UNIT 1 SCIENCE: PERSPECTIVES AND NATURE

Structure

1.1 INTRODUCTION

Science as a discipline has its unique perspective. Science is not limited to observation, experimentation and analysis only; rather it is a way of life. Science is an expanding body of knowledge through process of inquiry. A Science teacher should understand all its dimensions. Present unit will discuss in detail about meaning and nature of Science and facilitate you in resolving myths related to Science. The Unit also explains the process of scientific inquiry, as well deliberates on place of Science in society. It will facilitate you in developing understanding of relationship of Science and society in learners' minds. Science has its own values system, which will be discussed in this unit.

1.2 OBJECTIVES

After going through this unit, you will be able to:

- facilitate your learners in understanding meaning of Science,
- explain various domains of Science,
- explain Science as a process of inquiry,
- identify and resolve myths related to nature of Science in learner's mind,
- help your learners in realizing place of Science in the society, and
- identify and inculcate scientific values among your learners.

1.3 UNDERSTANDING SCIENCE

Being a Science teacher, your first responsibility is to facilitate your learners in understanding the Science. Science is not a new subject for them, as it has already been introduced to them at upper primary (Class VI-VIII) level. The focus of Science teaching at elementary level was on engaging learners in learning principles of Science through familiar experiences, working with hands-on to design simple technological units and modules and continuing to learn more on environment and health through various activities (NCF-2005). At Secondary level, you have to engage your learners in learning Science as a **composite discipline** i.e. as an integrated discipline Science and not as segregated subjects like Physics, Chemistry, Biology, etc. They need to understand the nature of Science as well as what comes under domain of Science. Let us discuss, how will you facilitate them in understanding what is Science?

1.3.1 What is Science?

Perhaps, India may be the only nation with a constitutional provision as fundamental duty 'to develop scientific temper' among its citizens. Article 51A (h) is: ***"To develop the scientific temper, humanism and the spirit of inquiry and reform"***. This reflects how we thought about Science. For us, Science is neither a pedagogical discipline nor a group of certain subjects. We have perceived Science as a way of life with rational thinking. This feeling and understanding should be inculcated among learners since childhood so that they can perceive Science as a part of their life. Our scientific traditions are ancient and our perception about Science is associated with the notions like logic, rationality, truth, knowledge and intelligence.

It is never easy to answer the question, what exactly the Science is. For some Science is what the scientists practice. For others, it is organized knowledge disciplines like Physics, Chemistry, Biology, etc., but no one can answer this question exactly. This leads us to think bit deeper.

Etymologically word 'Science' has been derived from the Latin word '***scientia***' which means 'knowing'. Before the 18th century, Science was referred as 'natural philosophy'. Still for some, it is a title; for some, it is a concept, few perceive it as a method or process while for some, it is inquiry. If we go through philosophical origin and understanding of term 'Science', we can see various perceptions about Science and this makes it more interesting and challenging. Similarly, when you look back towards your own childhood and school days, you can find, what was your own perception about Science.

When your teachers introduced Science as a subject for systematic study and divided it into many areas like: Physics, Chemistry, Zoology, Botany, do you think, at that time, you understood what Science is? Many of you may answer in the negative. Now how will you answer the question: What is Science?

Let us reflect on it. Science is a process of learning. It is very different from other areas of study because "***the way to learn Science is to do Science***". You can propose it as subject, which always tests ideas with the help of evidences collected

from the worlds around us. Some of the important characteristics of Science which need to be shared with learners are:

- You can help learners to understand that Science does not explain supernatural myths rather it focuses on the natural world around them. For example, Science helps to understand growth in plants, characteristics of animals, etc.
- Learners should understand that Science is not merely a collection of evidences of happenings; rather it attempts to understand happening through analysis, testing and verification.
- You can give examples of Scientists working in different areas and ask learners to find out what is common in their working. Learners will soon realize that scientists work on testing of ideas, that are generated and their verification with the help of evidences generated or collected.

Science is actually an integral part of our daily life. As a teacher you can help learners to understand that scientists are as human as we. They also have feelings of joy, rivalry, competition, success, failure, etc. as any human being.

As a teacher of Science at secondary level, you should ensure that learners should overcome the traditional stereotype/mental blocks related to Science like Science text books are heavy, scientists are persons wearing lab coats and working on microscopes, a natural scientist works in the rainforest, or busy in writing some equations and formula on a chalkboard…. all such images are the reflection of one aspect of Science, but do not offer a full picture.

It is always a debate that what is Science and what is not. As a Science teacher, we must think on certain issues like why there is no suffix 'Science' with subjects like Physics, Chemistry, Biology, Zoology, Botany, etc., and why there is always a suffix 'Science' with subjects like Social Science, Political Science, Management Science, Environmental Science, Health Science, Library Science, etc.

> In a public lecture at the Indian Institute of Science, Banglore, in January, 2010, David Gross, the celebrated theoretical physicist and winner of Nobel Prize for Physics in 2004, narrated an interesting incident in the life of John Nash. Nash was winner of 'Nobel Prize for Economics'. One journalist asked Prof Nash: "do you agree that economics was a Science?" (because the prize was given for Economic Science.) Nash apparently replied that any subject which needed to have the appendage 'Science' to it could not really be a Science. Gross then went on to say how the disciplines of Physics, Chemistry, Mathematics and Biology did not have the addition of 'Science' to them whereas 'Social Science' did.
>
> ***Defining Science, p.1., in Sarukkai, S. (2014). What is Science?, NBT, India***

As teachers of Science, you should also reflect such questions and identify the elements which justify the addition of 'Science' as suffix to any subject.

Check Your Progress

Note: a) Space is given below to write your answer.

b) Compare your answer with the one given at the end of this Unit.

1) Do you agree that Library Science is a Science? Give arguments in support of your answer.

.....

.....

.....

.....

.....

1.3.2 Myths about Nature of Science

In order to present nature of Science to learners, a teacher can keep in mind what McComos (1998) proposed 15 incorrect ideas about Science.

Table 1.1: Myths about Nature of Science (McComos, 1998)

S.No	Myth about nature of Science
1	Hypotheses become theories that in turn become laws.
2	Scientific laws and other such ideas are absolute.
3	A hypothesis is an educated guess.
4	A general and universal scientific method exists.
5	Evidence accumulated carefully will result in sure knowledge.
6	Science and its methods provide absolute proof.
7	Science is procedural more than creative.
8	Science and its methods can answer all questions.
9	Scientists are particularly objective.
10	Experiments are the principal route to scientific knowledge.
11	Scientific conclusions are reviewed for accuracy.
12	Acceptance of new scientific knowledge is straightforward.
13	Science models represent reality.
14	Science and technology are identical.
15	Science is a solitary pursuit.

It is important to understand the role of these myths in understanding the nature of Science and in planning how these can be discussed with learners. What kind of activities you will organize so that learners can understand that these statements are only myths. Let us discuss a few myths as examples and discuss activities/ examples/illustrations, which can be used in the classroom.

One of the most common myths about the nature of Science is that ***"a general and universal scientific method exists".*** Many times teachers and learners in Science have the view that there is a common series of steps that scientists follow in their investigations/research. In most text books of Science, initial chapters talk about the general steps of a scientific method i.e. defining the problem, forming a hypothesis, making observations, testing the hypothesis, drawing conclusions and reporting results. Slowly classroom and laboratory practices adopt this procedure of writing up the aims, hypothesis, method, results and conclusion. This, in the long run, turns into a wrong belief that a general and universal scientific method exists.

There is another common myth that ***"scientific laws and other such ideas are absolute".*** This has also taken the shape due to misconceptions and traditional way of teaching Science. In teaching learning Science, our focus remains on universal laws and theories. Even the cover page of various Science related books often reflects some equations like $E=mc^2$ and picture of law of gravitation or the Archimedes principle. An emphasis on the principles and theories which are of universal nature gives birth to such misconceptions.

As a teacher you need to appreciate that scientific knowledge is tentative not absolute. An example like the journey of atoms to subatomic particles is a case in point. Initially, atoms were considered as ultimate small particle of any elements. Later discoveries of electron, protons and neutrons as sub atomic particles. You must have read about the experiment in search of Boson or God particle by collision of sub atomic particles. Another very interesting example which you can use is the periodic table. Initially in Mendeleev's table, the number of elements was around 60, but the number has gone up to 118 and is still increasing. Similar examples can be used to establish the tentative nature of scientific knowledge.

1.3.3 Understanding Nature of Science

Generally speaking, nature of Science is a fundamental domain for guiding Science teachers in accurately portraying Science to learners. Science learners need to know not only facts/concepts but also about the processes through which this knowledge is generated. Thus, appropriate knowledge of nature of Science can help a teacher in enhancing her ability to implement conceptual changes and also in understanding learners' learning (Matthews, 1994).

Understanding nature of Science is important because if your understanding and the Philosophy of Science is not congruent with the current interpretations of the nature of Science, you will not be able to do justice to explanations and interpretations of scientific issues in scientific terms.

With more focus of constructivist approach for knowledge creation, a teacher has to understand various aspects of nature of Science so that s/he will be able to create or generate opportunities for knowledge for learners. It has been observed that introduction in Science imparted to learners depends upon the teachers' own views of the nature of Science (Gill, 1977, p. 4). Hence, enhancing teachers' understanding of nature of Science is clearly a prerequisite for effective teaching learning process in Science.

Understanding of nature of Science is also important for two reasons; one is curricular, that is what kind and amount of content is appropriate according to the cognitive level of learners and the second, to plan right kind of learning situations for learners i.e. the teaching learning strategies to be adopted. It is challenging task for a teacher to translate the understanding of Science into a knowledge generation opportunity for learners. A broad understanding can help you in designing meaningful situations and in selecting appropriate tools for classroom transition.

What is nature of Science? This is a debatable issue since long but an accurate description of the function, processes and limits of Science can engage learners' interest in the issue.

Aspects of nature of Science have been identified and explained by many researchers but the following list seems to be fit in our objective. Table 1.2 shows the convergent aspects of the nature of Science (identified by Lederman, 1992;McComos, 1998).

Table 1.2: Aspects of Nature of Science

S.No.	Aspects of Nature of Science
1	Scientific knowledge is long lasting yet tentative
2	Empirical evidence is used to refine and support ideas in Science
3	Social and historical factors play a role in the construction of scientific knowledge
4	Laws and theories play a central role in developing scientific knowledge, yet they have different functions
5	Accurate record keeping, peer review, and replication of experiments help to validate scientific ideas
6	Science is a creative endeavor
7	Science and Technology are not the same, but they have impact on each other

Let us analyze few of these characteristics.

Scientific Knowledge is Tentative

Scientific knowledge is subject to change. Why is it so? It is so because; we make new observations and tend to reinterpret the existing observations.

- Solar system is a very common topic, while discussing the Solar system; teachers can emphasize that now there are eight planets but earlier ninth planet Pluto also existed. But in 2006 Scientists reclassified it as a 'Dwarf Planet'. Astronomers discovered an object in the Kuiper belt which was larger than the former ninth planet Pluto and therefore Pluto was not given the status of a planet. This means Science is tentative – its facts, theories are subject to change in the light of new observations and new findings.

- Evolution and connecting links are some other common themes in Science. The tentative nature of Science can be emphasized by discussing many more examples. Let us discuss the case of 'dinosaurs'. Dinosaurs were earlier

believed to have evolved from reptiles (group to which lizards, snakes etc. belong) but now the perception about their lineage has changed. Today scientists are of the opinion that they have evolved from birds. Archaeopteryx, a feathered dinosaur, was discovered in Germany in 1861. Archaeopteryx forms a connecting link between two vertebrate groups – reptiles and birds. It has some reptilian features like presence of teeth and beak. The avian features include presence of wings and beak. John Ostrom from Yale University in late 1960s found 22 features in the skeletons of meat-eating dinosaurs which are only seen in birds. This forms the basis of bird lineage of dinosaurs.

Above examples support the argument that Science is tentative and subject to change but there are certain scientific ideas which have stood the test of time. Sir Isaac Newton's three laws of motion have survived the test of time. Although these laws have also been modified, instead of force at a distance, the concept of field has been introduced. As a Science teacher, you have to present both sides of the coin because there are certain scientific principles of universal application.

Activity 1

Present few examples to reflect that nature of Science is tentative and also few examples to show universal nature of few scientific principles (From Science text book of class IX or X. Ask your learner to compare both the situations and enlist few key differences in them.

Observations of the Natural World

Learners should be given enough opportunities to understand the difference between observations and inferences. For instance, you can show them different types of plants like a desert plant, a water plant, a climber, etc. and ask learners to make a list of observations about the these three different plants. Divide their answers into two lists: one labeled 'Observations' and the other 'Inferences.'

Table 1.3: Examples of Observations and Inferences

Observations	Inferences
A Desert Plant	
Very small sized leaves	Small sized leaves help in reducing loss of water
A Water Plant	
Leaves are covered with waxy coating	Waxy coating helps in preventing decay in water
A Climbing Plant	
Thread like spirally coiled structures are arising from the stem of the plant	These spirally coiled structures (tendrils) help in providing support to the plant

As a teacher, we can see the difference between an observation and inference. Observation is what one sees and inference is making a conclusion based on the basis of what one has seen. Let us consider the following example.

Case 1

Ms. Poonam is a Science teacher in a Nigam PratibhaVidhyalaya in semi urban area of South Delhi. Once she arranged a fun trip to Qutub Minar for her learners. In the Qutub complex, the learners saw an iron pillar. Ms. Poonam asked the learners to note down the details displayed about the pillar. It was stated that it is around 1600 years old and rust resistant. After returning to school, Ms. Poonam asked the learners to enlist those iron items in their house, which are being used regularly and are rusted. Learners presented a number of examples. She then asked them to compare their details about the iron pillar at Qutub complex with examples of iron items at their house. Then she introduced the concept of rusting of metals.

As a teacher, you can identify and use many such opportunities from the nearby region to introduce simple concepts of Science. At secondary level, Science should be evolved from natural contexts of the learners and also from laboratory experiments, theoretical principles and processes, but if examples are close to their immediate natural environment, Science will become interesting and understandable for learners.

Activity 2

Identify some topics from the Science textbook of class IX. Plan some visits to the nearby areas to provide the learners a feel that the content in text book is of their immediate use and they can observe its implications in the natural environment.

Check Your Progress

Note: a) Space is given below to write your answer.

b) Compare your answer with the one given at the end of this Unit.

5) List any five common myths about nature of Science.

.....

.....

.....

.....

.....

.....

1.3.4 Domains of Science

To think of Science, we have to take into account its multidimensionality. All though it is more application oriented, but also based on sound theoretical, philosophical and sociological parameters. You must have gone through Unit 2 i.e. Perspectives of Disciplinary Knowledge (Course BES-125: Understanding Disciplines and Subjects), where these aspects are discussed in detail. Whenever we talk about Science, three interwoven domains come to our mind (as shown in Figure 1.1).

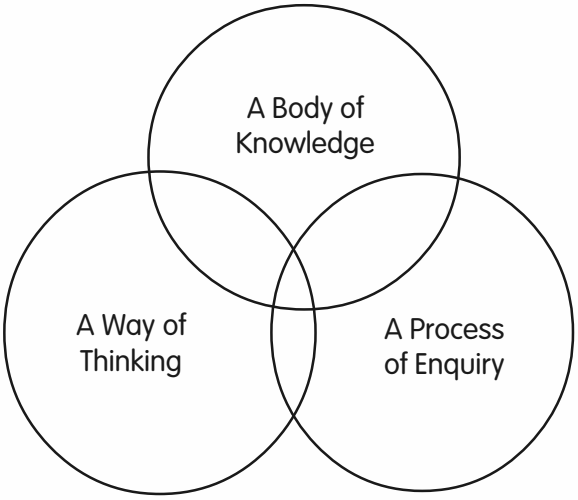

Figure 1.1: Three Domains of Science

Let us try to understand what these domains are. In order to do so, we have to enlist various activities, facts, and processes related to Science. You can think of scientific facts, concepts, theories, laws and some methods and processes. However, when describing the nature of Science, educators have converged on a key set of concepts, like: **tentativeness, empirical evidence, observation and inference, scientific laws and theories, scientific method, creativity, objectivity and subjectivity,**etc. All these can figure in the three major domains of Science, as shown in Figure1.2.

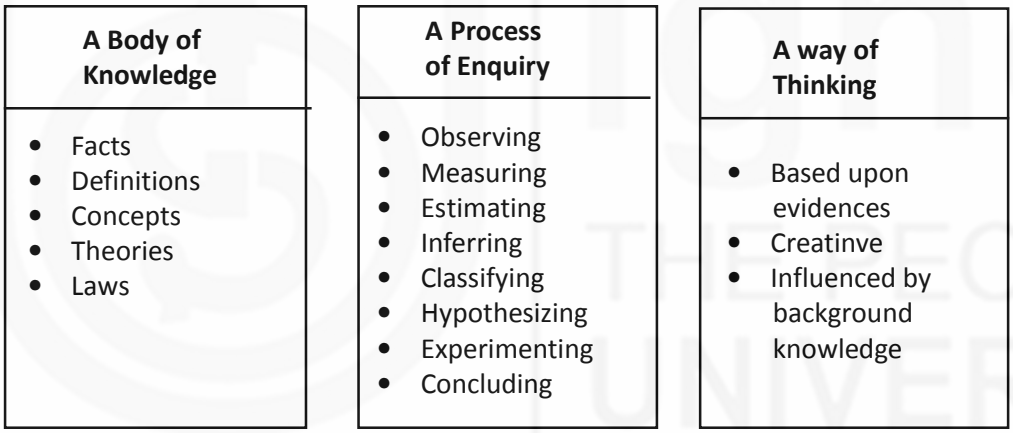

Figure 1.2: Nature of Science

Let us discuss each domain in detail:

Science as a body of knowledge

First domain represents the nature of Science as a body of knowledge. Generally we take Science as a body, which includes facts, definitions, concepts, principles, theories, laws etc. You must have come across many people talking about 'Scientific knowledge' about the planet, stars, etc. If you see any textbook on Science, you can easily find various facts, concepts, definitions, principles and theories associated with Science. A few of them have lasted long and have been a part of scientific knowledge since generations. Some important characteristics of scientific knowledge are:

- It is tentative

- Scientific ideas are influenced by social and historical background.
- The Objective of Science is to provide explanation of natural phenomena whereas the objective of technology is to provide solutions of problems related to life.

Sometimes, while responding to the questions raised by learners, we try to satisfy by telling them to just remember the fact or principle, if they are unable understand it; do you ever think that only the factual information can satisfy them completely? By emphasizing on theories and principles, you can provide only factual knowledge to learners, which is of no use to them. This only creates a burden on learners' minds and gradually they start losing interest in Science (Larsen and Cindy, 2011). It is the high time that you should come up with the strategy to provide them with real experience of Science. You should provide learners an opportunity to feel, experience, explore and analyze. They will themselves generalize and develop their own body of knowledge. If you want to establish Science as a body of knowledge, you have to plan such activities, in which learners find out the concepts, principles and theories after generalizing by themselves.

Activity 3

Take the Science textbook of class IX. Enlist the facts, concepts, definitions, principles and theories presented in the chapter 'Acids, Bases and Salts'. How will you present them as a body of scientific knowledge to your learners?

Science as a process of inquiry

Another domain is Science as a process of inquiry, though we will discuss it in details in the next section of the Unit; let's try to understand here, why Science is considered as a process of inquiry.

When you start teaching and learning of Science in your class, you have to go through various processes, which will allow your learners to investigate about various important issues in their surroundings. Certain process skills have to be developed like 'Observation, Inference, Classification, Communication, Measurement, Prediction', etc. These skills will be discussed in details in the Unit 3.

The process skills are important for scientific investigations and in everyday life. The learners should be able to establish causal relationships and distinguish them from mere associations.

In a Science classroom, the teacher is expected to provide opportunities to the learners to participate in some investigative activities which will help them to understand the nature of scientific inquiry. Such practices will encourage the learners to think about the relationships between facts, options, processes and incidents. It is expected that you will encourage your learners to identify relationships and analyze rationally the associated facts.

Science as a way of thinking

The third domain is Science as a way of thinking. Famous scientist Carl Sagan says that *"Science is more than a body of knowledge. It is a way of thinking."* On a wider note, you have to work for development of scientific thinking among your learners. Your success as a Science teacher will depend upon the degree of scientific thinking and scientific attitude developed in your learners. In previous

sub-sections, our focus was to establish Science as a body of knowledge and a process of inquiry but both these aspects are closely related to third one i.e. Science as a way of thinking.

Scientific way of thinking can be promoted by making our learners able to explore, analyze, evaluate and work in a scientific manner. Scientific way of thinking will make our learners collect evidence that can be physically observed and measured. This is known as empirical evidence. Scientific way of thinking also allows starting questioning why and how things are as they are.

Science as a way of thinking involves scientific temper, scientific inquiry, and a sense of humanity, accepting that scientific ideas are tentative and control of emotions while interpreting the evidences are its important ingredients. The discussion above clearly indicates that no domain can be segregated from the other and all three are integrated.

Check Your Progress

Note: a) Space is given below to write your answer.

b) Compare your answer with the one given at the end of this Unit.

2) Suggest some classroom activities, which will demonstrate Science as a body of knowledge, a process of inquiry and a way of thinking.

.....

.....

.....

.....

.....

.....

.....

.....

1.4 HOW SCIENCE WORKS?

As a Science teacher, first myth you have to resolve in your classroom that Science is not something that develops through scientific method only. There are examples, where scientific discoveries and inventions are not a product of any systematic scientific method. Examples given below can help you in resolving this myth among your learners. Learners must have studied a traditional 5-step scientific method which includes: 'Problem, Hypothesis, Experimentation, Observation and Results.' It has been observed that many learners develop a misconception that every scientific study takes place through these steps only. Your role as a Science teacher is to help them in coming out of this myth.

Let us discuss few path breaking inventions and discoveries of Science and how did they take place.

Law of Gravitation

In the biography of Newton entitled *Memoirs of Sir Isaac Newton's Life* written by William Stukeley, an archaeologist and one of Newton's first biographers and published in 1752, Newton told the apple story to Stukeley, who relayed it as such:

"After dinner, the weather being warm, we went into the garden and drank tea, under the shade of some apple trees...he told me, he was just in the same situation, as when formerly, the notion of gravitation came into his mind. It was occasion'd by the fall of an apple, as he sat in contemplative mood. Why should that apple always descend perpendicularly to the ground, thought he to himself..."

Source: *https://www.newscientist.com/blogs/culturelab/2010/01/newtons-apple-the-real-story.html*

Discovery of Penicillin

Scottish biologist Alexander Fleming took a break from his lab work investigating staphylococci and went on holiday. When he returned, he found that one Petri dish had been left open, and a blue-green mould had formed. This fungus had killed off all surrounding bacteria in the culture. The mould contained a powerful antibiotic, penicillin, which could kill harmful bacteria without having a toxic effect on the human body.

Source: https://newhumanist.org.uk/articles/4852/Science-and-serendipity-famous-accidental-discoveries

Radioactivity

French scientist Henri Becquerel was working on phosphorescent materials, which glow in the dark after exposure to light. The chance discovery came during an experiment involving a uranium-enriched crystal. He believed sunlight was the reason that the crystal would burn its image on a photographic plate.

One stormy day in 1896, he decided to leave it for the day and resume his experiments when the weather was better. A few days later, he took his crystal out of a darkened drawer. The image burned on the plate was "fogged" – the crystal had still emitted rays, despite the lack of sunlight. It was clear that there was a form of invisible radiation that could pass through paper, causing the plate to react as if exposed to light.

His research was continued by Pierre and Marie Curie, who named the phenomenon radioactivity.

Source: https://newhumanist.org.uk/articles/4852/Science-and-serendipity-famous-accidental-discoveries

The Microwave

The heating effect of a high-power microwave beam was discovered in 1945 by Percy Spencer, an American engineer working for the company Raytheon. He was working on a magnetron capable of beaming high waves of radiation, when he noticed that a chocolate bar in his pocket had melted. Curious, he

placed a bowl of popcorn in front of the tube and it began to pop. Spencer then created a high-density electromagnetic field by feeding microwave power from a magnetron into a metal box from which it could not escape. When food was placed in the box, its temperature quickly rose. In October that year, Raytheon patented the technology and it became available to the public in 1947.

Source: *https://newhumanist.org.uk/articles/4852/Science-and-serendipity-famous-accidental-discoveries*

What inference your learners can draw from many such stories?

You can use many such stories to help your learners in understanding that every discovery or invention is not a linear process. Sometimes, it is an observation (like law of gravitation), sometimes it may a critical question or a systematic inquiry (like radioactivity), which results into a discovery or invention, but yes, they have to follow scientific method to test, validate or establish any theory.

As a teacher of Science, you should provide them opportunity to discover Science in their surroundings by using a process of inquiry.

1.5 SCIENCE AS A PROCESS OF INQUIRY

Why moon usually comes at night? Why flowers are of many colours? Why we feel hot or cold? How does it rain? etc. are a few questions, which teachers have come across while dealing with learners in classroom. These questions are a reflection of curiosity among learners about the incidents in their surroundings. Being curious is a natural tendency of the learner, it drives him/her to find out answer of these questions either by exploring something or asking adults and teachers. This curiosity is at the center of inquiry.

Inquiry learning refers to finding an answer of a question in mind using various resources from surroundings to access information, data, knowledge and idea. These resources may be in the form of daily experiences, books, pictures, texts, stories, local animals and plants, things around them, diagrams, animations, video, movie clips, newspapers, etc. We can say that inquiry based learning promotes knowledge formation and its generation. Scientific inquiry is a way to investigate things and propose explanations for observations. When learners are engaged in scientific inquiry, they may think that there is a usual set of procedures to follow, that is the scientific method – suggest hypotheses, design an experiment, record observations, get data, analyze it and firmly draw conclusions. But this is not the only procedure. In scientific inquiry, they may follow other approaches to solve a problem or to seek answer of a question in mind.

Scientific inquiry may be considered as an approach to reach to a solution of the problem, but it is not essential that all people will follow the same route. In this sense, it can be said that scientific inquiry provides freedom in approach to deal with a problem. It is a process with many variations depending upon needs, experience, prior knowledge, available resources, personal likings and objectives. How does scientific inquiry work in young learners? Worth and Grollman (2003) through a simple inquiry learning model, answered this question.

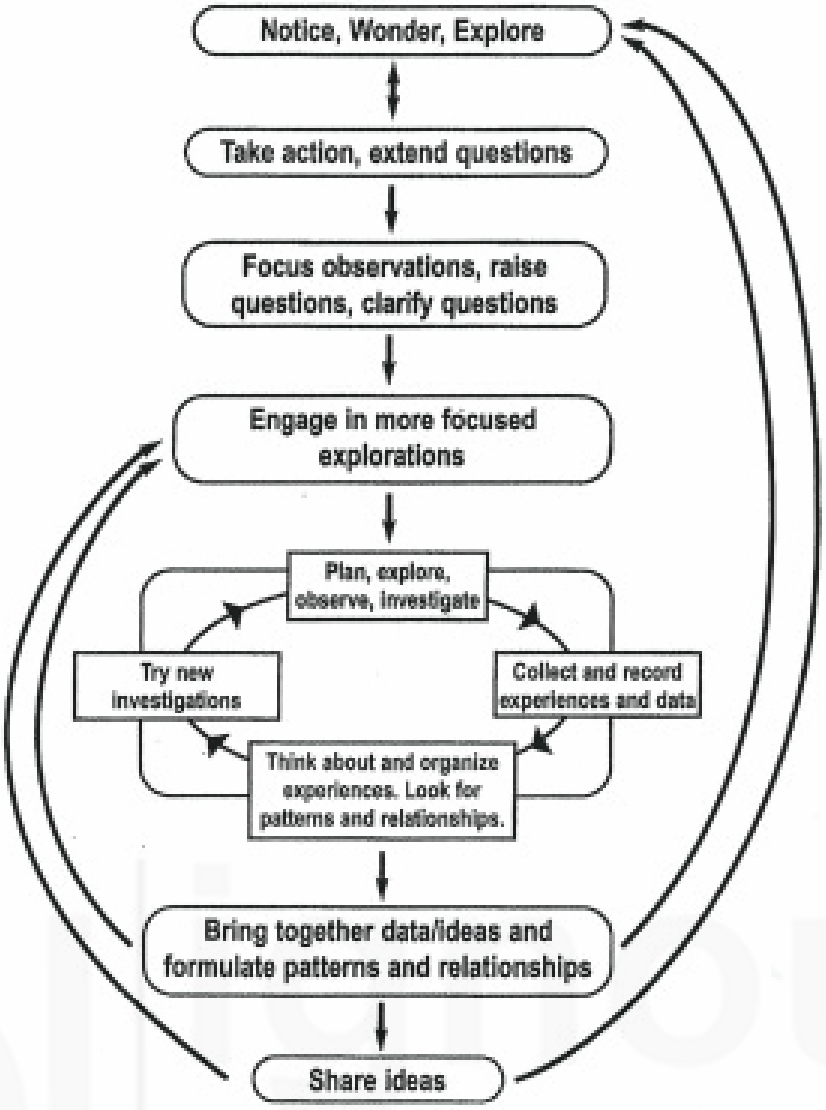

Fig. 1.3: Inquiry Learning Cycle (Worth &Grollman, 2003, p. 19)

If you go through this cycle, you will observe that learners learn through inquiry which begins with some incident they notice. It initiates a process of question formation in their mind, which they ask to themselves first and then to elders. It guides them to move on to next step of focused exploration and investigation. They collect data, information and analyze it to draw a conclusion. They correlate their observations with data, formulate patterns and find out relationships and share their ideas with their peers as well as teachers. Similar procedure is adopted by scientists, but yes with some sophistication.

Thus, we can say that scientific inquiry helps learners to develop a variety of skills. Few of them may be like exploration of objects, things, incident, questioning, careful observation, engaging in simple investigations, ability to describe, compare, analyze and classify, recording observation, using tools for data collection, identifying patterns and relationships, drawing out tentative conclusions, etc.

In order to understand the process of scientific inquiry in more specific terms, let us discuss various processes such as formulation of hypotheses, gathering of

data, recording of observations, reaching to conclusions, etc. which one has to undergo during scientific inquiry.

Constructing explanations and ideas

The very first process, which a learner undergoes in this process, is the construction of explanations and ideas. Let us see, how it takes place.

> *In a Science class, the Science teacher Mr. Moin, brought some material. It was a water bottle, a glass and a thick paper sheet. He poured water in the glass and put the thick paper sheet on it. Slowly and carefully, he inverted the glass and removed his hand from there. Learners were surprised that paper had stuck on the glass and water is not coming out.*
>
> *He asked learner to reflect on it.*
>
> *Learners started discussing by giving explanations for their observation.*
>
> *The responses were varied.*
>
> *Some said that paper had glue inside.*
>
> *Some said, it had stuck due to water inside.*
>
> *Others whispered that there was some other thing in the water bottle.*
>
> *For some it was a kind of a magical trick.*

What are these comments? As a Science teacher, how can you use their comments for generating interest in natural phenomenon?

These comments/observations are part of the process of developing ideas and construction of explanations. As a teacher, you must have understood that Mr. Moin was exhibiting the phenomenon of air and its pressure. You may not accept these explanations of learners as 'scientific explanations' but you agree that this is how the process of scientific explanations starts. In scientific process, explanations are based on some scientific evidence and observations are supported by theories and experiences.

During scientific explanations, scientists use evidence to establish relationships and causes of phenomena. Scientific explanations must always be based on evidence. These evidences can come from designing and conducting an investigation; observing a demonstration; collecting specimens; or observing and describing objects, organisms, or events.

In case of learners, their explanations may not be 'scientifically sound' but you have to encourage them for generating explanations based on their observation and previous scientific knowledge. How will you do this?

You will either ask them a few questions or give response to their questions in scientific way. In both the cases, you have to know the art of asking question and developing appropriate questions. In next subsection, we will focus on this very aspect of scientific inquiry.

Asking questions and using appropriate questioning technique

Generally in a Science classroom, various 'vague' ideas and explanations proposed by learners are not accepted by teachers. Learners have a natural tendency to ask

questions. Teacher can also ask questions to learners as a part of scientific inquiry. As a teacher of Science, you have to first understand a variety of question that can be asked or answered. There are two types of questions that can be asked in the classroom: Existence and Casual.

Existence questions start with *why* and are answered on the basis of recalling factual knowledge a learner already have. On the other hand **casual** questions begin with *how, what if, does* and *I wonder,* which are generally answered through scientific investigations.

In scientific inquiry, questions are a bit different from the questions generally asked. When a learner develops his/her understanding about scientific inquiry, s/he is able to generate his/her own set of questions. Generally, following types of questions are asked during scientific inquiry.

Testable Questions: These questions can be tested and can be answered through evidence based on observations or experimentation. These question lead to formation of hypotheses. For example, Can fish survive out of water?

Spontaneous questions: Questions raised by learners as reflection of their natural curiosity towards any incidence or phenomenon. For example: Why flowers are not green?

Stimulative Questions: These questions are generally asked by the teacher to stimulate learner thinking, observation and reflection towards provided material or demonstration. For example, the teacher may ask after a demonstration: Why paper boat floats and paper sinks?

Factual questions: Questions related to any scientific fact to justify any phenomenon.

Generally, learners ask factual questions as they are not aware about the actual process of scientific inquiry. Factual questions are comparatively easy to generate. As a teacher you have to encourage learners to ask more meaningful questions. As soon as learners will learn to ask a variety of questions, they will also learn to relate the questions with scientific inquiry process and investigations. They should be provided opportunities to explore information related to their questions and should be encouraged to find answers of their questions by themselves. Along with it, the teacher should try to modify factual questions into testable questions and provide opportunity to generate new questions.

Activity 2

Initiate a discussion on any topic (e.g. rain, air pollution, etc.) related to Science in your class. List the questions asked by learners. Categorize these questions into various types of questions mentioned above.

Developing testable questions and hypotheses

As discussed in the previous sub-section, in the process of scientific inquiry, the teacher has to develop testable questions. We have discussed that testable questions are answered through observations or experiments which provide evidence.

It is also suggested that you direct your learners to be able to distinguish between testable questions and other forms of questions and factual questions asked by learners should be modified into testable questions. Let us first try to understand what is a testable question?

BSCS (2005, p. 30) has suggested that 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.

Can you apply these criteria on the questions discussed in previous section?

Many times, you can observe that the questions are mostly related to an activity but cannot be accepted as testable questions because these can't be answered through an experiment only. There are a few questions, which can be answered on the basis of factual knowledge and explanation of cause-effect relationship.

Before answering the questions, the teacher has to provide an opportunity to learners to predict/give the probable answers of their questions. Learners may develop some predictions or tentative answers based on their observations. Some of their answers may be testable or not, the teacher has to help them in identifying the testable tentative answers. **These tentative or testable answers to the testable questions are often termed as hypotheses**.

According to Heyer (2006, p.4), the four most important things to remember about hypotheses are:

- A hypothesis should be consistent with existing observations and known information regarding the question.
- A hypothesis must be presented as a statement of the predicted outcome, not as a question.
- A hypothesis is formulated before the experiment, not after the experiment.
- A hypothesis must be specific and testable.

As a teacher you can create situations to encourage learners to form testable questions and find out probable answers on the basis of their observations and previous knowledge.

Activity 3

In order to encourage your learners for framing hypotheses, you can perform activities in the classroom based on:

- The increase in the rate of evaporation of water with heat.
- Factors affecting growth of salt crystal.
- Factors affecting growth of plants/seed germination.
- Effect of exercise on rate of respiration.

Planning, conducting and observing simple investigations

In order to test formulated hypotheses, you have to encourage learners to plan, conduct and observe some investigations or simple experiments. Whenever an investigation is to be carried out, it should be based on sound planning regarding the role of the teachers and learners and their participation during the investigation.

While planning any simple scientific investigation, you should prepare yourself by answering questions like:

- What is the objective of investigation?
- How is it related with scientific concept or theory?
- What are the required material/resources for investigation?
- Where will the investigation be carried out i.e. inside the classroom or outside the class/school?
- What will be the level of involvement of the learners?
- What will be role of learners?
- What are the precautions to be kept in mind? And so on…

After planning, the next task is to conduct the activity i.e. executing your plan. To encourage learners to be active participants of investigation, the teachers should guide them to perform the investigation. The activity set by the teacher should ensure the active and enthusiastic involvement of the learners in observation, establishing cause-effect relationship, collecting information, arranging data in sequential and logical manner etc. Teachers' role should be of a vigilant observer with minimum interference in the process of investigation.

It has been suggested that the teacher not only connects classroom teaching with the physical surroundings but also promotes the investigation by learners, helping them to establish a relationship with their surroundings.

As a teacher, you can perform many simple experiments in the classroom also. Some of them could be:

- Take two test tubes leveled as A and B. In test tube A, put some boiled rice, and in B, put the boiled rice after chewing it for 3-5 min. Add 3-4 ml. water in both. Now pour 2-3 drops of iodine solution in them. Ask the learners to observe the change. You can explain the role of saliva in breaking of **starch into sugar**.
- Take one iron rod. Apply wax on it and attach some nails with the wax. Start heating one end of the rod. Ask the learners to observe the changes. You can help them to understand the concept of **flow of heat.**

These are just a few suggestions; you can plan a lot more activities based on the content of the prescribed Science Textbook. The objective of discussion in this section is to sensitize you about making teaching learning more inquiry based and making the learner an active constructor of scientific knowledge.

Constructing explanations and communicating results

After completing the investigation, encourage learners to communicate about the conclusions obtained and justify the proposed explanations. You can tell

them that conclusion is the culmination of the entire inquiry process. The conclusion should include all aspects- from the observations that lead to questions, investigation that leads to the hypothesis and the experiment and data which leads to the determination if the hypothesis has been accepted or rejected. The conclusion also includes other questions that may have arisen in learners' mind during the course of the experiment/investigation and the experiences they might have undergone during the experiment.

After drawing conclusions, learners are expected to share and communicate the results obtained. Communicating results is another important part of scientific inquiry. Here it is not expected that learners should communicate the result in same way as the scientists communicate their results, all though, they have to learn to report their result in a sequential way in the light of objectives decided earlier. The teacher can help learners to present the results of their inquiry in an understandable form for others.

Solving problems

A learner of Science is expected to solve her/his day to day problems with a scientific attitude. S/he should apply the process of scientific inquiry in understanding, analyzing and solving a problem. As a teacher you have to create situations, in which learners feel encouraged to analyze the problem in a scientific process, apply scientific inquiry approach to understand it, formulate testable questions and hypotheses, organize scientific investigation, draw a conclusion and report it as a solution of the problem.

It should be remembered that scientific inquiry only leads us towards possible solution of problems and we have to decide whether it is right or wrong based on evidences, observations and experimentation.

The question is how can we motivate learners towards it? Through a problematic situation of their day to day life, incidents from their surroundings, news clips, newspaper reports, natural disasters, linkage of scientific concept explained in text book with the examples of their life experiences, we can motivate learners. Here are some examples given in the box, where a scientific concept can be explained with the help of every day experiences.

Concept	**Example form daily life experience**
Food material and sources	Analysis of meals
Solute, solvent and solution	During summer Home-made drinks
Separation of substances	Tea separation, butter formation, threshing
Different habitats of animals of animals in their surroundings	Visit to the zoo and close observation
Magnet	Doors of refrigerators, pin holders
Food chain and food web	Grassland, pond or forest visit

If you analyze the content given in your Science textbook, you can find many such examples.

Check Your Progress

Note: a) Space is given below to write your answer.

b) Compare your answer with the one given at the end of this Unit.

3) What are the types of questions in scientific inquiry?

.....

.....

.....

.....

.....

4) What should be the characteristics of a good conclusion?

.....

.....

.....

.....

.....

1.6 SCIENCE IN SOCIETY

As a teacher of Science, your role is to help your learners in understanding the relationship of Science with society. Science is not something which has emerged on its own. There is an important role of needs and demands of society in development of Science.

Science has developed for facilitating society in explaining various natural phenomena. In our own Indian literature, there are examples from *Rigveda*, where it has been explained that how Earth rotates around Sun in 12 months. There are slokas and verses in Kalpsutra which have explained many relationships of squares, triangles, circles, even many years before Pythagoras. How Aurveda and Surgery were being used to help society in being healthy, there are books on it. In modern Science, Have you read a famous book '***A brief History of Time'*** by Stephen Hawking, or can you imagine the impact of '***Origin of Species'*** written by Charles Darwin. These are few examples to initiate the discussion on relationship of Science and society. Science is a social enterprise; this is to be explained for learners by you as a Science teacher.

Innovations and discoveries of Science have transformed the whole social structure.

- Can you compare the society before and after the invention of mobile phone? How mobile phone technology as changed the whole social structure.

- Can you compare the year when only books and newspapers were source of information and now when internet and social media has become major source of information?

- Can you imagine the contribution of Science in the area of medical Sciences, where every day something new is being invented in form of vaccine, medicines, surgical equipment, and diagnostic test kits, etc.?
- How do recent developments in Space and Atomic research affect the social relationships in global world?

There are many such questions, which may emerge in your mind when you start thinking about relationship of Science and society.

You will not find any aspect of social or personal life, which is not affected by innovations and discoveries in Science.

Ask your learners to perform a small activity.

Ask your learners to list down various duties they perform as a member of society, and also enlist the scientific discoveries/inventions which are helping them in performing their duties:

Duty	Their Role	Scientific discoveries/inventions, which help

You can organize many such activities where they can learn how important Science is for the society. You can invite Doctors, Agriculture Experts, Engineers, Environmentalists, etc. for talks so that learners can develop an understanding of their contribution in the society.

Activity

Organize any of the following events at your school in collaboration with society members:

- Science exhibition
- Discussion on role of various types of scientific discoveries/inventions for benefit of society
- Small group projects on latest development in Science and technology
- Reading circles about contribution of various scientists to society
- Poster Competition on contribution of Indian Scientists to the world

These activities will help you a lot in developing a fair understanding of relationship of society and Science among your learners.

1.7 VALUE DEVELOPMENT THROUGH SCIENCE

Value development is always an area of concern. Responsibility of value development is on all teachers. There are values which are universal across the

disciplines as well as discipline specific also. There is a need to adopt integrated approach for value development in which values should not be taught as content rather they should be imbibed in the process and activities of various subjects. Your role as teacher at secondary level is to facilitate learners with such activities where they can not only create knowledge and develop understanding of scientific phenomenon but also inculcate values among themselves.

A good Science curriculum should promote values like honesty, co-operation, objectivity, freedom from fear and prejudice, and develop in the learner a concern for life and preservation of environment (National Focus Group on Teaching of Science, 2006, p. 3)

Let us discuss few activities through which a Science teacher can inculcate values among learners. You have to complete the following table.

S.No.	Activity	Associated Value
1		Honesty
2		Interdependence
3	A group project on flora and fauna of tropical forest	Co-operation
4		Objectivity
5	Seed generation in a pot, Awareness campaign on cleanliness, Role play for awareness about wastage of water, Small project on natural disasters and their impact on human life, etc.	Environmental concern
6		Freedom from prejudices
7	Inspirational short stories from life of various scientists like Jagdish Chandra Bose, C. V. Raman, A.P.J. Abdul Kalam, Madam Curie, while teaching the scientific concepts related to their area of work.	Concern for life

With the help of this, activity you can understand that value development is possible by visualizing and integrating value development with teaching-learning process. You will also agree that a value cannot be developed by any one particular activity or a section of content; continuous efforts are required for it. It is expected from you being a teacher of Science that whenever you plan your teaching-learning process for any content, you will also plan the value associated with it and also the assessment strategy. If you keep it in mind during planning and transaction, you will be able to develop desired values among your learners.

Check Your Progress

Note: a) Space is given below to write your answer.

b) Compare your answer with the one given at the end of this Unit.

5) What are the major contributions of Science to modern Society?

.....

.....

.....

.....

.....

6) What are the values, which you can plan to develop through teaching-learning of Science at secondary level? Give suitable examples from content of Science textbooks.

.....

.....

.....

.....

.....

1.8 LETS US SUM UP

Unit has discussed in brief about meaning and nature of Science. It is suggested that as a Science teacher, you should help learners in understanding the Science as a process of inquiry. Various myths about nature of Science are to be resolved so that learners can understand true nature of Science. Learners also realize that Science is not only the body of knowledge or a process of inquiry; rather it is a way of thinking. Unit explains with examples that Science does not work only through scientific method, rather it develops through process of inquiry. Unit discusses in brief that Science has developed for facilitating society in explaining various natural phenomena. With the help of inventions and discoveries, Science has transformed the whole social structure. It is suggested in the Unit that there are certain values, which are to be developed along with teaching-learning process of Science. As a Science teacher, you have to integrate values development with content transaction in Science.

1.9. UNIT END EXERCISES

1) What are various myths related to Science? How will you help learners in resolving these myths? Give suitable examples.

2) Discuss various steps of inquiry with help of an example from secondary level Science curriculum.

3) How will you develop values while teaching Science? Explain with suitable examples.

1.10 SUGGESTED READINGS AND REFERENCES

- BSCS. (2005). *Doing Science: The process of scientific enquiry*. Colorado Springs: NIH Publication

- Goldston, M. J. and Downey, L. (2013). *Your Science Classroom: Becoming an Elementary/Middle School Science Teacher*, California: Sage.

- Heyer, B. (2006). *The process of scientific enquiry– Collecting, graphing, & interpreting data*. Retrieved from http://www.facultyfiles.deanza.edu/gems/heyerbruce/B11L02.pdf.
- Lederman, N.G. (1992). *Students' and teachers' conceptions of the nature of Science: A review of the research. Journal of Research in Science Teaching,* 26(9), 771-783.
- McComas, F. W. (1998). *The Nature of Science in Science Education: Rationales and Strategies* (Ed.). The Netherlands: Kluwer Publishers.
- McComas, W. (1998). *The Principle Elements of the Nature of Science: Dispelling the Myths*. Retrieved from http://coehp.uark.edu/pase/TheMythsOfScience.pdfon July 18, 2013.
- NCERT (2005). National Curriculum Framework (NCF-2005).
- NCERT (2006). *Position paper-National Focus Group on Teaching of Science*, NCERT Publications.
- NCERT (2013). *Pedagogy of Science: Physical Science Part-I,* New Delhi: National Council of Educational Research and Training.
- NSTA (n.d.). *Science and Children: Methods and Strategies*. Understanding the true Meaning of Nature of Science. Retrieved from http://www.nsta.org/publications/news/story.aspx?id=51055 on July 17, 2013.
- Settlage, J. and Southerland, S. A. (2012). *Teaching Science to every learner: using culture as a starting point (2nd Ed.)*. New York: Routledge.
- Shackle, S. (2015, April 2). *Science and serendipity: famous accidental discoveries*, New Humanist, Retrived from https://newhumanist.org.uk/articles/4852/Science-and-serendipity-famous-accidental-discoveries.
- UNESCO (1993). *Strategies and Methods for Teaching Values in the Context of Science and Technology*, retrieved from http://www.unesco.org/education/pdf/325_96.pdf.
- Worth, K., & Grollman, S. (2003). *Worms, shadows, and whirlpools: Science in the early childhood classroom*. Washington, DC: National Association for Education of Young Children. Retrieved from http://eric.ed.gov/PDFS/ED481899.pdf.

1.11 ANSWERS TO CHECK YOUR PROGRESS

1) Answer based on your understanding of section 1.3.1.
2) Discuss one classroom activity each for explaining Science as a body of knowledge, a process of inquiry and a way of thinking.
3) Testable Questions, Spontaneous questions, Stimulative Questions and Factual questions.
4) The conclusion should include all aspects from the observations that lead to the question, to the investigation that lead to the hypothesis and the experiment and data which lead to the determination if the hypothesis has been accepted or rejected.
5) Discuss major scientific contributions to society, which you observe.
6) Honesty, co-operation, objectivity, freedom from fear and prejudice, concern for life and preservation of environment.