Chapter 4

Science Education

Science is the study of the natural and physical world around us through a systematic process of observing, questioning, forming hypotheses, testing hypotheses through experiment, analysing evidence, and thereby continuously revising our knowledge.

The process of Science is not something that only scientists do in laboratories alone. It also develops an important set of capacities (and dispositions) essential for leading a rational and fulfilling lives. These capacities (and dispositions) help us make informed and good decisions that benefit us and our communities.

Learning Science enables us to gain valid knowledge about the world as well as acquire scientific values, capacities, and dispositions, such as curiosity, creativity, evidence-based thinking, and sound decision-making.

As a subject in schools, Science draws significantly from the disciplines of Biology, Chemistry, Physics, Earth Sciences, as well as from Mathematics, Computational Sciences, and, where relevant, from Social Science and Vocational Education, in order to provide an interdisciplinary understanding and appreciation of the role of Science in everyday life.

Good education in Science, including the development of a mindset of inquiry and research in students, is critical in addressing the challenges that India and the world face today, such as climate change, improving healthcare, technological advancement and use for sustainable development, creation of just and equitable livelihoods, and living in harmony with nature. Therefore, ensuring high quality education in Science, and its relationship with other subjects such as Social Science and Vocational Education forms a key focus of this NCF. This would help students to gain an understanding of how science and scientific research can address the central challenges faced by our society.

Children must start learning the process of science and the basics of the scientific method starting in the Foundational Stage itself. In the Preparatory Stage, they gain further experience in the process of Science and the scientific method through observing patterns and relationships in their natural environment and conducting simple hands-on experiments.

Science is introduced as a separate Curricular Area only in the Middle Stage. In this Stage, the approach integrates the disciplines of Biology, Chemistry, and Physics. This integrated approach continues in the first two years of the Secondary Stage (Grades 9 and 10). In the final two years of the Secondary Stage (Grades 11 and 12), a disciplinary approach is taken, with Physics, Chemistry, Biology, and Earth Science being offered separately. Students thereby get the opportunity to choose and understand the nature of one or more of these disciplines more deeply and develop competencies specific to each. As in the case of other Curricular Areas, Grades 11 and 12 are not dealt with in this chapter, but in *Part B, Chapter 10.*

Section 4.1
Aims

Science aims to develop an understanding of the natural and physical world through systematic inquiry. Learning Science also builds important capacities such as observation, analysis, and inference. This in turn enables the meaningful participation of individuals in society and the world of work with scientific temper, critical and evidence-based thinking, asking relevant questions, analysing practices and norms, and acting for necessary change.

Science Education aims to achieve:

a. **Scientific understanding of the natural and physical world.** Scientific understanding develops through specific observations, questions, experiments, theories, laws, principles, and concepts. An adequate knowledge of these is essential to build a systematic and verifiable understanding of the way the natural and physical world functions. In Science Education, students must thus learn the fundamental methods, concepts, and theories on which Science rests.

b. **Capacities for scientific inquiry.** The abilities to put forth hypotheses, arguments, predictions, and analyses, and to test hypotheses, evaluate situations, and draw logical conclusions, are fundamental to the learning of Science. Science Education must thus build these skills in students systematically over the Stages in school.

c. **Understanding the evolution of scientific knowledge.** There are crucial historical moments in the development of Science and scientific knowledge that could not have occurred without the efforts of various individuals and organisations over thousands of years. Understanding these key moments and discoveries will develop students' understanding of how scientific knowledge and the methods of science evolved and still evolve over time.

d. **Interdisciplinary understanding between Science and other curricular areas.** Learning in Science involves understanding interlinkages across disciplines. Concepts, principles, laws, and theories cannot be viewed as isolated, but instead they together contribute to a holistic understanding of the world. Students would learn to inquire and learn about the world through such an interdisciplinary approach.

e. **Understanding of the relationship between Science, Technology, and Society.** The contribution of Science to Society and how different societal needs led to the generation of scientific knowledge is also an important part of learning Science. Engaging with issues related to connections between Science, Technology, and Society, including the ethical aspects and implications, and appreciating the role Science plays in addressing the challenges and the world is undergoing, will add to the breadth of students' learning.

f. **Scientific temper.** Developing the capacities for critical and evidence-based thinking and freedom from fear and prejudice is central to the learning of Science. Students will imbibe scientific values and dispositions such as honesty, integrity, scepticism, objectivity, tenacity, perseverance, collaboration and cooperation, concern for life, and preservation of the environment.

g. **Creativity.** Asking good questions, observing patterns in the world around us, formulating plausible hypotheses given those patterns, and designing good experiments to test those hypotheses often requires artistry and creativity. Developing such creativity and a sense of aesthetics in the pursuit of scientific understanding and exploration is another very important but oft-ignored aim of Science Education.

Section 4.2
Nature of Knowledge

Science is an organised system of knowledge, that evolves as a result of curiosity followed by inquiry, logical reasoning, experimentation, and the examination of empirical evidence. It enables an understanding of the physical and natural environments and phenomena, the identification of meaningful patterns and relations including causes and effects, and supports the development of models, theories, laws, and principles.

a. Science is fundamentally a creative endeavour. Science involves imagining new ideas and concepts to understand the world. Creative imagination is required to engage with the concepts of Science — e.g., natural selection to explain diversity (theory of evolution), planetary models to represent the motion of planets, and atomic theory to envision the microscopic world beyond our capacity for observation. Asking questions, formulating hypotheses, designing experiments and making models all require creativity.

b. **Science provides the methods and tools necessary to explore and understand the world.** These methods and tools lead to explanations supported by empirical evidence that can be tested in a variety of diverse real-life situations against rigorous criteria (observation, rational argument, inference, replicability).

c. **Scientific knowledge keeps evolving and this is reflected in its history.** Scientific knowledge is very reliable but also subject to change when presented with new evidence or with a re-conceptualisation of prior evidence and knowledge. Science, therefore, develops an appreciation for change as well as for the rigorous process through which scientific knowledge evolves.

Section 4.3
Current Challenges

A major challenge related to Science in the school curriculum is the focus on facts and definitions, often with a neglect for the development of conceptual understanding and the capacities for scientific inquiry.

a. Science teaching-learning has traditionally been based mostly on the textbook, with a **focus on facts and definitions.** One reason for this is the curricular load, which reduces the time available for exploration and discussion. The development of conceptual understanding and capacities requires time which is currently missing due to the high content load. This challenge only increases as students move to higher grades — the demand on them increases as the curricular load becomes even greater. The need for abstract thinking also increases. It is critical that the students develop the capacities to be able to make the progression. However, the current focus on facts does not build these capacities adequately.

b. The content to be included in the curriculum is often determined by the content and demands of entrance examinations for higher education. This is not sound logic. Science content in school should be determined by the Aims of School Education and what all students should aim to learn in Science. Meanwhile, higher education entrance examinations (or other methods) must change to being competency-based rather than rote-based and 'fact recounting'.

   Content of Science syllabus must not assume that all students will pursue Science in Higher Education, as some syllabi seem to, today.

c. Another challenge is the **disconnect between the school curriculum and what students observe and experience outside school.** Students come to school with their own theories about the world. These theories develop as they observe the world around them and seek explanations for what they see. Often, these theories may conflict with what is being discussed in the classroom; common intuition and scientific theories at times may not match. Illustratively, through mere perception, it is very hard to think that the Earth is not flat.

d. While a lack of **infrastructure** is common across Curricular Areas, learning Science especially requires access to apparatus, equipment, and laboratories. Unfortunately, this remains a neglected need. Low-cost, easily available materials are also not used, since

Teachers often lack the capacity to develop such local, low-cost teaching-learning materials. At the Secondary Stage, access to a laboratory is non-negotiable — students must be able to assemble and manipulate apparatus, use materials, and design simple experiments to truly develop important competencies related to Science.

Section 4.4
Learning Standards

4.4.1 Curricular Goals and Competencies

This section lays out the Learning Standards (Curricular Goals and Competencies) for Science as an integrated Curricular Area.

In the Middle Stage and Grades 9 and 10 of the Secondary Stage, Science is taught using integrated approach. This integrated approach develops fundamental capacities related to the disciplines of Biology, Chemistry, Physics, and Earth Science while the use of connections across them helps students appreciate the interrelations between these subjects and make sense of their observations and experiences.

At all Stages, along with conceptual understanding, the capacities of scientific inquiry are developed as age appropriate. These concepts and capacities are chosen both from a disciplinary perspective and in terms of what is useful and necessary in their everyday lives. Students thereby understand the world around them with increasing depth, explore scientific questions at different levels through discussion and experimentation, and learn to communicate this understanding in different ways.

It is important to note that the Curricular Goals are interdependent, and not separate curricular pieces of study. For example, the Curricular Goals CG-1 (explore matter) and CG-6 (how to do Science) given in the Middle Stage would need to happen together, say through a project, for a student to attain both Goals.

4.4.1.1 Middle Stage

CG-1 Explores the world of matter and its constituents, properties, and behaviour	C-1.1 Classifies matter based on observable physical (solid, liquid, gas, shape, volume, density, transparent, opaque, translucent, magnetic, non-magnetic, conducting, non-conducting) and chemical (pure, impure; acid, base; metal, non-metal; element, compound) characteristics C-1.2 Describes changes in matter (physical and chemical) and uses particulate nature to represent the properties of matter and the changes C-1.3 Explains the importance of measurement and measures physical properties of matter (such as volume, weight, temperature, density) in indigenous, non-standard and standard units using simple instruments C-1.4 Observes and explains the phenomena caused due to differences in pressure, temperature, and density (e.g., breathing, sinking-floating, water pumps in homes, cooling of things, formation of winds)
CG-2 Explores the physical world in scientific and mathematical terms	C-2.1 Describes one-dimensional motion (uniform, non-uniform, horizontal, vertical) using physical measurements (position, speed, and changes in speed) through mathematical and diagrammatic representations C-2.2 Describes how electricity works through manipulating different elements in simple circuits and demonstrates the heating and magnetic effects of electricity C-2.3 Describes the properties of a magnet (natural and artificial; Earth as a magnet) C-2.4 Demonstrates rectilinear propagation of light from different sources (natural, artificial, reflecting surfaces), verifies the laws of reflection through manipulation of light sources and objects and the use of apparatus and artefacts (such as plane and curved mirrors, pinhole camera, kaleidoscope, periscope) C-2.5 Observes and identifies celestial objects (stars, planets, natural and artificial satellites, constellations, comets) in the night sky using a simple telescope and images/ photographs, and explains their role in navigation, calendars, and other phenomena (phases of the moon, eclipse, life on earth)

CG-3 Explores the living world in scientific terms	C-3.1 Describes the diversity of living things observed in the natural surroundings (insects, earthworms, snails, birds, mammals, reptiles, spiders, diverse plants, and fungi), including at a smaller scale (microscopic organisms) C-3.2 Distinguishes the characteristics of living organisms (need for nutrition, growth and development, need for respiration, response to stimuli, reproduction, excretion, cellular organisation) from non-living things C-3.3 Analyses patterns of relationships between living organisms and their environments in terms of dependence on and response to each other C-3.4 Explains the conditions suitable for sustaining life on Earth and other planets (atmosphere; suitable temperature-pressure, light; properties of water)
CG-4 Understands the components of health, hygiene, and well-being	C-4.1 Undertakes a nutrition-based analysis of food components with special reference to Indian culinary practices and modern understanding of nutrition, and explains the effect of nutrition on health C-4.2 Examines different dimensions of diversity of food — sources, nutrients, climatic conditions, diets C-4.3 Describes biological changes (growth, hormonal) during adolescence, and measures to ensure overall well-being C-4.4 Recognises and discusses substance abuse, viewing school as a safe space to raise these concerns
CG-5 Understands the interface of Science, Technology, and Society	C-5.1 Illustrates how Science and Technology can help to improve the quality of human life (health care, communication, transportation, food security, mitigation of climate change, judicious consumption of resources, applications of artificial satellites) as well as some of the harmful uses of science in history C-5.2 Shares views on news and articles related to the impact that Science/Technology and society have on each other

CG-6 Explores the nature and processes of Science through engaging with the evolution of scientific knowledge and conducting scientific inquiry	C-6.1 Illustrates how scientific knowledge and ideas have changed over time (description of motion of objects and planets, spontaneous generation of life, number of planets) and identifies the scientific values that are inherent and common across the evolution of scientific knowledge (scientific temper, Science as a collective endeavour, conserving biodiversity and ecosystems) C-6.2 Formulates questions using scientific terminology (to identify possible causes for an event, patterns, or behaviour of objects) and collects data as evidence (through observation of the natural environment, design of simple experiments, or use of simple scientific instruments)
CG-7 Communicates questions, observations, and conclusions related to Science	C-7.1 Uses scientific vocabulary to communicate Science accurately in oral and written form, and through visual representation C-7.2 Designs and builds simple models to demonstrate scientific concepts C-7.3 Represents real world events and relationships through diagrams and simple mathematical representations
CG-8 Understands and appreciates the contribution of India through history and the present times to the overall field of Science, including the disciplines that constitute it	C-8.1 Knows and explains the significant contributions of India to all matters (concepts, explanations, methods) that are studied within the curriculum in an integrated manner
CG-9 Develops awareness of the most current discoveries, ideas, and frontiers in all areas of scientific knowledge in order to appreciate that Science is ever evolving and that there are still many unanswered questions	C-9.1 States concepts that represent the most current understanding of the matter being studied — ranging from mere familiarity to conceptual understanding of the matter as appropriate to the developmental stage of the students C-9.2 States questions related to matters in the curriculum for which current scientific understanding is well-recognised to be inadequate

4.4.1.2 Secondary Stage

CG-1 Explores the world of matter, its interactions, and properties at the atomic level	C-1.1 Describes classification of elements in the Periodic Table, and explains how compounds (including carbon compounds) are formed based on atomic structure (Bohr's model) and properties (valency) C-1.2 Investigates the nature and properties of chemical substances (distillation, crystallisation, chromatography, centrifugation, types and properties of mixtures, solutions, colloids, and suspensions) C-1.3 Describes and represents chemical interactions and changes using symbols and chemical equations (acid and base, metal, and non-metal, reversible, and irreversible)
CG-2 Explores the physical world around them, and understands scientific principles and laws based on observations and analysis	C-2.1 Applies Newton's laws to explain the effect of forces (change in state of motion — displacement and direction, velocity and acceleration, uniform circular motion, acceleration due to gravity) and analyses graphical and mathematical representations of motion in one dimension C-2.2 Explains the relationship between mass and weight using universal law of gravitation and connect it to laws of motion C-2.3 Manipulates the position of object and properties of lenses (focus, centre of curvature) to observe image characteristics and correspondence with a ray diagram, and extends this understanding to a combination of lenses (telescope, microscope) C-2.4 Manipulates and analyses different characteristics of the circuit (current, voltage, resistance) and mathematises their relationship (Ohm's law), and applies it to everyday usage (electricity bill, short circuit, safety measures) C-2.5 Defines work in scientific terms, and represents the relationship between potential and kinetic energy (conservation of energy) in mathematical expressions C-2.6 Demonstrates the principle of mechanical advantage by constructing simple machines (system of levers and pulleys) C-2.7 Describes the origin and properties of sound (wavelength, frequency, amplitude) and differences in what we hear as it propagates through different instruments

CG-3 Explores the structure and function of the living world at the cellular level	C-3.1 Explains the role of cellular components (nucleus, mitochondria, endoplasmic reticulum, vacuoles, chloroplast, cell wall), including the semi-permeability of cell membrane in making cell the structural basis of living organisms and functional basis of life processes C-3.2 Analyses similarities and differences in the life processes involved in nutrition (photosynthesis in plants; absorption of nutrients in fungi; digestion in animals), transport (transport of water in plants; circulation in animals), exchange of materials (respiration and excretion), and reproduction C-3.3 Describes mechanisms of heredity (in terms of DNA, genes, chromosomes) and variation (as changes in the sequence of DNA)
CG-4 Explores interconnectedness between organisms and their environment	C-4.1 Applies the knowledge of cellular diversity in organisms along with the ecological role organisms play (autotrophic/ heterotrophic nutrition) to classify them into five-kingdoms C-4.2 Illustrates different levels of organisations of living organisms (from molecules to organisms) C-4.3 Analyses different levels of biological organisation from organisms to ecosystems and biomes along with interactions that take place at each level C-4.4 Analyses patterns of inheritance of traits in terms of Mendel's laws and its consequences at a population level (using models and/or simulations) C-4.5 Analyses evidences of biological evolution demonstrating the consequences of the process of natural selection in terms of changes — in allele frequency in population, structure, and function of organisms
CG-5 Draws linkages between scientific knowledge and knowledge across other curricular areas	C-5.1 Explores how literature and the arts have influenced Science C-5.2 Examines a case study related to the use of Science in human life from the perspective of Social Sciences and ethics (e.g., Marie Curie, Jenner, treatment of patients with mental illness, the story of the atomic bomb, green revolution and GMOs, conservation of biodiversity) C-5.3 Applies scientific principles to explain phenomena in other subjects (sound pitch, octave, and amplitude in music; use of muscles in dance form and sports)

CG-6 Understands and appreciates the contribution of India through history and the present times to the overall field of Science, including the disciplines that constitute it	C-6.1 Knows and explains the significant contributions of India to all matters (concepts, explanations, methods) that are studied within the curriculum in an integrated manner
CG-7 Develops awareness of the most current discoveries, ideas, and frontiers in all areas of scientific knowledge in order to appreciate that Science is ever evolving, and that there are still many unanswered questions	C-7.1 States concepts that represent the most current understanding of the matter being studied — ranging from mere familiarity to conceptual understanding of the matter as appropriate to the developmental stage of the students C-7.2 States questions related to matters in the curriculum for which current scientific understanding is well-recognised to be inadequate
CG-8 Explores the nature of Science by doing Science	C-8.1 Develops accurate and appropriate models (including geometric, mathematical, graphical) to represent real-life events and phenomena using scientific principles and use these models to manipulate variables and predict results C-8.2 Designs and implements a plan for scientific inquiry (formulates hypotheses, makes predictions, identifies variables, accurately uses scientific instruments, represents data — primary and secondary — in multiple modes, draws inferences based on data and understanding of scientific concepts, theories, laws, and principles, communicates findings using scientific terminology)

4.4.2 Essential Concepts

There is a general agreement that the processes of Science are equally important to learn as the concepts. But usually, this does not seem to get translated into our classrooms. There is a tendency to treat Science as merely a 'bunch of facts'. This approach assumes that there are certain concepts, theories, facts, and information that students must know, and once acquired, they have knowledge of Science. However, the knowledge base of Science known today is vast and continues to grow at an unprecedented rate. This implies that no matter how many 'facts of Science' we learn, it will never be enough.

The question that this throws up is — what are the essential concepts that students must learn in Science at the school level?

Even though it would be clear that this is not complete 'knowledge of Science', this 'essential set' could be decided based on the following criteria:

a. It provides adequate knowledge of the world for that age group.
b. It provides the base and platform for further learning of scientific ideas.
c. It provides adequate 'material' for developing the capacities and values related to Science Education.
d. It provides sufficient scope for inquiry and development of capacities for scientific inquiry.

In addition, whatever concepts are chosen, they should be interesting, challenging, and intelligible for young minds.

At the same time, students must develop capacities for scientific inquiry and the ability to communicate scientific questions and ideas aligned with each Stage. These are addressed in the Curricular Goals and Competencies for both the Middle and Secondary Stages.

The Learning Standards must make a judicious choice of content on the basis of these principles to reduce the 'content load' on the students.

4.4.2.1 Middle Stage

Curricular Goals at the Middle Stage are based on the concrete experiences of students. They are based on how the Science curriculum can respond to the following questions:

a. What do students see around them?
b. What are the common observations they make?
c. What are the aspects of Science and Technology that are part of their daily lives?
d. What are their immediate concerns related to their own selves?
e. How can they start making sense of multiple aspects of their environment — How can they start learning to abstract 'Science' as the explanation of their observations and experiences?
f. How do students learn best? What capacities enable them to learn at this Stage?
g. What are the scientific values and dispositions that must be developed at this Stage?

Essential concepts selected on the basis of these questions include those that can build on students' observations of their immediate environment and help them find scientific explanations (e.g., characteristics of matter, changes in matter, diversity of living things, magnets, path of light and how it changes as it reflects from different surfaces). They are intended to enable the students to see differences and relationships between different parts of their environment (e.g., characteristics of living and non-living things, relationship between living organisms and their environment). They are related to aspects of their daily life that are of immediate interest and concern (e.g., nutrition-based analysis of food, substance abuse, the role of Science and Technology in improving their lives).

These concepts will provide a base for interested students to explore other scientific concepts and take up hobbies related to Science. Further, the concepts selected help students engage with the nature and processes of Science and develop scientific values and dispositions (including through examining the lives and works of scientists, and the development of scientific knowledge) that will enable them to take decisions in their daily lives as well as participate in larger society.

4.4.2.2 Secondary Stage

Curricular Goals at the Secondary Stage move from the concrete nature of the Middle Stage towards abstraction - from perceptual and practical concepts to theoretical concepts. This abstraction could be in the nature of exploring what cannot be seen or in terms of more abstract representations (e.g., using a circuit diagram instead of drawing the components of a circuit). They help students extend their understanding with increasing complexity and abstraction. The effort is to continue with the concepts discussed in the Middle Stage; a few new concepts are also introduced. The questions the curriculum must respond to at this Stage are:

a. Is there something happening around us that we cannot directly observe?
b. Why do events and phenomena repeat themselves? What are the general principles that govern the world?
c. What are the reasons for the diversity around us?
d. What is the role of Science and Technology in Society?
e. What is the contribution of India to scientific knowledge?
f. How can Science be applied in other areas?
g. What are the connections between other areas and Science?
h. How should Science be practised?
i. What are the scientific values and dispositions that must be developed at this Stage?

At this Stage, essential concepts selected on the basis of these questions include those that help students develop foundations of key ideas in Science that have wider application (e.g., origin, properties and propagation of sound introduce students to the idea of waves) and help students explain processes and materials around them in scientific terms (e.g., nature and properties of chemical substances used in daily life, work and energy). At this Stage, students must begin to engage with what they cannot 'see' to provide explanations for what they can observe (e.g., atomic structure and valency, cellular processes) and be able to represent the world in scientific terms, draw inferences, and make predictions (e.g., representation of simple chemical interactions and changes). They must be able to see scientific patterns and relationships (e.g., Periodic Table, classification of living organisms) and formalise their observations and understanding in the form of generalisation and mathematisation (e.g., Newton's laws, Mendel's laws of inheritance, natural selection and evolution). They must be able to identify and manipulate variables to develop causal relationships (e.g., manipulation of object and lenses and image characteristics).

Students must develop an interdisciplinary understanding of Science, and its linkages with other curricular areas, as well as the connection between Science, Technology and Society (e.g., how literature and art have influenced Science). Students must also understand the contribution of India to the world's scientific knowledge (e.g., indigenous practices related to health and medicine).

Students must also be enabled to conduct scientific inquiry independently and connect their findings to their understanding of scientific concepts, laws, and principles, as well as communicate their findings in different modes with accuracy and creativity.

Section 4.5
Content

The approach, principles, and methods of selecting content have commonalities across subjects - those have been discussed in Part A, Chapter 3, §3.2 of this document. This section focusses only on what is most essential to education of Science in schools. Hence, it will be useful to read this section along with the above-mentioned section.

Concepts by themselves are abstract. They need to be presented to students through content that helps them connect the concept with their previous knowledge as well as with their observations and experiences in the real world. For example, simply stating the rectilinear propagation of light is insufficient. This concept must be demonstrated to students, or they should be able to conclude that light travels in a straight line through observation or manipulation. Without suitable content, we reduce Science to mere facts. To extend the example of rectilinear propagation of light, students can observe this through the formation of shadows, or the simple manipulation of cardboard sheets with small holes in front of a candle, or using a pinhole camera/periscope made in the classroom. Thus, content is extremely important and must be selected carefully.

With the above in mind, the principles for content selection are:

a. **Content should be connected to the students' lives and surroundings to the maximum possible extent.**

A student in Andaman and Nicobar Islands and a student in Jharkhand will observe different kinds of plants and animals around them. But they should also understand the role of environmental factors. This generalisation will require them to understand environments they may not have experienced as well as some abstract ideas (e.g., temperature, precipitation).

Light and its use is also all around us — we use mirrors, we see rainbows, we see the sun, and other sources of light. Light reflects off different surfaces in different ways. When we see objects in water, they get distorted. The content must encourage students to question and inquire about these phenomena, which will lead them to explore scientific ideas related to light. Thus, they will engage with a critical area that shows the progression of concepts (from the representation of the behaviour of light through a simple ray diagram in the Middle Stage to the representation of the behaviour of plane waves in the Secondary Stage) as well as the advances in Science and Technology (from the use of lenses and mirrors, to optic fibres in telescopes).

b. **Content should enable scientific inquiry for the progression of concepts across Stages.**

For example, in the earlier Stages, students explore ideas of floating and sinking by making simple observations of different objects and making inferences about common properties. In the Middle Stage, students identify and measure the physical properties and determine the mathematical relationship between physical properties (e.g., relationship between mass, volume, and density and how this relates to floatation). They understand the concepts and represent diagrammatically the states of float and sink. They measure displacement of liquid and relate it to density. They may design simple experimental designs (e.g., clay boats of different shapes, weight) using instruments for measurement (measuring jar and overflow jar). Given data about the density of liquids, they make predictions about the state of float and sink of objects in them (relative density). They communicate their inferences in different modes (oral, mathematical, diagrammatic, in words). Thus, from verifying similar properties at earlier Stages, they progress to making quantitative predictions and measurements to arrive at theories about floatation. At the Secondary Stage, they can arrive at the conclusion that the density of water is 1 and they engage with the idea of buoyancy through quantitative measurements.

In this approach, students are active participants in the learning process as opposed to passive receivers of information.

c. Content should allow a comprehensive assessment of capacities of scientific inquiry at each Stage.

Content must be chosen to allow students to use the range of capacities in an observable manner so that Teachers can assess these capacities explicitly. This is aligned with the approach of defining competencies related to capacities of scientific inquiry under separate goals. Student achievement related to these capacities should be recorded explicitly.

This means making a choice between the presentation of a concept versus ensuring students 'do' something to attain the understanding of the concept. On the other hand, content can offer tasks (e.g., activity, experiment, writing task) that are observable and provide scope for interpretation and understanding by students. For example, the effect on the time period of the pendulum on changing the length of the thread and mass of a simple pendulum can be discussed through a description and presentation on the blackboard/textbook. On the other hand, students can make simple pendulums using different, easily available materials and record their observations. Their conclusion may not be entirely perfect compared to a well-designed pendulum, but they can draw inferences, which lead to constructing theory (e.g., the relationship between mass and length of thread and time period). The content selected changes from 'time period of a simple pendulum' to 'investigating factors affecting the time period of a simple pendulum'.

Content of this nature enables self-reflection. If the experiment is not proceeding well (e.g., the bob swings wildly), the student must examine what needs to be done. This is relevant for each Stage and ensures the progression of the attainment of the capacities of scientific inquiry across Stages. This also enables students to take up collaborative as well as independent study.

d. Content should enable an adequate sense of achievement at each Stage. While concepts become complex across Stages, milestones can be defined for subsidiary concepts that are complete and whole.

For example, we introduce students to plane mirrors, then spherical mirrors, and then lenses and system of lenses. They build a progressive understanding of reflection and image characteristics at each Stage in a complete manner.

Similarly, in the Preparatory and early Middle Stage, observing the diversity of living organisms and classifying them based on the observable characteristics allows students to make sense of the living world around them. In the later part of the Middle Stage and the

Secondary Stage, when microscopes are introduced, they make observations of living organisms and their cellular organisation which allows the students to re-classify or comprehend other ways of classifying the organisms based on the nature of their cellular organisation such as the five-kingdom system. At each Stage, different scales of complexities of living organisms are observed and understood. Thus, at each Stage, the criteria for classification are valid while providing scope for expanding these criteria with newer concepts.

e. Content should provide opportunities for students to engage in extended durations of inquiry.

Content should lead to extended, long-term inquiry beyond the classroom engagement. This can be in the form of long-term projects such as documenting the cycle of food production over a season. It can also be a recording of simple observations over a period of a month or so to understand a concept better, such as drawing the phases of the moon on a classroom calendar. Or it can be a short observation, such as fermentation by yeast to make a bread. Students could monitor the life cycle of mosquitoes, butterflies, or moths; they could also grow fruit flies to observe organisms around them. This encourages students to go into the depth and breadth of a concept. It also connects concepts to real life situations.

f. Content should cater to the diverse needs of students.

The content should cover a range of concepts that are interesting for all students. They must have opportunities to engage with the concept in different ways. For example, if a student is struggling to represent a concept in mathematical terms, they can start with representation through a simple working model, diagram, or verbal description and progress from there.

Students with disabilities should be included in the process of learning as far as possible. In this context, a range of materials and technology (simulation, audio-video resources) is necessary. For example, a force diagram can be made using tactile materials and detailed descriptions of the force diagram can be made available.

g. Content must develop the ability to use the language of Science.

Communicating scientific ideas is critical — for this, both representation of the world as well as the development of a scientific vocabulary are critical. While the development of the scientific vocabulary progresses as engagement with scientific ideas increases, content must enable representation of natural phenomenon — from simple diagrammatic representations (evaporation, solar system, structure of plants) to more complex representations (atomic structure, structure of the cell) and abstractions that make understanding easy (forces acting on a body) to mathematical representations (laws of motion, vectors).

h. Content should prepare students to engage with life as responsible members of the community.

Science Education at the school level should enable the students to use available scientific evidence to make decisions and choices of their everyday lives, such as decisions to vaccinate oneself, make healthier eating choices, examine media claims critically, or contribute to an inclusive society by critically examining one's beliefs, and so on.

i. **Content should enable students to examine and practise scientific values and other human values.**

Content must also demonstrate scientific values (integrity, honesty, transparency, pluralism, objectivity acceptance of uncertainty) and enable processes of rational thinking that will help the individual take a position on societal issues.

For example, examining how the geocentric conceptualisation of the universe shifted to the heliocentric conceptualisation (established beliefs) and observations of the orbit of Pluto eventually led to it being classified as a dwarf planet (Middle Stage and Grades 9 and 10). The journey of these scientific ideas reflects the changing nature of scientific theories and the tenacity of scientists.

Also, studying heredity, evolution, and biological diversity can lend itself to an examination of how long-held beliefs were challenged by Science based on evidence — e.g., the superiority of humans (anthropocentricism) or assumptions regarding the notion of 'races' and their 'superiority' — leading to an understanding of how every life matters for the symbiotic existence of every other life and of the similarity of the origins and beginning of life despite later diversity of physical characteristics.

j. **Content must enable integration across and within curricular areas.**

Learning about Science can be enhanced through integration with other curricular areas. For example, playing with different musical instruments allows students to understand frequency and amplitude. Games allow students to develop concepts related to motion; examining play on the moon helps them engage with concepts of gravity and force. The use of muscles while playing, stretching, is related to both science physical education, e.g., in understanding which muscles are used for different purposes and what each muscle's use is in the body.

Section 4.6
Pedagogy and Assessment

The approach, principles, and methods of pedagogy and assessment have commonalities across subjects — those have been discussed in **Part A, Chapter 3, §3.3 and §3.4** of this document. This section focusses only on what is essential for Science Education in schools. Hence, it will be useful to read this section along with the above-mentioned section.

4.6.1 Pedagogy for Science

Learning Science involves not just learning theories and facts of Science, but also making connections between conceptual learning and real life, acquiring the capacities of scientific inquiry, and most importantly, applying these to understanding the world.

Students like to explore the world around them and understand why and how things happen. In this process of exploration, they use trial-and-error methods to test their hypotheses and reach possible conclusions. This exploration need not take place individually - students learn Science best through engaging with peers and adults.

Students have theories about why things happen, patterns they see around them, and about cause-and-effect relationships. As they learn about Science in a more formal set-up, these ideas get tested. Some concepts fit into the students' current understanding, while others require a shift in thinking. If there is an alignment between current ideas and what is discussed in classrooms, ideas get strengthened.

At the same time, some concepts do not fit into the students' current thinking. If not addressed, they can turn into alternative conceptions. For example, heavy objects fall faster, plants are non-living because they don't move, or heavy/ big objects always sink in water. If these ideas are not challenged and suitably modified through investigation, they can turn into alternative conceptions which may persist as students move through school.

Apart from these theories, students also bring with them the ability to reason, understand, and explain relationships between cause and effect. These capacities serve as the basis for developing scientific reasoning. Opportunities, therefore, to inquire are important, as opposed to being 'told'.

Scientific values, such as honesty and integrity, also develop through 'doing Science'. For example, while demonstrating an experiment on the boiling point of water, we should write the reading on the thermometer accurately, even if the water is not boiling at 100 degrees.

The role of the Teacher in aligning pedagogy and assessment with how students learn Science is critical. Teachers must build an environment that promotes natural curiosity, encourages questions, gives maximum possible opportunities for hands-on activities, and gives ample space to discuss ideas. Opportunities for students to express their understanding through different modes and formative assessments to track growing understanding are also key to learning Science.

4.6.1.1 Pedagogic Principles

Science pedagogy across stages must be informed by the following principles:

a. Learning Science requires an active engagement of students with the world around them to understand it. Science pedagogy achieves this through:

   i. Simulating the processes of Science such as asking questions, hypothesising, observing, testing, finding evidence, collecting data, analysing, modifying conclusions, communicating, and re-questioning.

   ii. Exposing students to a variety of aspects of learning Science in varied settings — the laboratory, classroom, and field — through approaches such as inquiry, discovery, didactic, hands-on Science.

   iii. Encouraging and sustaining curiosity by providing varied experiences that may challenge students' existing notions and ideas.

b. Learning Science requires communication and sharing of ideas and observations. Science pedagogy achieves this through:

   i. Using scientific vocabulary during instruction and creating a variety of contexts and situations for students to communicate their understanding, ideas, and observations.

   ii. Peer and collaborative learning.

c. Learning Science requires a gradual increase in the capacity to engage with complex and abstract ideas, aligned with the cognitive and procedural capacities of students. Science pedagogy achieves this by building on students' existing knowledge and using multiple representations (mathematical, graphical, diagrammatic, and models).

d. Learning Science requires making linkages between knowledge for the holistic and multidisciplinary learning emphasised in NEP 2020. Science pedagogy achieves this through:

   i. Connecting scientific knowledge inside and outside the classroom.

   ii. Horizontal connections with other curricular areas.

e. Learning Science enables the development of certain values, such as collaboration, sensitivity, empathy, equality of opportunities, respect for diversity, and other values mentioned in NEP 2020. Science pedagogy must facilitate this process.

4.6.1.2 Recommended Pedagogical Approaches and Settings

The same pedagogical approach can be used across the three settings most suitable for learning Science - the classroom, the field, and the laboratory. This section recommends pedagogical approaches across a variety of settings in detail. The following is a list of considerations based on which Teachers can choose pedagogical approaches and settings:

a. The nature of a concept should guide the decision regarding the approach and setting. For example, speed can be discussed in the playing field, but the structure of a cell requires a microscope.

b. The approach and setting chosen should enable the attainment of learning outcomes and competencies.

c. Each of the recommended approaches and settings must be selected at least once in an academic year, if not more. This will ensure exposure to varied approaches and settings.

d. Even when Teachers choose a didactic approach, areas that students could have potentially inquired about or discovered should be highlighted.

a. Hands-on Science

The most important part of learning Science is actually 'doing Science' through hands-on experiential learning. 'Doing Science' can range from trial and error, using materials around them, or using basic scientific instruments (measuring instruments), and laboratory apparatus. In this process, students gain conceptual understanding and develop capacities through manipulating, designing, and building experiments and demonstrations.

b. Discovery approach

Students explore the natural world following their own interests and discover patterns of how the world works during their explorations. Teachers may also create opportunities or draw attention to natural phenomena that students can explore further. Often, this discovery is followed by other, more structured approaches to ensure learning. For example, the Teacher draws the attention of the students to changes in the length of the shadows as the day progresses or to the venation patterns of the leaves of different plants. Students' observations on shadows are then connected to scientific concepts such as the path of light, and the venation pattern is connected to the shapes of the leaves.

c. Inquiry approach

The inquiry approach allows students to navigate through unknown questions and explore solutions on their own. It allows students to work in the same way as scientists. The inquiry approach engages students with systematic observation, visualising, experimenting, inferring, communicating, and discovering relations. This approach allows Teachers to choose the appropriate type of inquiry with respect to the concept and to scaffold (support as per need) students' learning. For example, students could explore questions such as: How do the image characteristics vary with the relative position between lens and object? How does the surface area of the reactants affect the rate of reaction? How does the intensity of light affect the rate of photosynthesis?

d. Project-centred approach

This approach allows learning within the classroom to continue outside the classroom and extend over a period of time. For example, observing the changes in the moon over a month to understand the phases of the moon. In this process, connections to daily life are also made. The project-centred approach allows students to develop artefacts/products (charts, presentations, speeches) that reflect and communicate their emerging understanding. It also allows the integration of concepts across different curricular areas. For example, visits to the sites of local professional communities and interactions with the people engaged there, such as potters, weavers, craftspersons, farmers, blacksmiths, carpenters, and electricians would enable integrating concepts from vocational education and art with Science.

e. Didactic approach

Often, teaching Science involves communicating certain important information in the form of scientific terms, phenomena, and the historical development of concepts and ideas. In this approach, the Teacher largely regulates the direction and flow of the lesson. For example, after students have discovered changes in the length of the shadows throughout the day, the Teacher can explain the effect of the position of the sun on the length of the shadow and how students can use it to keep track of the time as well.

f. Demonstration

The Teacher demonstrates the working of certain instruments or outcomes of experimental set-ups to draw the attention of the students to relevant concepts. These demonstrations enrich students' learning experiences of the concepts.

These approaches can be implemented in a variety of settings. A combination of the recommended pedagogical approaches and settings is also often needed to be used for teaching a concept.

The box below illustrates a Science class that uses some of these pedagogical approaches within a laboratory setting in the voice of a Teacher.

Teacher's Voice 4.6i

Demonstrating Osmosis in Living Cells

For my Grade 9 students, I planned a demonstration of osmosis in living cells. They already are familiar with the concept in form of daily life examples such as what causes pruning of our fingers if kept in water for long, but in this session, we go a level deeper to observe the process in living cells under the microscope.

We will have a total of 90 minutes to perform this. Hence, I prepare the material such as common salt (NaCl) solution and cut onion pieces and equipment such as glass slides, forceps, and microscopes. Students work in multiple groups. Hence, I prepare as many instruction/observation recording sheets.

On that day, I begin by demonstrating the experiment — I prepare three slides A, B and C, add drops of solution in varying quantity, place coverslip, and then observe under the microscope what is happening to the cells in the onion peel on the slide.

Then all groups repeat this same set of actions and record their observation by drawing on the sheet provided. Post this, we discuss whatever we observed. After the students discuss possible inferences, I introduce the term 'osmosis' to the class, using the concept to explain their observations and share more daily life examples where we see this phenomena — for example, in the process of pickling.

4.6.1.3 Horizontal Connections

a. Horizontal connections with other curricular areas are necessary for the holistic and multidisciplinary learning emphasised in NEP 2020. Some curricular goals and competencies in both the Middle and Secondary Stage are designed to ensure horizontal connections between Science and other curricular areas. At the same time, pedagogy must be designed so that these connections are made in the classroom.

b. Pedagogic approaches and methods such as inquiry and projects, by their nature, provide scope to utilise concepts and capacities that cut across the disciplines of Science — for example, a project on investigating the sound produced by different musical instruments, and how this sound can be varied. Qualities and properties of sound produced both in terms of aesthetics, physics concepts involved, mathematical patterns, and human perception lead to a holistic appreciation and integration of competencies across curricular areas.

c. Pedagogic methods such as surveys and field-based methods enable students to see concepts through socio-cultural, economic, emotional, and scientific lenses — for example, a survey of traditional medicinal and cooking practices and their connection with the seasons.

4.6.1.4 Resources in Science Teaching

Science laboratories are essential for a good Science Education class. However, there are no separate rooms for Science laboratories in the majority of Middle schools currently, although

Science kits are provided. In this situation, Teachers can use their classrooms or any open space for conducting experiments. The following must inform the use of resources:

a. The materials and equipment should be simple and easy to use. This makes it more likely that they will be used in classrooms by Teachers. At the Middle Stage, Science kits available at most schools provide a good start.

b. However, teaching should not be restricted to the Science kits. The more materials students use, the more opportunities they get to do Science and hence learn Science. Improvised apparatus can be made using inexpensive materials to extend the use of materials beyond the Science kit. For example, a measuring jar can be made out of discarded transparent glass bottles, - using measuring cups (that usually come with syrup bottles) and syringes for calibration.

c. At this Stage, if the school can provide dedicated lab space, with adequate space for simple materials and resources, it must be done.

d. At the same time, doing Science must not be restricted to Science laboratories or Science kits. Classrooms, especially in the Middle Stage, must allow the doing of Science. At the same time, all safety considerations must be kept in mind.

e. Tinkering laboratories – informal spaces where students can 'play' with simple scientific materials and equipment independently – can be set up in any room within the school. This will help students strengthen design thinking, creating, and experimental capacities. Initially, students would have to be supported by the Teacher.

f. Students at the Secondary Stage would require standard scientific equipment and apparatus and basic infrastructure in which they can perform experiments with convenience and safety. Therefore, Secondary schools should have well-equipped, resourceful, and spacious Science laboratories to conduct Science experiments and investigations.

g. If a school has a laboratory but the number of students is large, the Teacher can either allow students to do the experiments in groups or ask students to perform the experiments on alternate days.

h. Budgets for Science in the Middle and Secondary Stages are limited, so Science equipment and materials should be inexpensive. However, if the equipment is of inferior quality (e.g., weak magnet, cheap microscope with plastic lens), it may not be worth using.

i. Alternatives can be used. For example, in case of unavailability of litmus paper, a Teacher can use turmeric solution or turmeric paper strips for identifying the acidic and basic characteristics of the substances. For this, the Teacher can take turmeric (powder or solid) and add it on a paper or in a glass cup containing water. This solution can be used for the identification of acids and bases. The Teacher can also make wet paper strips dipped in turmeric solution. Students can be asked to do the following — dry these paper strips, prepare solutions of each substance in water, dip the strip in the solution, and check the colour change of the turmeric paper strips. Could you make a list of changes in the colours of these substances?

4.6.1.5 Classroom Management

Classroom environment plays a vital role in student's learning. An ideal classroom of Science is one which has sufficient space and flexible seating to enable both small group work and whole class seating. The flexibility of the classroom is key in terms of allowing enough space to accommodate a wide range of activities.

The displays, charts, and other TLMs in the classroom should change and get renewed in sync with the concepts being dealt with in the classroom. Some storage space in the room makes it easier for the Teacher to have materials handy.

Classroom arrangement should complement instructional strategies – one way to ensure this is to have the same classroom for Science lessons, with students coming to the room. Having a dedicated Science classroom for Middle and Secondary Stages will also help in managing the resources efficiently and reduce the operational load for the Teacher. Bringing materials together and ensuring they are replaced, arranging the classroom to enable students to work in groups, access to simple equipment that students may want to use (e.g., magnifying glass in a lesson on magnets in case students want to examine the surface of the magnets), and so on will be taken care of with ease in case of a dedicated classroom.

4.6.2 Assessment in Science

The following principles must inform assessment in Science across Stages:

a. Students must be assessed for understanding of concepts and for the ability to use the scientific method, i.e., observe, ask questions, hypothesise, predict, experiment, collect data, infer, predict, analyse, decide, and evaluate.

b. Students must be assessed through a variety of ways, e.g., answering good questions, designing, and conducting experiments, developing models, and participating in debates and discussions.

A few Teacher Voices illustrate assessment in Science below.

Teacher's Voice 4.6ii

Conditions Suitable for Life

I teach Grade 8. I wanted to assess my students' understanding of the connection between conditions suitable for life (in this case, bacteria) and the processes of food preservation.

I didn't want to ask them to simply state the conditions for sustaining life and why they are needed, or the steps for food preservation. These questions can be answered using rote memory.

I tried something different. I asked the question below, which is directly related to their everyday lives and requires an application of chemistry and biology to processes they see all the time.

Question:

Mohan is about to pickle lemons. He plans to take the following steps to do this:

1. Make a mixture of salt, red-chilli, and carrom seeds.
2. Cut the lemons and rub the spice mixture into them.
3. Put the lemons in a clean glass jar and close the lid tightly.
4. Place the jar directly under the sun for a few hours.
5. Open the jar, add a lot of salt and some lemon juice to the jar.
6. Cover the mouth of the jar with a clean cloth and close it tightly with the lid.
7. Shake the jar vigorously and place it under the sun for a few days.

Why do you think Mohan follows all these steps? Please select the most appropriate option amongst the ones given below.

a. Reason 1: Adding salt draws out water from the lemons so that harmful bacteria cannot grow.

b. Reason 2: The combination of salt, red chilli, and carrom seeds prevents the growth of mould.

c. Reason 3: The sunlight prevents growth of mould and yeast that would spoil the pickle.

d. Reasons 1 and 3 are correct.

e. Reasons 2 and 3 are correct.

I used the following marking scheme: 2 marks for choice D, 1 mark for choice A or C, and no marks for choice B or E.

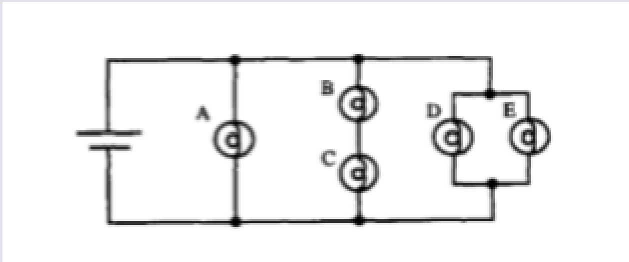
Teacher's Voice 4.6iii

Circuits

I teach Grade 9. I wanted to assess my students' ability to apply their understanding of current, voltage, resistance, energy, circuits in an unfamiliar situation. Students tend to associate circuits with a very specific representation which is usually seen in textbooks. This question presents a different arrangement.

Question:

Arrange the bulbs in the following circuit diagram in decreasing order of their brightness, by choosing the most appropriate among the options given below.



1. A=D=E>B=C
2. B=C>A>D=E
3. A>B=C>D=E
4. A=B>C>D=E

Only students who chose option 1 were able to apply their understanding of these concepts and got marks for this question.

Teacher's Voice 4.6iv

Experiment: Hot Container

I teach Grade 7. I find experiments very useful for a comprehensive assessment of both conceptual understanding, its application, and the ability to use the scientific method.

The following experiment enables assessment of students' understanding of measurement, and the properties of matter, especially the specific property that is causing the phenomenon observed in the experiment and their ability to extend it to real life situations. It also enables assessment of skills such as safe and accurate use of equipment, data collection

and interpretation, verification of scientific ideas, and communication of observations and conclusions along with use of scientific vocabulary.

Hot container activity

You have been provided with three containers — a paper cup, a metal can, and a ceramic mug, three thermometers, and a stopwatch.

Your challenge is to determine which of the three containers will keep a hot drink warm for the greatest length of time. Your experiment will last ten minutes, and you are expected to keep a record of your observations.

Gently place a thermometer in each container and ask your Teacher to pour hot water into each of them. Measure the temperature of the water in the container. Decide how you will gather your data and record it in the table. Please add rows as necessary.

S. No	Time	Cup A	Cup B	Cup C

After collecting data for 10 minutes, please answer the following questions.

a. According to your data, which container has kept the water warmer compared to the others over the period of 10 minutes? What do you think are the reasons for this?

b. Which container do you think will be the best for keeping ice cream cold? Give reasons for your answer.

I used the following criteria to grade my students' performance:

Criteria for assess-ment	Grade C	Grade B	Grade A
Handling equipment	Needs assistance with using the thermometer	Needs assistance with reading the thermometer	Uses thermometer properly and safely without any help
Recording data	Records data at the beginning and end of 10 minutes	Records data accurately over 10 minutes at arbitrary intervals	Records data accurately at preset intervals over 10 minutes
Interpreting data	Unable to make a clear choice based on data	Explanations focus on data related to only the chosen container	Explanations contrast chosen container with the other two based on data
Application of conceptual understanding	Does not connect explanation to container's properties in response to questions	States the properties of the containers without extending the explanation to both hotness and coldness	Compares properties of all containers and extends the argument to both hotness and coldness in response to questions
Communication	Responds to questions based on observations and does not provide explanations	Provides written explanations using accurate scientific vocabulary	Uses a visual representation to show relationship between time and temperature for different containers to provide explanations using accurate scientific vocabulary