the stem cell lines were fabricated. Two of his papers in the prestigious journal *Science* were retracted by the editor of the journal. Soon after that the scientist himself apologised for his wrong doings. He was sacked from the university and later he was tried on charges of embezzlement.

Another recent incident of fraud concerns a brilliant physicist. He was publishing papers at an incredible rate during 2001–2002. In 2001 he claimed in a paper in the highly respected journal, *Nature*, that he had produced a transistor at the molecular scale. This created a lot of excitement in scientific community because of its tremendous importance for technology. Other groups also got into the act and tried to repeat his experiments, but did not succeed. This created suspicion in their minds.

What gave away the game for the physicist was that two identical graphs were found in two of his research papers dealing with different topics. Other anomalies were also discovered. Eventually, the scientist had to admit that in many of his papers, data was incorrect and in some papers he had falsified data.

The point to be emphasised is that the tradition that the scientific work must be reproducible takes care of many of these misconducts. This is a kind of self-regulation by the scientific community to keep fraudulence under check. Another incident, though not fraud, which occurred in 1989, shows how replication of work is essential to gain its acceptance by scientific community.

We know that fusion is a process in which lighter nuclei fuse together to produce a heavier nucleus. A lot of energy is released in the process. This is the process that takes place inside the stars and produces energy for them. Many groups of scientists have been trying for long to replicate the process on earth. If these experiments are successful, we could get a source of abundant energy. However, the scientists have not met with much success. The fusion process in the laboratory occurs at a very high temperature, $\sim 10^7$ K. Therefore, it was exciting news when two scientists announced that they had observed fusion at room temperature, hence the name *cold fusion*. Several laboratories in many countries jumped into the fray to try and observe cold fusion. However, nobody has succeeded so far, though a few people are still trying. It is generally believed that the scientists made a mistake in their measurements and there is little evidence for the existence of *cold fusion*.

ACTIVITY 1.7

Search the internet for misconduct in science; you will come across many interesting cases. Describe briefly any one of these cases.

1.2.7 Science demands perseverance from its practitioners

There is another characteristic of science that is not generally highlighted, but is really important for its development and progress. This is the tenacity and perseverance that science demands from scientists. A scientist, getting an inspirational idea or a creative thought on making a chance observation, or otherwise, has to persist with the idea to take it to its logical conclusion. Sometimes, the scientist works alone all the way to the discovery or invention, while at other times the scientist can make only a beginning and then others join him/her in developing the idea further.

A chance observation that two lenses placed in a certain arrangement make far off things appear nearer was made by an unknown spectacle maker. Hans Lippershey (1570–1619) of Holland heard of this device. He refined it to make a practical telescope and disseminated its design. Galileo heard of this invention and set out to make a telescope for himself. With this telescope he observed the phases of planet Venus and the nearest moons of Jupiter. It is well known how his observations ushered a revolution in science. He was able to convince scientists that the sun could be at the centre of the solar system. Kepler, Huygens, Newton and many others contributed towards the improvement of telescope.

It is a tribute to their hard work, and that of the generations of scientists following them, that today we have very large and efficient telescopes on land as well as in space. Not only that, we have today telescopes working in several other regions of the electromagnetic spectrum, such as at X-ray, infrared and radio wavelengths.

Take another example– Wilhelm Rontgen, a German physicist, was experimenting with discharge tubes on 8 November 1895, when he chanced to observe that a fluorescent screen kept some distance away from the discharge tube glowed whenever he applied voltage to the electrodes of the tube. It was known at that time that the discharge tube produced cathode rays when potential difference is applied between the electrodes. To prevent cathode rays from leaking from the tube, Rontgen had covered it with card-board. So, when he observed the fluorescent screen glow, he thought he had discovered some invisible rays coming from the tube which caused the screen to glow. A less diligent person might have ignored this observation as a fluke, but not Rontgen. From that day till the end of the year, he virtually lived in his laboratory with his apparatus, verifying the properties of the observed radiation. He convinced himself that what he had observed was a reality indeed. At the end of this period he invited his wife into the laboratory and got the picture of her hand. The picture showed only the skeleton. He then announced his discovery of the unknown rays, calling them X-rays. For his discovery Rontgen received the Nobel Prize in physics in 1901. We all know how important X-rays are to diagnostic procedures today.

The discovery of X-rays by Rontgen also underlies the importance of attuning to science which a training in science should ensure. Without this attuning, Rontgen would not have grasped the significance of his chance observation.

Another such example is the discovery of penicillin by Alexander Fleming. Fleming was a physician by training and enjoyed reputation as a brilliant researcher. At any given time he was engaged in research on many topics, so his laboratory was always cluttered. In 1928, on returning from a vacation, he was clearing culture-laden petri dishes when he noticed a mould growing in one of the dishes. He was surprised to notice that the area immediately surrounding the mould was clear of the culture. He surmised that the mould had produced a chemical which had killed the bacteria that produced the culture. He tried this chemical on many other types of bacteria. Once convinced of the antibiotic nature of the chemical, he announced in 1929 the discovery of penicillin. We all know how important penicillin is for the treatment of bacterial diseases. For his efforts, he received the Nobel prize in 1945.

ACTIVITY 1.8

Collect a few more instances of discovery involving a chance observation followed by hard work. Share your work with your friends.

1.2.8 Science as an approach to investigation and as a process of constructing knowledge

Most investigations in science involve some form of scientific method. It shows creativity of humankind in seeking solution to its problems. The approach used by the scientists in the study of astronomy and ecology is observation and prediction. In microbiology they rely on laboratory experiment focused on cause and effect relationship. This is a glimpse of the process by which science works. The essential elements of this process have been collected in what is known as scientific method. These elements are discussed below.

(i) Observations: Scientists usually have to find cause and effect relationship. Suppose a scientist needs to explain a phenomenon, or may be a problem has been posed to him which he needs to solve. For this purpose the scientist carries out observations of the phenomenon that is to be explained. These observations are repeated several times, sometimes by more than one person and at more than one place, so that there is no doubt about their correctness. Observations are properly recorded and studied to discover if there are any hidden patterns.

We interact with the world outside through our sense organs. Whatever we observe through our sense organs (see, listen, smell, taste, feel) is information. Besides senses, we have mind which processes this information by registering, classifying, generalising, etc. and converts it to knowledge. Our mind sorts out the information on the basis of differences and places them into various categories on the basis of similarities, which later on can be recalled for use in different situations, thus becoming a part of knowledge.

Here you can notice that knowledge is constructed by the individual herself by applying her own mental abilities. It depends on the individual's ability to observe and her intelligence to process the information. Individuals in the same environment may possess different levels of knowledge. Basic unit of knowledge is fact.

In science, any repeatedly verifiable observation becomes a fact. In this respect, the meaning attached to 'fact' in science is different from the meaning of 'fact' in day-to-day usage as part of ordinary language. Let us see some examples of 'facts' in science.

- 'The rainbow is always seen in a direction opposite to that of the Sun' is a fact, because every time or any time one observes a rainbow, it is found to be in a direction opposite to that of the Sun.
- 'A ball rolling on any surface comes to a stop after some time' is a fact, because it has been repeatedly verified.
- 'The reaction of copper sulphate with zinc resulting in the production of zinc sulphate and copper' is a fact because this reaction has been repeatedly observed in the laboratory.
- 'The occurrence of photosynthesis, by which plants convert carbon dioxide into organic compounds using the energy of the sunlight,' is a fact too.

ACTIVITY 1.9

Cite a few more examples of scientific facts.

Now consider some observations about a particular object at different times.

- It is a piece of a solid.
- This solid has a shining appearance (lustre).
- This solid can be beaten into sheets (malleable).
- This solid can be drawn into wire (ductile).
- This piece of solid can conduct heat and electricity.
- This solid produces ringing sound when struck with another solid.

You may have observed many solids with the same or similar properties with difference in colour and lustre or any other property.

The above listed observations have been made at different times. These can be combined into a simple sentence as:

This solid has lustre, it is malleable and ductile, it conducts heat and electricity and produces ringing sound when struck with another solid.

Here you have associated all the properties with a given solid. You would like to remember this solid with one word or name. This name will then represent that solid with all these properties. The name of the solid is 'Metal'. 'Metal' is an example of a concept.

Metal, Acid, Solid Water, Glass, Paper, Pen, Chair, Molecule, Mixture, Salt, Solution, Combustion, Evaporation, Oxidation, Waves, Interference, X-ray, Semiconductors, etc. are some other examples of concepts. Thus, concept is a word, an idea or a mental image of an object, process or phenomenon.

A learner is said to have learned or attained the concept, if she can give examples of the concept learned and also can differentiate non-examples from examples of the concept. For example, ice is a non-example of liquid, and common salt is a non-example of acid. She can list the characteristics of the concept and can define the concept on the basis of its characteristics.

Direct experiences and observations are essential for the formation of many concepts. Each individual has to interpret natural phenomenon in terms of her own experiences. Learner's environment and prejudices may affect concept formation. Sometimes much time elapses between the original experience, the development of the concept and its application.

Many concepts can be combined in a way to convey meaning which can be tested and verified universally. Then they become a principle. For example,

- Metals expand on heating.
- Liquids evaporate on heating.
- A body can be moved from one place to another by applying a force on it.
- Archimedes Principle.
- Bernoulli's principle, etc.

A principle is a comprehensive generalisation describing a property related to a natural phenomenon. The principle is based on concepts which are formed through concrete examples. People apply these principles to understand the realities around them, to explain the phenomena they have observed, and to test their hypotheses in laboratories.

ACTIVITY 1.10

What different concepts are involved in Bernoulli's principle? Discuss.

(ii) Hypothesis: The observations of a phenomenon, or facts, raise certain questions, such as, 'what caused it to happen?' Or, 'why did it happen this way and not in any other way?' On the basis of the answers to these questions, the scientist thinks of a tentative explanation or formulates a hypothesis. For example, to explain how we see things, a hypothesis was formulated in the ancient times that the human eyes emit rays which fall on objects to make them visible. Let us take an example from everyday life. Suppose you switch on your television set and its screen is still dark. Your first guess, a hypothesis, could be that there is no electric supply. If electric supply is there then you make another guess, a second hypotheses. This could be that the switch is faulty. In science, all hypothesis are testable. One of the most important features of science is that it requires hypotheses to cast into a form that can not only be verified but also significantly proved wrong.

(iii) Prediction from a hypothesis and its testing by experimentation: Prediction of science does not mean telling something about the future which has not occurred in the past. It is about foretelling results of an experiment which might be obtained and have remained or not remained unnoticed to throw some light on the scientific phenomena. The hypothesis is analysed to make predictions which are verifiable by experimentation. In the context of the hypothesis given in the above paragraph to explain how we see objects around us, one of the predictions of the hypothesis, which can be tested experimentally, can be that the objects will be visible even when no light from an external source is falling on them. This prediction needs to be tested to confirm or discard the hypothesis.

If experiments show that the hypothesis formulated is not correct, a new hypothesis is formulated and subjected to experimental verification.

It is possible that a hypothesis can make more than one predictions. Such a hypothesis is accepted only when all the predictions made by it have been confirmed by experimentation.

(iv) Scientific Theory: The process of formulating and verifying hypotheses continues till all the predictions of a hypothesis (or a group of related hypotheses) are found to be correct by experimentation

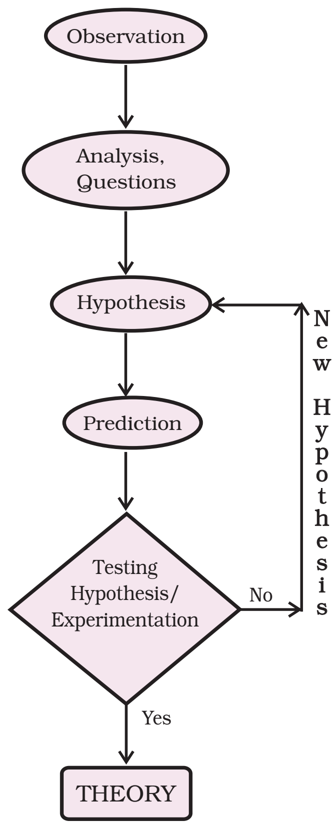


Fig. 1.3 *Flow chart of scientific theory*

(Fig. 1.3). At this stage possible generalisations of the hypothesis are looked for. The results are communicated to the scientific community through publications in scientific journals. The results are then open to experimental scrutiny by scientists all over the world. If the results pass the test of reproducibility, the hypothesis along with generalisations is then promoted to the status of a theory. **Notice the rigorous testing of a scientific idea; such rigour is the corner stone of the scientific method.**

Newton's theory of gravitation is a prime example of a theory which passed all the tests set for it, including generalisation to universal application. The theory is expressed in the form of an equation,

$$F = G\frac{M_1 M_2}{r^2}$$

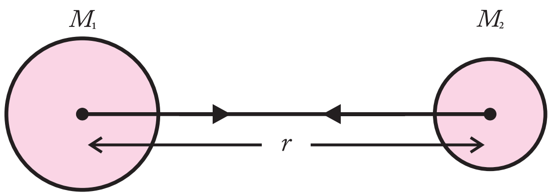


Fig. 1.4

which gives the magnitude of the force between two masses M_1 and M_2 placed at a distance r from each other (Fig. 1.4). G is gravitational constant.

Theories are often expressed in terms of a few concepts and equations. Newton's theory of mechanics or Newtonian mechanics is expressed in terms of concepts like inertia, momentum and force and in the form of well-known equations.

For example:

- The second law of Newton is expressed as

$$\vec{F} \propto \frac{d\vec{p}}{dt}$$

where $\vec{F}$ is the force and $\vec{p}$ is the momentum.

- The first law of thermodynamics, which expresses the conservation of energy, is expressed through an equation

$$dU = dQ - dW$$

where dU is the change in the internal energy of a system, dQ is the heat supplied to the system, and dW is the work performed by the system.

The equations which express the laws are then called the **laws of nature**, meaning that they are applicable universally. These laws help us not only to understand nature but also to explore it. The integrated whole of these laws provide us a framework to understand a part of nature in a particular perspective and constitute a theory. Laws are concise verbal statements or mathematical expressions.

There is difference between theory and law. **A law may describe a single action or phenomenon whereas a theory explains a set of phenomena.** A theory is a set of interconnected concepts, assumptions and principles giving a systematic explanation of natural phenomena. More importantly, a theory should predict new phenomena which are verifiable by experimentation.

ACTIVITY 1.11

Observe the laws given in the textbooks of Class XI and Class XII physics/ chemistry. Discuss do they satisfy the characteristic given above.

Some theories make huge demands on our imagination for their understanding. It is useful then to present them in the form of models. They represent phenomena or abstract ideas that we cannot see. Thus, models help us to conceptualise ideas.

One of the most well-known examples is the Bohr model of an atom (Fig. 1.5). In this model, the atom consists of a positively charged nucleus which contains almost all the mass of the atom, and electrons orbiting the nucleus in the same way as the planets orbit the sun.

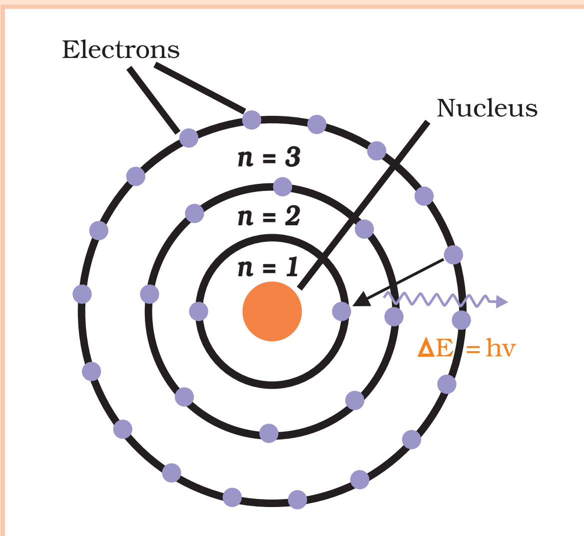


Fig. 1.5 *The Bohr model of an atom*

The utility of the Bohr model is that it allows us to calculate quantities like the energy levels of the electrons and the energy radiated or absorbed when an electron jumps from one energy level to another. **However, it must be clearly understood that a model has only a limited validity and the reality could be much different.**

As we have discussed above, let us emphasise that no theory is final. It is always tentative, subject to modification or even rejection in the light of newer observations. Newton's theory of mechanics, extremely successful for a long time, failed to explain the observed changes in the orbit of planet mercury round the sun and was overtaken by the theory of general relativity. Remember that in most day-to-day situations, Newton’s theory is still quite valid; it is only in special situations that we have recourse to the theory of relativity.

A few words need to be said about **experimentation.** The outcome of an experiment may depend on several variables. If the scientist allowed all the variables to vary at the same time, the result would not be understandable at all. So, an experimentalist studies the influence of one variable at a time as a function of another variable by keeping all other variables constant. In other words, he conducts a controlled experiment. For example, both volume and pressure of a gas are affected by its temperature. If we allow both variables to change with temperature, the result of the experiment will be difficult to understand. So, in a controlled experiment we keep the pressure constant and study the effect of temperature on volume. In another controlled experiment, we keep the volume constant and study the variation of pressure with temperature.

1.3 SCIENTIFIC METHOD: A CRITICAL VIEW

A few points about the scientific method need to be emphasised.

- Scientific method is not a prescribed pathway for making discoveries in science. Very rarely the method has remained a key to a discovery in science. **It is the attitude of inquiry, investigation and experimentation rather than following a set steps of a particular method that leads to discoveries and advancement in science.**
- Sometimes a theory may suggest a new experiment; at other times an experiment may suggest a new theoretical model. Scientists do not always go through all the steps of the method and not necessarily in the order we have outlined above. Investigation in science often involves repeated action on any one or all steps of

the scientific method in any order. Many important and path-breaking discoveries in science have been made by trial and error, experimentation and accidental observations. Both Rontgen and Fleming, in the examples given above, did not set out to discover X-rays and penicillin. They did not go through the scientific method described above. They had qualities of healthy intuition and perseverance which took them to their goal. Besides intuition, informed guesswork, creativity, an eye for an unusual occurrence, all play significant role in developing new theories, and thereby in the progress of science.

- The validity of a hypothesis depends solely on the experimental test and not on the prestige, stature, faith, nationality or any other attribute of the personality of the person who proposes the hypothesis. There is no authority in science that tells you what you can criticise and what you cannot criticise. In this sense, science is a highly objective discipline.
- A scientific method with its linear steps makes us feel that science is a 'closed box approach' of thinking. However, in practice science is more about thinking 'out of the box'. There is tremendous scope of creativity in science. Many times in science, an idea or a solution to a vexing problem (a problem that causes lots of discussion) or an interpretation of observation appear to arise out of creativity and imagination. The stories of Archimedes, Kelkule's, etc. come to our attention.
- People keep floating all kinds of theories. Often they couch their arguments in scientific terms. This confuses a large number of people, and hoodwinks them, but we should remember that a theory is valid only if it passes the test of experimentation, otherwise it may just be a matter of faith. The theory of evolution advanced by creationists is not based on scientific argument and is not consistent with scientific method; it is based entirely on faith.
- The scientific method imposes operational limitation on science. It does not help us to make aesthetic or value judgment. For example, frequency of the colour of paintings may be determined but there is no scientific method to label the paintings of two artists as *great* or *not so great*. Scientific method does not prove or refute the ideas such as *existence of god* and *existence of life after death*.
- Following scientific method does not ensure that a discovery

can be made. However, the skills learnt in making observation, analysis, hypothesis, prediction from a hypothesis and its testing by experimentation help us in developing scientific attitude.

- **All of us will benefit immensely if we imbibe the spirit of scientific method in our personal lives.** The scientific method tells us to be honest in reporting our observations or experimental results, keep an open mind and be ready to accept other points of view if our own view is proved wrong. These values form what is called the **scientific temper** or **scientific attitude,** or **rational thinking.** The adoption of these values is very important for an individual as well as for a society to get rid of superstition and prejudice. **In fact, it will make the world a much better place to live if individuals and societies often examine their beliefs and prejudices in the light of the modern scientific knowledge and try to get rid of those beliefs and prejudices which are not in consonance with this knowledge.**
- Scientific method is a logical approach to problem-solving and repeating or replicating other scientist's work. For example, as discussed above the recent claim of cold fusion discovery could not be replicated.

The way for developing rational thinking is quite simple:

- We should be sceptic and accept something only when we are convinced that it is logical or has passed the test of experimentation.
- We should keep our ears, eyes and minds open. We should be ready to appreciate others' point of view. We should try to convince others or get convinced by them without rancour and ill feeling.
- Accept an idea only when we are sure that it is logically sound. Suppose, for example, somebody tells you that the radiation emitted by your cell phone is harmful. Before accepting this view uncritically, you must consider the following— the amount of radiation emitted by the cellphone, the frequency at which this radiation is emitted, the safe dose of this radiation at this frequency, etc. If you do not have the expertise, you could consult experts or reliable scientific literature on this matter. The point is that we should not accept anything uncritically without investigation/verification/convincing argument in its favour. Persons possessing scientific temper think rationally and do not fall easy prey to superstition and prejudice.

ACTIVITY 1.12

Suppose your name is Seema. Somebody tells you to make it Sima for better luck. How would you react?

ACTIVITY 1.13

Suppose somebody tells you that for better health you should sleep resting your head in the south direction. What would be your reaction?

1.4 AN ILLUSTRATION OF HOW SCIENCE WORKS

In science, experimentation and theory building complement each other. Sometimes a new experiment throws up observations which force modification in an existing theory or demand the development of an altogether new theory. At other times, theoretical development in a theory predicts new phenomena which needs to be verified by experiment. This interplay between theory and experiment is a fascinating facet of the scientific process.

History of science is replete with examples of such interaction between experimentation and theory. Just to illustrate, we briefly review the development of our understanding of the *Nature of Light*.

Light (in the form of sunlight and moonlight) must have hit man almost as soon as he developed consciousness. He must have been speculating about its nature since then. The earliest thoughts on its nature seem to have come from Indian seers and philosophers. In the sixth–fifth century BCE, they described light rays as streams of high velocity atoms of *tejas* (fire) and said that depending on the arrangement of the atoms, light can exhibit different characteristics.

The above ideas were only qualitative. The first quantitative theory was proposed by Euclid, the great mathematician, in third–second century BCE. In his book *Optica* Euclid noted that light rays travel in straight lines. Using geometry, he explained why distant objects appear smaller and nearby objects appear bigger. He also described laws of reflection. Interestingly, he believed that vision is caused by the light rays emanating from the eye and falling on the objects seen. However, Aryabhatta pointed out in the fifth century CE that an object is seen when it is illuminated by light from an external source.

Reflection and refraction of light are the oldest phenomena known to us. Much of the discussion on the nature of light during renaissance centred around these phenomena. In the seventeenth century, Huygens proposed that light consists of waves. Later Newton proposed that light is composed of particles or corpuscles. Both of them were able to explain successfully the phenomena of reflection and refraction. However, when in the early years of the nineteenth century, interference of light was observed by Thomas Young, wave theory of light received a big boost because interference (and later diffraction and polarisation of light) could be explained only if light propagated as waves. Wave theory was firmly established when Maxwell in the latter half of the 19th century showed theoretically that light must be electromagnetic wave.

Almost a hundred years after Young's experiment, Einstein revived the idea of Newton's corpuscles to explain the photoelectric effect. He gave the name photons to the corpuscles of light. Science was at the threshold of a new idea. It was realised that light has dual nature. It behaves sometimes as waves and sometimes as particles. In phenomena like interference, diffraction, and polarisation, light behaves as waves, while in phenomena like photoelectric effect, pair production and Compton scattering light behaves as if consisting of particles. There the matter stands today. A future theory may provide a more satisfactory answer.

This brief account shows how science progresses. Notice that the path of development is not uni-directional. An idea may receive support at sometime, while at another time it may receive a setback. Through such jumbled movements do scientific theories emerge. However, they always remain tentative, to be replaced by better theories. Notice also that persons from many nationalities are involved. So, science can never belong to a country or region. It belongs to the whole mankind.

1.5 ROLE OF A SCIENCE TEACHER

You may have wondered at the significance of studying the nature of science in the pedagogy course. Science teachers face a challenging task to inculcate the essence of the scientific enterprise among students. Students should be made conversant with scientific way of knowing and thus constructing their knowledge in science. Teacher should structure the learning experiences in such a way that the nature of science becomes an inherent part of all teaching-learning situations. Historical aspects of the development of scientific concepts should be emphasised. It would help students to appreciate how science evolved by human endeavour and resulted in the development of various technologies. It is important to simultaneously reduce the overload of memorising facts which often cause a disinclination towards science.

Laboratory work in science, infused with the spirit of inquiry, provides students with hands-on experiences and develops a scientific attitude which is one of the important aims of teaching-learning of science.

The role of the science teacher is crucial to the development of scientific temper among students. **It goes without saying that the teacher should herself be competent in the area she teaches; she must be familiar with all the aspects of the nature of science; and she must have imbibed scientific temper herself.** Such a teacher can exemplify the content of scientific temper from her everyday conduct. From time to time, she can engage her students in discussions to develop scientific temper among them, and foster the values hidden in scientific method like truth, honesty and open-mindedness. She can help her students retain and sharpen further the sense of inquiry by allowing them to explore their environment and encouraging them to ask questions, even if sometimes these questions appear trivial. By her own enthusiasm for science she can transmit the excitement of doing science. During teaching- learning she can convey that science is tentative and nothing is fixed or final and the quest for progressive refinement of theories and explanations continues in which the students can participate at that time and later when they grow old.

Activities such as projects, field work, paper reading along with laboratory work and discussion would encourage students to do science. This in turn, would help them to learn the skills associated with the inquiry and processes of science such as observing, measuring, hypothesising, predicting, analysing and communicating.

ACTIVITY 1.14

Outline a few steps you would take to inculcate scientific temper among your students.

While assigning projects the science teacher can remind her students of honesty of reporting their observations. She must herself be ready to appreciate if students report their findings honestly even if they lead to wrong results. She could also tell her students that they are not too young to do good science. She can relate to them a recent report that a science journal in England published about a scientific study by 8 year olds. The students were from an elementary school and they were investigating, as a part of their project, the way bumblebees see colours and patterns. The scientific organisation, which is more than 300 years old and which includes some of the world's most eminent scientists, said that the children reported findings that were a genuine advance in the field of insect colour and pattern vision. So, the science teacher must impress on her young students that projects assigned to them can lead to fruitful investigations and results, provided these are done in the spirit of genuine inquiry.

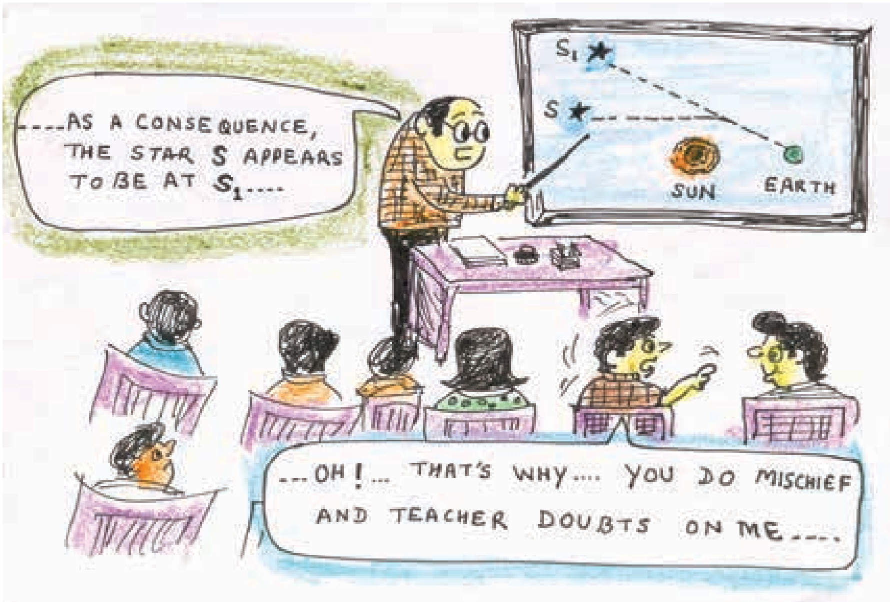
We have discussed above that people from all over the world contribute to the progress of science. As a science teacher you must instil confidence in your students that they can also contribute in this process.

Understanding the nature of science is a valuable goal of science education and must be reflected in the process of assessment. It is not enough to merely examine students' learning of facts and principles of science. It is necessary to assess their spirit of inquiry, sceptic attitude towards existing ideas, and tendency to try out new ideas.

A consequential aspect of science education is understanding how science is related to technology and society about which we shall study in Chapter 2 *Science and Society*.

1.6 SUMMARY

We learnt in this chapter that science is an organised system of knowledge which is based on inquiry born out of human curiosity, logical reasoning and experimentation. As humans face nature in its various manifestations, this knowledge is expanding fast, not the least with the help of international collaboration. Broadly speaking, science is a particular way of looking at nature, which may also be called scientific attitude. One of the most important characteristics of science is that even the most established theories can be modified, or even abandoned, if new experimental results do not fit into the existing theories. This promotes scepticism among scientists. They look at every new observation or theoretical calculation with a healthy dose of scepticism and do not accept it till the result has been reproduced by many scientists at various places. Reproducibility is one of the important criteria for a scientific result to be acceptable. It is believed that scientists, in their exploration, employ inquiry and scientific method. The method consists of several steps, such as observation of a phenomenon, formulation of hypothesis to make predictions which are verifiable, verifying hypotheses, formulation and propagation of a theory flowing from the hypotheses. The theories are often expressed in terms of a few concepts and equations. The use of scientific method and inquiry in daily life promotes scientific temper and rationality. That is why it has been emphasised that all of us should imbibe the spirit of scientific inquiry in our personal lives. Finally, the importance of the role of the science teacher has been stressed in inculcating the spirit of inquiry among their students and orienting them towards developing scepticism and scientific temper.



EXERCISE

1.1 Explain how her own understanding of the nature of science helps a science teacher in promoting meaningful learning among her students.

1.2 Is all scientific knowledge empirically based? Discuss.

1.3 Some people maintain that scientists and scientific knowledge are subjective. Discuss giving supporting evidence.

1.4 How are observations and inferences different? Are there cases where they are not different? Cite examples.

1.5 In what sense are scientific laws and scientific theories different types of knowledge? In what sense are they related?

1.6 To what extent is scientific knowledge socially and culturally embedded? In what sense does it transcend society and culture? Discuss with relevant examples.

1.7 How does the notion of scientific method distort how science actually works? Discuss with suitable examples.